International Journal of Pressure Vessels and Piping xxx (2016) 1–9

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

journal homepage: www.elsevier.com/locate/ijpvp

Strain capacity of girth weld joint cracked at “near-seam zone”

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A R T I C L E I N F O

Article history:
Available online xxx

Keywords:
Strain-based design
Weld joint
Tensile strain capacity
Single-Edge notch tensile test
Curved wide plate test

A B S T R A C T

Cracking occurs often at “near-seam zone” in the girth weld joint of an X70 pipeline in tensile test, which is considered unacceptable for strain-based design pipelines according to some current standards. The tensile strain capacity of girth weld joints for X70 pipelines with “near-seam zone” cracks has thus been studied via the approach of crack driving force and fracture resistance curve. The high strain capacity has been demonstrated by resistance curve tangency approach and curved wide plate test. The results prove that the girth weld joint has considerable fracture resistance and is thus of high strain capacity.

1. Introduction

Strain-based approach is the latest progress as a solution to the pipeline design in harsh environment. Ductile fracture under axial tensile strain is one of the most severe limit states. For land pipelines, it is generally related to the ground movement such as seismic activities, discontinuous frost soil and mining subsidence. For offshore pipelines, it is always the result of pipeline laying, such as S-lay, J-lay and reeling lay which can produce the strain up to 2%, and the uneven seabed, etc.

The tensile strain limit of a pipeline depends on the tensile strain capacity of its girth welds joint. The girth welds here refers to the entire weld region, including the weld metal and the heat-affected zone (HAZ). It tends to be the weakest link among the pipeline due to the possible existence of weld defects and regular deteriorative metallurgical and/or mechanical property changes from welding thermal cycles. Consequently, tensile strain capacity is related to the girth welding procedure qualification and flaw acceptance criteria. The welding procedure qualification involves the control of variables to ensure the equivalence of procedure qualification welds, field production welds and the definition and execution of mechanical tests of welds. The flaw acceptance criteria are implemented in field production welds to ensure a certain level of performance. In this case, certain tensile strain capacity is achieved [1], and the weld joint with flaws can ensure its integrity under plastic deformation. These designs are complicated because of the difficulty in the determination of the value of different variables as the variables are generally interactive. When girth weld flaws occur, strain capacity will depend on more material and geometric factors [2]. Numerical studies and pressurized full-scale tension (FST) tests have shown that once the threshold level of toughness ensuring ductile failure is achieved, the following variables do influence strain capacity.

- Fracture resistance.
- Weld strength mismatch level.
- Uniform strain (uEL) capacity of the pipe metal.
- Pipe and weld metal strain hardening capacity.
- Flaw location (surface or buried) and dimensions (length and depth).
- Flaw depth to wall thickness ratio.
- High-low weld misalignment.
- …

Although related issues are under research, there is no comprehensively general standard for strain capacity of girth welding joint. According to the current standard in China, the tensile test of weld joint crack on weld, heat affected zone, or “near-seam zone” (which means the softening zone near the weld and HAZ) is not allowed under strain-based design conditions. For the reason of sensitivity to material properties and flaws size, weld joint strain capacity cannot be analysed quantitatively only by

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http://dx.doi.org/10.1016/j.ijpvp.2016.03.006
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Please cite this article in press as: H.Y. Chen, et al., Strain capacity of girth weld joint cracked at “near-seam zone”, International Journal of Pressure Vessels and Piping (2016), http://dx.doi.org/10.1016/j.ijpvp.2016.03.006

tensile test results for weld.

The resistance-curve approach is a failure criterion by which fracture instability is predicted to occur when the driving force curves exceed the material fracture resistance. The failure mode is assumed to be ductile fracture. The crack driving force, in terms of crack tip opening displacement (CTOD) or J-integral, is derived from finite element analysis (FEA) for various structural geometries (including flaw size) and material properties. The resistance curve (R-curve) is directly measured from test specimens. The failure point or the unstable ductile tearing point is determined by the traditional tangency criteria. There are several organizations pursuing tensile strain capacity prediction by using the tangency approach, two of which are SINTEF [3–5] and ExxonMobil [6–10]. According to the approach, the crack driving forces are presented as a group of curves (iso-strain CTODF curves) of different strain levels. Each iso-strain CTODF curve is expressed as a function of flaw growth.

In the paper, the strain capacity of girth weld joint of Φ813 mm × 14.7 mm X70 strain-based designed pipeline is studied in detail. The fracture locations of weld joint tensile test are always found on near-seam zone as shown in Fig. 1. The tensile test, hardness test, and single-edge notched tensile tests for related zone are conducted for the description of the mechanical properties of weld joints. Then FE analysis is performed for the calculation of crack drive force during ductile tearing. Accordingly, the tensile strain capacity is evaluated by tangency approach of CDF curve and CTOD R-curves, which is demonstrated by wide plate tensile tests.

2. Pipe material and welding procedure

2.1. Pipe

The pipe nominal size is Φ813 mm × 14.7 mm, the specimens are cut from the same pipe. The chemical compositions of the pipe material are listed in Table 1.

2.2. Girth weld joint

SMAW has been used for root pass and hot pass, self-shielded flux-core FCAW has been used for fill pass and cap. Extra cap welding has been used for over match of the girth weld joint, as shown in Fig. 2.

The welding material and the procedures are listed in Table 2.

Table 1
Chemical compositions of the pipe material.

C	Si	Mn	P	S	Mo
0.052	0.13	1.49	0.0079	0.0021	0.17
Cr	Nb	V	Ni	Cu	Pcm
0.036	0.051	0.0041	0.17	0.031	0.15

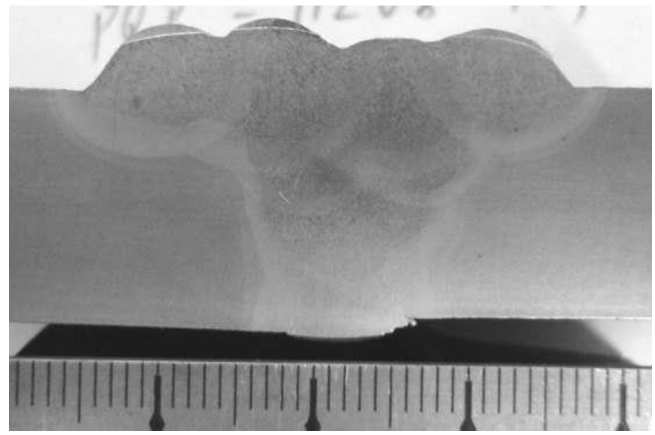

Fig. 2. Macro profile of the girth weld.

3. Experimental research

The mechanical performance tests include the tensile test, hardness test, single-edge notched tension (SENT) and curved wide plate (CWP) test.

3.1. Tensile test

Table 3 shows the longitudinal tensile test results from eight positions along the circumference of the pipe body, including yield strength, tensile strength, the ratio of yield strength to tensile strength (Y/T) and uniform elongations. The pipes used in the strain-based designed pipelines have better strain hardening capacity in longitudinal direction with lower Y/T, higher stress ratios and uniform elongation than common pipes for which the longitudinal tensile properties are not specified.

The all-weld-metal tensile specimens are also tested. Fig. 3 and Fig. 4 show the specimens and one of the stress-strain curves

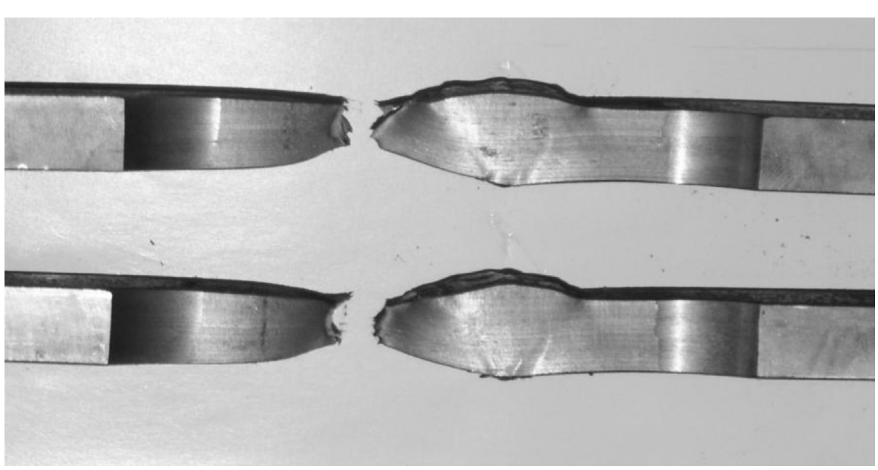

Fig. 1. The specimens cracked on near seam zone.

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