Alternative Acceptance Criteria for Pipeline Girth Welds

An overview is provided of API 1104, Appendix A, which can be used to evaluate weld imperfections using alternative acceptance criteria

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Weld acceptance criteria for pipeline girth weld volumetric nondestructive testing and inspection is provided in Section 9 of API 1104, Welding of Pipelines and Related Facilities (Ref. 1). Like most AWS and ASME codes, it is primarily based upon workmanship criteria, with the primary importance placed on the discontinuity/imperfection length. The appendix is used to calculate alternative acceptance criteria for NDE, different from the standard workmanship criteria used in most all industry.

The use of Appendix A for more critical applications does not prevent use of the API 1104 Section 9 requirements for determining acceptance criteria for welds. Instead, the Appendix presents the minimum requirements to facilitate use of an “alternative acceptance criteria.” The purpose of the Appendix is to define, on the basis of technical analyses, such as fracture mechanics analysis or fitness-for-service criteria, the effect of various types, sizes, and shapes of weld anomalies, discontinuities, or imperfections for the suitability of a specific critical weld joint design and qualified procedure for a specific service. Use of the Appendix for the evaluation of any and all weld imperfections is completely at a company's discretion. Appendix A covers only circumferential welds between pipes of equal nominal wall thicknesses. Other limitations include, but are not limited to, welds subjected to applied axial strains of more than 0.5%. Fabrication of steel centenary risers (SCRs) used extensively in fields subjected to applied axial strains of more than 0.5%. The oil and gas industry is an example of where this alternative acceptance criteria has or may have been applied by qualified NDE personnel with the appropriate experience to apply alternative acceptance criteria.

Considerations

Welding Procedure Qualifications

The qualification of welding procedures to be utilized when Appendix A is invoked shall be in accordance with API 1104 Sections 5 or 12 and per Section A.3.1 of the Appendix, which also imposes exceptions and/or additional requirements that any responsible company’s welding engineer/management and NDE personnel must consider through front end engineering design review.

Of primary consideration is the crack tip opening displacement (CTOD) test results that are to be performed in accordance with A.3.3, which states “it is to be performed per BS 7448: Part 2 (Ref. 2) as supplemented by this Appendix.” The CTOD testing determines the material/weld fracture toughness. According to Appendix A, the CTOD values can be 0.0005 or 0.010 in. or a value somewhere in between.

Determining these values for a project is typically accomplished by a limited number of qualified destructive testing companies. Test specimens from the base metal, weld metal, and heat-affected zones, which have preinduced fatigue cracks, are placed in a test fixture. The rate of crack growth and displacement from the adapted clip gauge are then monitored. Section A.3.2 of the Appendix provides further detail and guidance.

The CTOD values obtained for each welding procedure qualified must include, from the weld metal and heat-affected zone, three specimens each with acceptable results at or below the lowest anticipated service temperature (refer to A.3.3 in the appendix for further details). This WPS qualification CTOD value, along with the strain value, becomes the basis for determination/calculation of the welding NDE alternative acceptance criteria to be utilized for the specific project. The company must perform a stress analysis to determine the maximum axial design stresses for the pipeline.

Typical NDE Acceptance Criteria Applied to Pipeline Girth Welds

Workmanship. Does not consider the effects of discontinuities or defects on the probability of failures. These criteria are conservative and primarily were developed to monitor and observe the welder’s performance rather than the overall weld integrity.

Fracture mechanics, engineering critical assessments (ECAs), and fitness for service (FSS). These are all based upon the actual applied stress(es), measured material properties, and use of calculations to determine the actual flaw size that would cause a failure. The maximum allowable flaw size is defined, with an appropriate design safety factor also considered and factored in, which is what Appendix A facilitates.

One observation that seemingly could provide better clarification in the current Appendix A is that Section A.3.2, Fracture Toughness Testing, does state “for the purpose of the Appendix, the minimum fracture toughness can be 0.005 in. or 0.010 in. or a value between these two values”; however, Table A-1, Acceptance Limits for Buried Volumetric Imperfections, clearly states in the Notes: “The simplified limits given in this table may be applied for minimum CTOD levels of either 0.005 in. or 0.010 in. with Table A-3 of Appendix A, i.e., ‘Imperfection Length Limits’ stating the same requirement.” Which means it does not state “or a value between these two values” when one when one would need to consider the use of this table.

Applying Acceptance Criteria Using Appendix A

As noted, Table A-1 of Appendix A provides alternative accep
tance criteria limits for buried volumetric imperfections, using the simplified limits to be applied for CTOD values within the ranges previously stated, i.e., either 0.005 or 0.010 in.

API 1104 does make provision for the use of both NDE methods, radiographic testing (RT) or automated ultrasonic testing (AUT). AUT seems to treat porosity as a planar flaw in Appendix A, i.e., Table A-1, A5.1 (for ECA style criteria); however, no provision is made in paragraph 9.6.2 of API 1104. Therefore, it would seem to require assessment of some items not possible to reliably characterize when utilizing AUT vs. radiography, i.e., for cluster pores and single pore sizes. This could be considered unfortunate as it does impose the notion that AUT is to look like radiography in these regards (Ref. 3).

Consider that many codes expect manual UT and/or AUT to duplicate standard radiographic interpretations, which is not considered a reasonable expectation or insinuation. Although conventional radiography may well be adequate for measuring an imperfection’s length, it is substantially insufficient for determining an imperfection’s height or discontinuity sizing, particularly for planar discontinuities or cracks, incomplete fusion, and some types of incomplete penetration. Consider that API 1104 requires that the accuracy of the NDE sizing technique be established, but provides no guidance in this regard. It is believed that the current requirements of A.5 in Appendix A can be satisfied by use of automated ultrasonic testing utilizing zonal discrimination techniques (Ref. 4), in which the weld bevel is actually divided into zones for AUT examination accordingly, per the AUT qualified testing procedure.

Appendix A addresses the inspection and acceptable limits for these planar and volumetric imperfections in Sections A.5 and A.5.2. The length and height of an imperfection, and its depth below the surface as well as imperfection interaction relations (proximity of one flaw to another) must also be considered.

Calculations for applying alternative acceptance criteria are illustrated in Appendix A Section A.7.1–A.7.9. The API 1104 appendix has one set of calculations for fractures based solely on brittle fracture.

Sample parameters for calculations utilizing API 1104 Appendix A:

<table>
<thead>
<tr>
<th>Parameters:</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe diameter</td>
<td>30.0 in.</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>0.577 in.</td>
</tr>
<tr>
<td>Crack tip opening displacement attained</td>
<td>0.01 in.</td>
</tr>
<tr>
<td>Maximum applied strain</td>
<td>0.002 (100% yield) (inches per inch)</td>
</tr>
<tr>
<td>Examination error</td>
<td>0.05 in. (flaw height measurements)</td>
</tr>
</tbody>
</table>

First, see Fig. 1, the length of the surface flaws: the separation “s” must be greater than the average of the two flaw lengths to avoid interaction. For example, \( s_1 = 12.5 \text{ mm} \) so \( s_2 = 6.25 \text{ mm} \). \( c_1 + c_2 = 6.25 \text{ mm} \). 12.5 mm is the required minimum separation. Otherwise the flaws interact if less than 12.5 mm apart. For subsurface flaws, the rules for length are the same.

For height, two buried flaws 2.3 mm high each, we can look at case 2. A subsurface flaw has a height \( 2a_1 \), so \( 2a_2 = 2.3 \text{ mm} \), for example, if buried. Vertical separation must be less than the average of the two flaws’ heights, i.e., \( s < a_1 + a_2 \) causes interaction. If “a” is 1.15 mm, then they must be separated by 2.3 mm vertically, otherwise interaction occurs. If one of the flaws is surface and the other subsurface, case 3 states that for interactions \( s_1 < c_1 + c_2 \), which is essentially the same as case 2 since the surface flaw total vertical dimension is “a” (not 2a as it is for subsurface flaws).

For API 1104 Appendix A interaction consideration, we can summarize by stating that a separation of two flaws by less than the average height or length of those flaws (as appropriate) constitutes interaction (see also API 1104 Fig. A-6, Criteria for Evaluation of Imperfection Interaction).

Conclusions

The requirements presented in this overview of API 1104 Appendix A are considered optional, and the requirement to utilize Appendix A when API 1104 is specified as the construction
code must be agreed upon by the buyer and purchaser. The appendix may appear to not provide for a user-friendly approach; rarely would most AWS CWIs ever be exposed to the requirements of this appendix in the API 1104. This article may be used to gain a basic understanding of the appendix and its application upon review. Of course, radiographers and/or automated ultrasonic testing personnel would be exposed to the determined acceptance criteria of this appendix or be required to use the simplified limits stated on a more frequent basis as part of an approved NDE operating procedure.

References