

Recent Advances in Curved Wide Plate Testing and Implications for Strain-Based Design

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The wide plate test has been used for about a half-century to assess the structural significance of weld defects. Early work mostly utilized plate specimens, but within the last 20 years the curved wide plate test (CWPT) has become popular for pipeline girth weld testing. More recently, the CWPT has been used to measure girth weld strain capacity for strain-based design applications. Considering that the wide plate test was not originally intended for assessment of structures loaded well into the plastic regime, it is appropriate to consider improvements and new approaches that may be applicable to high strain applications. This paper presents recent CWPT results on X80, X100 and X120 girth welds. A noncontact photographic measuring system was used to quantify surface strains. Finite element analysis (FEA) was used to optimize specimen geometry by increasing specimen length-to-width ratio, which suppresses premature strain localization in the pipe body. This is particularly useful for testing high-strength steels. Unloading compliance in combination with FEA was used to assess crack growth. Compliance transfer functions were developed and tearing resistance was quantified using the CWPT. It was found that tearing can initiate at low levels ($\sim 0.5\%$) of plastic strain. Welds with high tearing resistance are useful for strain-based design applications.

INTRODUCTION

From the earliest days of structural fabrication by welding, it has been realized that welds may contain defects that can lead to structural failure. In mid-20th century, methods to assess (quantify) the significance of weld defects started to emerge. Eventually fracture mechanics-based approaches evolved into industry standard techniques, such as PD 6493 and its successor BS 7910. It has often been questioned if the small-scale tests, e.g., crack tip opening displacement (CTOD) tests, used in standard assessments adequately measure the material's resistance to failure. One technique used to address this question is the wide plate test, originally credited to Wells (1956). The test is not particularly sophisticated: A large welded panel with a preplaced defect in the weld or heat affected zone (HAZ) is pulled to failure in tension. The appeal of the test is mostly due to the specimen size (about 1 m²). This geometry is perceived to be large enough to adequately represent the structure itself. The pure tensile loading and the residual welding stresses contained in the large sample make the wide plate test more structurally relevant than a CTOD test.

By the late 1970s, wide plate testing was well established when researchers at the University of Gent in Belgium decided to extract "wide plate" specimens from girth welds in large-diameter pipe. This technique became known as the curved wide plate test (CWPT) and provided pipeline engineers with a valuable materials testing tool. The first publication appears to be by Lian, Denys and van de Walle (1986). CWP testing for stress-based applications was widely used through the 1990s, primarily in the European community (Hopkins, Demofonti, Knauf and Denys, 1991; Hopkins and Denys, 1993; Schipaanboord, Denys, Lefevre

and Roovers, 1999). Around 1990, workers at Gent began extending the use of the CWPT to assess girth welds in the plastic regime. Early work was for private clients, and it wasn't until 2002 that the first publication relating CWPT and strain-based design (SBD) appeared (Denys, Lefevre and De Beats).

Associated with SBD pipeline applications, ExxonMobil has conducted more than 200 CWPT within the past few years and has developed weld qualification strategies using the CWPT as a primary test method (Hukle et al., 2005; Lillig et al., 2006). Due to the resources necessary to conduct weld qualification using the CWPT, ExxonMobil is currently researching new or improved techniques to assess and predict girth weld performance for SBD applications. A companion paper is provided by Minnaar, Gioielli, Bardi and Kan (2007), while other ExxonMobil work includes Gioielli, Minnaar, Macia and Kan (2007) and Gordon, Zettlemoyer and Mohr (2007).

This paper describes recent CWPT results by which non-standard testing methods have been used to extract information potentially useful for SBD applications. Elastic-plastic finite element analysis (FEA) was used to model these CWPT to better understand post yield strain distributions. This aided in CWPT specimen design for testing higher-strength steels. Unloading compliance (UC) was used in combination with FEA to assess defect tearing. Acoustic emission was used to monitor cracking. A noncontact photographic measuring system was used to quantify surface strains, and these results were compared to FEA predictions. The volume of data collected in these tests, along with the FEA, has created a wealth of information and analysis is ongoing. This paper will cover some initial results while future papers will provide additional details.

EXPERIMENTAL TESTING AND FEA

Base Materials and Welding Conditions

Three UOE pipe steels were used: X80, X100 and X120. The pipe geometries were 762 mm (30 in) by 15.6-mm wall, 1067 mm (42 in) by 14.3-mm wall, and 1016 mm (40 in) by 19-mm wall, respectively. The welding processes included mechanized pulsed

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KEY WORDS: Curved wide plate test (CWPT), strain-based design (SBD), pipeline girth welds, defect assessment, toughness, tearing, high-strength steel.