

Reducing Pipeline Construction Costs With Girth Weld ECA

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Using an engineering critical assessment (ECA) alternate acceptance criteria for pipeline girth weld inspection can significantly reduce the cost of constructing a cross-country transmission pipeline by minimizing unnecessary repairs. As an alternative to the traditional workmanship acceptance criteria, the ECA acceptance criteria is based on fracture mechanics and requires advanced weld inspection techniques, higher strength and toughness weld metal, and stricter welding controls. This article focuses on a widely used alternative defect acceptance criteria for pipeline girth welds, API 1104 Appendix A, 20th edition errata/addendum, released in 2007.

Pipeline girth weld acceptance standards

the defect severity required for safe pipeline operation, and unfortunately, often results in unnecessary repairs to innocuous weld imperfections. This increases costs, lowers productivity, and may lower weld integrity by creating additional residual stress and additional heat-affected regions.

ECA is an alternative defect acceptance criterion based on fracture mechanics principles. ECA allows engineers to assess the suitability of a pipeline containing imperfections for intended service conditions or fitness for service (FFS). ECA methods commonly used in the North American pipeline industry are API 1104, Appendix A, and CSA Z662, Annex K. BS 7910 is also widely used for fracture mechanics assessment. This article will

testing (AUT) to accurately size weld imperfection height and length;

- Higher strength and toughness welding consumables;
- Increased use and industry acceptance of mechanized welding;
- Higher quality line pipe steels;
- Favorable stress profile of the girth weld (axial stress is half the hoop stress resulting from internal pressure); and
- Acceptance by the regulatory agencies.

API 1104, Appendix A

API 1104 incorporated Appendix A as an optional alternative defect acceptance criteria into the 16th edition in 1983. The construction of the costly TransAlaska oil pipeline prompted the development of fracture-mechanics-based alternative defect acceptance criteria. Appendix A is ECA of the allowable weld imperfection sizes based on fracture mechanics analysis and fitness-for-purpose criteria. Using fracture mechanics, the maximum planar imperfection sizes are determined which will remain stable under the designed service conditions and these imperfections may safely remain in the completed girth weld.

Appendix A can provide more generous allowable flaw sizes, but requires additional qualification testing, stress analysis, additional inspection requirements, stricter limits on production welding variables, and is applicable only for certain service conditions. See the document for detailed requirements. Listed here are some of the limitations where API 1104, Appendix A may be applied:

- Only circumferential welds between pipes of equal nominal wall thickness where 100% NDT is performed;
- Maximum axial design stress no greater than the specified minimum yield stress (SMYS);
- Maximum axial strain no greater than 0.5%;
- Excludes welds in pump or compressor stations, fittings and valves in the main line, and repair welds; and
- No gross weld strength undermatching.

Three Assessment Options

API 1104, Appendix A, 20th edition errata/addendum offers three assessment options:

- Option 1 is a simplified graphical format approach determined for two toughness

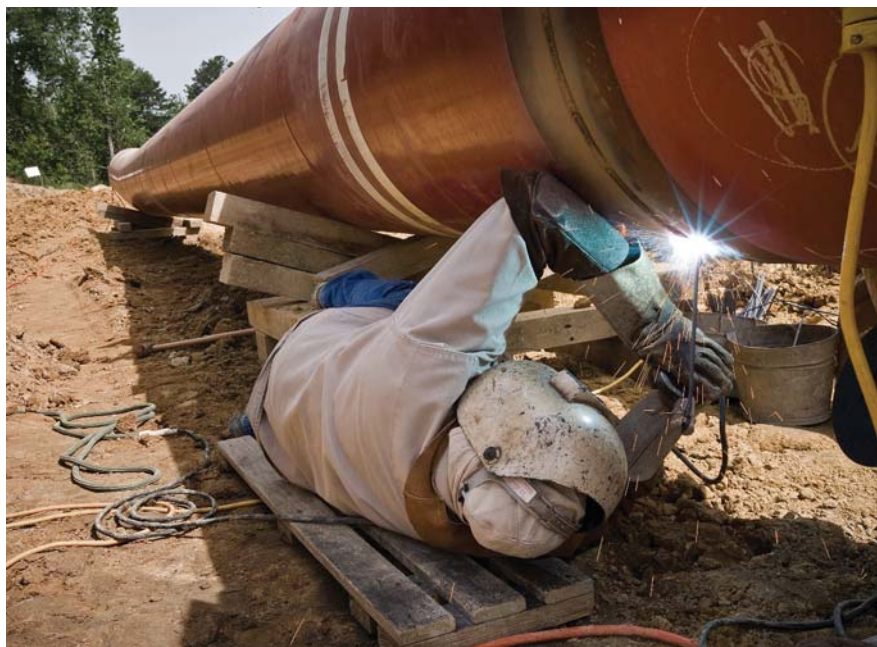


Figure 1: Pipeline welding with cellulosic electrodes.

(e.g. API 1104 Welding of Pipelines and Related Facilities) have traditionally been based on “good workmanship,” or the weld quality a competent pipeline welder can achieve using cellulosic SMAW electrodes (Figure 1), and on the imperfections detectable by radiographic testing (RT). This empirically based criteria, while historically proven safe in practice, does not quantitatively determine

focus on the latest 2007 revision of API 1104, Appendix A, 20th edition errata/addendum. The ECA of pipeline field girth welds has been successfully used to construct many cross-country pipelines and was made possible by:

- Advancements in the understanding and application of fracture mechanics and validated by full-scale testing;
- Advancements in automated ultrasonic

levels (0.004 inch and 0.010 inch CTOD).

- Option 2 is a more detailed assessment with the failure analysis diagram (FAD) approach using the actual toughness level.
- Option 3 allows the use of validated fitness for purpose procedures when fatigue loading exceeds the Option 1 and 2 requirements.

Weld Strength

API 1104 Appendix A requires that the girth weld not significantly undermatch the strength of the base pipe, which differs from the workmanship acceptance criteria. Undermatching may result in excessive localized strain in the weld and cause imperfection growth. Therefore, Appendix A requires a cross-weld tensile test and the fracture location is required to be outside the weld.

For example, compare workmanship and Appendix A weld strength requirements for API 5L X70 pipe. Using the workmanship acceptance criteria, a girth weld on X70 pipe is required to meet the minimum strength requirements for X70. Using Appendix A, the weld must meet or exceed the actual strength of the pipe, which may be much higher than the X70 minimum. Thus, higher strength weld metal is needed. A girth weld on X70 pipe may require an X80 or X90 strength weld to meet Appendix A.

CTOD Toughness Testing

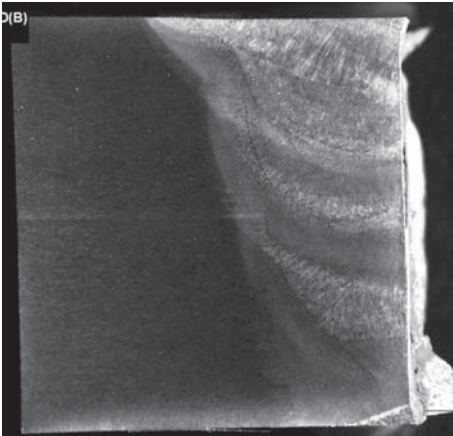


Figure 2: Etched crack tip opening displacement specimen displaying weld metal region.

To maximize the benefits of using an ECA, high toughness in the weld metal and heat-affected zone (HAZ) is required. Instead of the popular inexpensive Charpy V-Notch (CVN) test for fracture toughness, Appendix A specifies the crack tip opening displacement (CTOD) test to obtain a better assessment of fracture toughness. The CTOD specimen tests nearly the full thickness of the weld (Figure 2), instead of a 10 mm or smaller Charpy sample. The CTOD test uses an actual crack, instead of rounded machined V-notch, to better predict crack behavior. To characterize the toughness around the pipe circumference, specimens are taken from the top, side and bottom of the pipe in the weld and HAZ. The allowable height and length of surface and buried imperfections are then calculated from the minimum CTOD, maximum axial design stress, pipe diameter, wall thickness, and inspection error.

Consumables And Pipe Steel

Because ECA welds need to be stronger

and tougher than the welds made in the past with traditional cellulose electrodes, manufacturers of welding consumables are developing filler metals to better meet these requirements. An example is Lincoln Electric's Pipeliner® brand of SMAW, GMAW, SAW, FCAW-G, and FCAW-S filler metals. The metals offer higher strength, higher CTOD toughness, and are manufactured under lot control and testing to better meet the demands of the pipeline industry.

Improved pipe steels are needed to obtain good toughness in the HAZ. Recent improvements such as fully killed steels made to fine grain practice, micro-alloying with Nb, V, or Ti, low carbon, low sulfur, controlled rolling, and segregation control have resulted in better pipe steel properties.

Mechanized Welding



Figure 3: Automated ultrasonic testing (AUT) inspection of pipeline field girth weld.

Mechanized welding is increasingly being used for mainline construction and is ideally suited for use with ECA for several reasons. It can more easily produce higher strength and higher toughness welds using the GMAW or FCAW-G processes. It allows welding at lower heat inputs to increase HAZ toughness, and provides excellent control over production weld procedures. ECA helps maximize the high potential production rates which can be obtained with mechanized welding.

AUT Weld Inspection

While the traditional workmanship acceptance criterion is based primarily on imperfection length, ECA requires evaluating the imperfection length and depth. This can be a

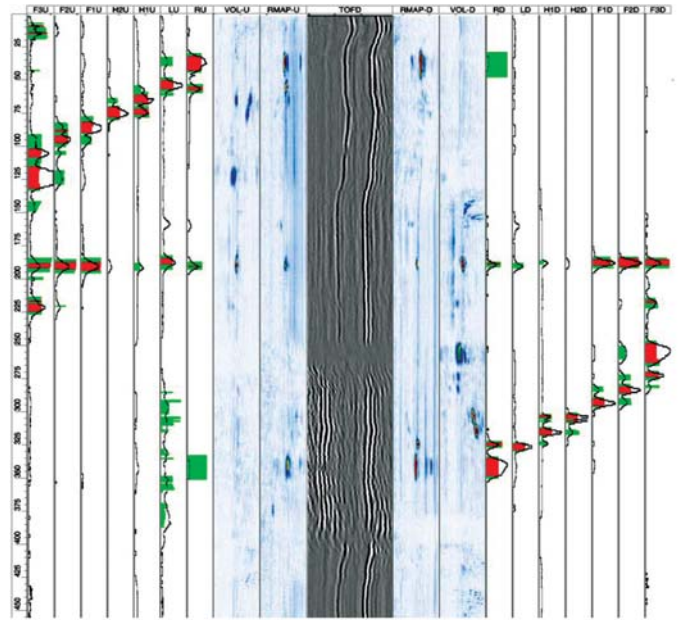


Figure 4: AUT scan output record.

challenge as conventional radiographic testing (RT) detects only imperfection length and density, not imperfection height. AUT is now being utilized for pipeline field girth weld inspection and offers the benefits of high speed, no radiation, and the ability to accurately size imperfection length and height (Figures 3 and 4). Recent AUT advancements, such as zone discrimination, phased-arrays, and time-of-flight diffraction (TOFD) methods, have greatly improved its field usability and its ability to accurately locate and size weld imperfections.

Conclusion

ECA, based on fracture mechanics principles, has been proven to be a safe alternative method to determine girth weld defect acceptance for pipeline construction. Utilizing ECA minimizes unnecessary repairs, thereby reducing pipeline construction time and costs. *P&GJ*



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REFERENCES:

- API Standard 1104, Welding of Pipelines and Related Facilities, 20th edition, Errata/Addendum, July 2007. American Petroleum Institute, Washington, DC.
- BS 7910: 2005, Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures, 2005. British Standards Institution.
- CSA Z662-07, Oil and Gas Pipeline Systems, 2007. Canadian Standards Associations.