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Test Method

Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking

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Foreword

Absorption of hydrogen generated by corrosion of steel in a wet hydrogen sulfide (H_2S) environment can have several effects that depend on the properties of the steel, manufacturing or forming processes, the characteristics of the environment, and other variables. One adverse effect observed in pipeline and pressure vessel steels is the development of cracks along the rolling direction of the steel. Cracks on one plane tend to link up with the cracks on adjacent planes to form steps across the thickness. The cracks can reduce the effective wall thickness until the pipeline or pressure vessel becomes overstressed and ruptures. Cracking is sometimes accompanied by surface blistering. Several service failures attributed to such cracking have been reported.[1,2]

The terms *stepwise cracking* (SWC), *hydrogen pressure cracking, blister cracking,* and *hydrogen-induced stepwise cracking* have been used in the past to describe cracking of this type in pipeline and pressure vessel steels, but are now considered obsolete. The term *hydrogen-induced cracking* (HIC) has been widely used for describing cracking of this type, and has been adopted by NACE International. Therefore, it is used throughout this standard test method.

HIC is related to hydrogen blistering, which has been recognized since the 1940s as a problem in pressure vessels handling sour products.[3] It was not until much later, however, that HIC gained wide recognition as a potential problem in pipelines. As a result of pipeline failures experienced by two companies in the early 1970s, several companies began investigating the cracking and publishing results of tests on various steels. Many investigators found, however, that they could not reproduce published test results. It was eventually determined that lack of reproducibility resulted largely from differences in test procedures. Consequently, NACE Unit Committee T-1F, "Metallurgy of Oilfield Equipment," established Task Group (TG) T-1F-20, "Stepwise Cracking of Pipeline Steels," to study the problem and prepare a standard test method.

This standard was originally prepared in 1984 to provide a standard set of test conditions for consistent evaluation of steel pipes and for comparison of test results from different laboratories. Subsequently, the concern for HIC damage turned to steel plates used for pressure vessels. Requirements for testing steel plates for resistance to HIC were included in this standard in 1996. More recently, concern for HIC damage in steel fittings and flanges used in pipelines and pressure vessels led to their inclusion in the 2011 revision of this standard. Therefore, the scope of this standard now includes the testing of steels furnished in the form of pipes, plates, fittings, and flanges for use in fabricating pipelines and pressure vessels. In the 2016 revision of this standard, Fitness-For-Purpose testing in an alternative test solution, to be used with gas containing mixtures of H_2S and CO_2, was included to assess HIC damage under mildly sour test conditions with reduced partial pressure of H_2S in a range of pH values.

Test conditions are not designed to simulate any particular pipeline or process operation, even though in Fitness-for-Purpose tests, partial pressures of H_2S and pH values appropriate to the intended application must be selected. The test is intended to evaluate resistance to HIC only, and not to other adverse effects of sour environments such as sulfide stress cracking (SSC), pitting, or mass loss from corrosion.

This test may be used for many purposes, and the applications of the results are beyond the scope of this standard. Those who use the test should be aware that in some cases, test results can be influenced by variations in properties among different locations in a single length of pipe or individual plate, fitting, or flange, as well as by variations within a heat of steel. When the test is used as a basis for purchasing, the number and location of test specimens must be carefully considered.[4] This standard is intended for end users, manufacturers, fabricators, and testing laboratories.

This standard was originally prepared by TG T-1F-20 in 1984. It was revised in 1996 by TG T-1F-20, and in 2003, 2011, and 2016 by TG 082, "Stepwise Cracking of Pipeline Steels," which is administered by Specific Technology Group (STG) 32, "Oil and Gas Production—Metallurgy" and sponsored by STG 34, "Petroleum Refining and Gas Processing," and STG 62, "Corrosion Monitoring and Measurement—Science and Engineering Applications." It is issued by NACE under the auspices of STG 32.

In NACE standards, the terms *shall, must*, *should,* and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual.* The terms *shall* and *must* are used to state a requirement, and are considered mandatory. The term *should* is used to state something good and is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

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Section 1: General

1.1 This standard establishes a test method for evaluating the resistance of pipeline and pressure vessel steels to HIC caused by hydrogen absorption from aqueous sulfide corrosion.

1.1.1 Details are provided on the size, number, location, and orientation of test specimens to be taken from each steel product form—pipes, plates, fittings, and flanges.

1.1.2 Special procedures or requirements for testing small-diameter (nominal diameter [DN] 50 through 150, nominal pipe size [NPS] 2 through 6), thin-wall (up to 6 mm [0.2 in] wall thickness), electric-resistance welded (ERW) and seamless pipes are included. The test specimens taken from small-diameter, thin-wall pipes shall be tested in the same manner as the test specimens taken from other pipes except as otherwise stated in this standard.

1.2 The test method consists of exposing unstressed test specimens to one of the three standard test solutions: Test Solution A, an acidified brine solution consisting of sodium chloride (NaCl) and acetic acid (CH_3COOH) dissolved in distilled or deionized water saturated with H_2S at ambient temperature and pressure; or Test Solution B, a synthetic seawater solution saturated with H_2S at ambient temperature and pressure; or Test Solution C, a buffered solution consisting of sodium chloride (NaCl) and sodium acetate (CH_3COONa) dissolved in distilled or deionized water saturated with gas containing mixtures of H_2S and CO_2 at ambient temperature and pressure enabling testing to be conducted at different H_2S partial pressures in the range 0.001 to 1 bar. After a specified time, the test specimens are removed and evaluated.

NOTE: The length of the test may not be sufficient to develop maximum cracking in any given steel, but has been found to be adequate for the purpose of this test.

1.3 In Fitness-for-Purpose testing, the test environment and partial pressures of gases appropriate to the intended application are selected.

NOTE: The test conditions do not duplicate all aspects of service conditions, for example temperature, but will allow sufficient discrimination of the applicability of candidate steels. See Paragraph 8.1.5 and associated notes.

1.4 This standard does not include acceptance or rejection criteria; however, guidance is provided in NACE MR0175/ISO(1) 15156,[5] Part 2, Section 8 and Annex B of EFC(2) 16.[6]

1.5 For additional information, the presence or absence of HIC in the exposed specimens may be evaluated by automated ultrasonic testing prior to metallographic sectioning and examination. A procedure is provided in Appendix A (nonmandatory).

Section 2: Reagents

2.1 The reagents for Test Solution A shall be an inert gas (nitrogen, argon, or other suitable non-reactive gas) for purging, H_2S gas, NaCl, CH_3COOH, and distilled or deionized water. The reagents for Test Solution B shall be an inert gas for purging, H_2S gas, and synthetic seawater. The reagents for Test Solution C shall be an inert gas for purging, a mixture of H_2S and carbon dioxide (CO_2), with H_2S content sufficient to produce the specified H_2S partial pressure, NaCl, CH_3COONa, hydrochloric acid (HCl) or sodium hydroxide (NaOH) added to achieve the specified pH and distilled or deionized water.

NOTE: H_2S is highly toxic and must be handled with caution. See Appendix B (nonmandatory).

2.2 The NaCl, CH_3COOH, CH_3COONa, HCl and NaOH shall be reagent grade chemicals.

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(2) European Federation of Corrosion (EFC), 1 Carlton House Terrace, London, SW1Y 5DB, U.K.