Date: 2023-11-22

ISO/FDIS 3845:2023(E)

ISO/TC 67

Secretariat: NENISO/TC 67

Date: 2024-02-01

Oil and gas industries including lower carbon energy — Full ring ovalization test method for the evaluation of the cracking resistance of steel line pipe in sour service

Méthode d'essai de déformation du diamètre d'une conduite en acier pour évaluer sa tenue mécanique en environnement corrosif

FDIS stage

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Foreword

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Introduction

Sour service cracking problems in susceptible steel line pipe are caused by the various forms of hydrogen damage due to the presence of wet hydrogen sulfide (H_2S). The main mechanisms are hydrogen-induced cracking (HIC) or stepwise cracking (SWC), sulfide stress cracking (SSC) and stress-oriented hydrogen-induced cracking (SOHIC). An industry-proven technique for assessing the cracking resistance of steel line pipe is to stress a full ring pipe specimen in a sour environment.

The advantages of the full ring test specified in this document are that it is not necessary to pressurize the line pipe full ring specimen to achieve the required stress, and residual stresses are retained. Equivalent internal stresses can be produced by ovalization of the pipe using mechanical means.

Additional advantages are more representative samples, when compared to machined four-point bend specimens and single-sided exposure can allow in-situ inspection during test exposure.

A known stress is exerted at two regions on a full ring section of steel pipe. The pipe specimen is then exposed internally to the sour test solution.

Ultrasonic testing can be conducted regularly on internally loaded test specimens during the exposure period to monitor crack initiation and propagation. Hydrogen permeation measurements may also be conducted. Both crack initiation and propagation can therefore be monitored. Finally, a metallurgical examination is undertaken to classify any indications found by non-destructive testing (NDT), such as visual inspection, magnetic particle testing (MT), penetrant testing (PT) or ultrasonic testing (UT).

The method has been in use since 1984, but in 1991 a Joint Industry Sponsored Project was set up with the aim of systematically developing, defining and validating the full ring test. The resultant test method designed to determine the susceptibility of steel line pipe, bends, flanges and fittings, including all associated welds to hydrogen damage caused by exposure to sour environments, was published by the UK HSE as OTI 95 635[1][1] and subsequently in 2016 as BS 8701, prior to adoption as ISO 3845.

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WARNING — The use of this document can involve hazardous materials, operations and equipment. It does not purport to address all the safety or environmental problems associated with its use. Attention is drawn to national and health safety practices and regulations regarding the use of hazardous materials prior to use, in particular for hydrogen sulfide.

1 Scope

This document gives a method for determining the resistance to cracking of steel pipes in sour service.

This test method employs a full-scale test specimen consisting of a short length of pipe (a 'full ring'), sealed at each end to contain the sour test environment within. The test method applies to any pipe; seamless, longitudinally welded (with or without filler), helical welded, and to girth welds between pipes.

NOTE 1 The specimen is usually a pipe but can also consist of flange neck or section of a bend, or other tubular component or a combination of the above.

NOTE 2 This test method can also be used for corrosion resistant alloys (CRAs).

The method utilizes ovalization by mechanical loading to produce a circumferential stress, equal to the target hoop stress, at two diametrically opposite locations on the inside surface of the test specimen. The test specimen is then subjected to single sided exposure to the sour test environment.

NOTE 3 The test also allows measurement of hydrogen permeation rates.

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32 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2400, *Non-destructive testing –— Ultrasonic testing –— Specification for calibration block No. 1*

ISO 3059, *Non-destructive testing –— Penetrant testing and magnetic particle testing –— Viewing conditions*

ISO 3452 (all parts), *Non-destructive testing – Penetrant testing*

ISO 4787, *Laboratory glass and plastic ware — Volumetric instruments — Methods for testing of capacity and for use*

ISO 6892--1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 7963, *Non-destructive testing –— Ultrasonic testing –— Specification for calibration block No. 2*

ISO 8044, *Corrosion of metals and alloys – Basic terms and definitions*

ISO 8501--1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 9934 (all parts), *Non-destructive testing — Magnetic particle testing*

ISO 11666, *Non-destructive testing of welds –— Ultrasonic testing –— Acceptance levels*

ISO 16810, *Non-destructive testing – Ultrasonic testing – General principles*

ISO 17635, *Non-destructive testing of welds — General rules for metallic materials*

ISO 17638, *Non-destructive testing of welds — Magnetic particle testing*

ISO 17640:2018, *Non-destructive testing of welds –— Ultrasonic testing –— Techniques, testing levels, and assessment*

ISO 22232 (all parts), *Non-destructive testing — Characterization and verification of ultrasonic test equipment*

ISO 23277, *Non-destructive testing of welds — Penetrant testing — Acceptance levels*

ASTM D1193, *Standard Specification for Reagent Water*

ASTM E1237, *Standard Guide for Installing Bonded Resistance Strain Gages*

ASTM F21, *Standard test method for hydrophobic surface films by the atomizer test*

NACE TM0284:2016, *Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

43 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ——ISO Online browsing platform: available at https://www.iso.org/obp

— ——IEC Electropedia: available at https://www.electropedia.org/

3.1
ancillary components
parts of the apparatus necessary for the test which are not the loading components to impart *stress* (3.26)

3.2
corrosion-resistant alloy
CRA
alloy intended to be resistant to general and localized corrosion of oilfield environments that are corrosive to carbon steels

[SOURCE: ISO 15156-1:2020, 3.6]

3.3
imperfection
discontinuity or irregularity in the product wall or on the product surface that is detectable by inspection methods outlined in this document

3.4
indication
evidence obtained by non-destructive inspection

3.5
girth weld
butt weld joining one pipe to another (or bend or flange)

3.6
hardness
resistance of metal to *plastic deformation* (3.16,), usually determined by indentation

3.7
heat-affected zone
HAZ
portion of base metal not melted during brazing, cutting or *welding* (3.31,), but whose *microstructure* (3.14) and properties are altered by the thermal cycle of these processes

3.8
helical weld
DEPRECATED: spiral weld
weld running helically (spirally) around the circumference of a pipe formed from strip

3.9
hydrogen-induced cracking
HIC
planar cracking that occurs in carbon and *low alloy steels* (3.12) when atomic hydrogen diffuses into the steel and then combines to form molecular hydrogen at trap sites

[SOURCE: ISO 15156-1:2020, 3.12, modified] — Note 1 to entry has been removed.]

3.10
hydrogen permeation
process of atomic hydrogen diffusion through a metal

3.11
longitudinal weld
straight weld running along the longitudinal axis of a pipe

3.12
low alloy steel
steel with a total alloying element content of less than about 5 % mass fraction, but more than specified for carbon steel

[SOURCE: ISO 15156-1:2020, 3.15]

3.13
measured strain
***ε*1, *ε*2, *ε*3**
surface *strain* (3.24) as measured by various techniques in one or more of three known directions at the surface

3.14
microstructure
structure of a metal as revealed by microscopic examination of a suitably prepared specimen

[SOURCE: ISO 15156-1:2020, 3.16]

3.15
Modulusmodulus of elasticity
Young's modulus
E
the ratio of tensile or compressive *stress* (3.26) to corresponding *strain* (3.24) below the elastic limit

3.16
plastic deformation
permanent deformation caused by straining beyond the elastic limit

3.17
~~**Poisson effect**~~
~~component subjected to loading in one direction causing extension or compression in that direction, experiencing tangentially a lesser opposing compression or expansion~~

~~**3.18**~~
Poisson's ratio
v
dimensionless material constant (approximately constant for steel) given by the ratio of contraction/expansion per unit length tangential to the direction of loading over the expansion/contraction per unit length in the direction of loading

3.1918
principal strain
***ε*p**
maximum and minimum *strain* (3.24) levels existing at a point on the test surface acting at 90° to each other as calculated from *measured strain* (3.13) values

3.2019
residual stress
σ_{res}
stress (3.26) present in a component free of external forces or thermal gradients

[SOURCE: ISO 15156-1:2020, 3.18], modified — The symbol σ_{res} has been added.]

3.2120
sour environment
environment where hydrogen sulfide exists in the presence of water

3.2221
specific service
conditions of application for the materials/components for which testing is defined to match the customer's requirements

Note 1 to entry: Fitness-for-purpose has also been historically used to define these same requirements.

3.2322
specified minimum yield strength
SMYS
relates to the minimum *yield strength* (3.34) permitted for a given grade of material in product specifications

3.2423
stepwise cracking
SWC
cracking that connects hydrogen-induced cracks on adjacent planes in a steel

Note 1 to entry: This term describes the crack appearance. The linking of hydrogen-induced cracks to produce stepwise cracking is dependent on the local *strain* (3.24) between the cracks and the embrittlement of the surrounding steel by dissolved hydrogen. HIC/SWC is usually associated with low-strength plate steels used in the production of pipes and vessels.

[SOURCE: ISO 15156-1:2020, 3.21]

3.2524
strain
ε
dimensionless ratio of the change in length per unit length (e.g. mm/mm)

Note 1 to entry: It is normally expressed in parts per million (($\varepsilon \times 10^6$) of microstrain (με).

3.2625
strain gauge
device using electrical resistance, which changes in proportion to applied *strain* (3.24)

3.2726
stress
σ
applied force per unit area existing on any object as a result of external mechanical or thermal influences acting in that direction

3.2827
stress-oriented hydrogen-induced cracking
SOHIC
staggered small cracks formed approximately perpendicular to the principal *stress* (3.26) (residual or applied) resulting in a "ladder-like" crack array linking (sometimes small) pre-existing HIC

Note 1 to entry: The mode of cracking can be categorized as *SSC* (3.28) caused by a combination of external stress and the local *strain* (3.24) around hydrogen-induced cracks. SOHIC is related to SSC and HIC/*SWC* (3.23.). It has been observed in parent metal of longitudinally welded pipe and in the *heat-affected zone (HAZ)* (3.7) of welds in pressure

5

vessels. SOHIC is a relatively uncommon phenomenon usually associated with low-strength ferritic pipe and pressure vessel steels.

[SOURCE: ISO 15156-1:2020, 3.23]

3.2928

sulfide stress cracking

SSC

cracking of metal involving corrosion and *tensile stress* (3.29) (residual and/or applied) in the presence of water and H_2S

Note 1 to entry: SSC is a form of hydrogen stress cracking (HSC) and involves the embrittlement of the metal by atomic hydrogen that is produced by acid corrosion on the metal surface. Hydrogen uptake is promoted in the presence of sulfides. The atomic hydrogen can diffuse into the metal, reduce ductility, and increase susceptibility to cracking. High-strength metallic materials and hard weld zones are prone to SSC.

[SOURCE: ISO 15156-1:2020, 3.24]

3.3029

tensile stress

ratio of load to original cross-sectional area

Note 1 to entry: These stresses include axial or longitudinal, circumferential or hoop and residual.

3.3130

ultrasonic testing

testing of material by ultrasound for the presence of *imperfections* (3.3)

3.3231

welding

joining of two metallic materials, usually by fusion techniques

3.3332

weldment

portion of a component on which *welding* (3.31) has been performed, including the *weld metal* (3.33,), the *heat-affected zone (HAZ*) (3.7),), and the adjacent parent metal

[SOURCE: ISO 15156-2:2020, 3.24], modified — The abbreviated term for "heat-affected zone", HAZ, has been added.]

3.3433

weld metal

portion of a *weldment* (3.32) that has been molten during *welding* (3.31)

3.3534

yield strength

stress (3.26) at which a material exhibits a specified deviation from the proportionality of stress to *strain* (3.24)

Note 1 to entry: The deviation is expressed in terms of strain by either the offset method (usually at a strain of 0,2 %) or the total-extension-under-load method (usually at a strain of 0,5 %).

[SOURCE: ISO 6892-1:2019, 3.10.2]

54 Symbols and abbreviated terms

AYS	actual yield strength
CAR	crack area ratio
CRA	corrosion-resistant alloy
DAC	distance-amplitude-corrected
E	modulus of elasticity
EPDM	ethylene propylene diene monomer
EPM	ethylene propylene copolymer
HAZ	heat-affected zone
HIC	hydrogen-induced cracking
MT	magnetic particle testing
NBR	nitrile butadiene rubber
NDT	non-destructive testing
PT	penetrant testing
PTFE	polytetrafluoroethylene
$R_{p0,2}$	0,2 % proof stress in accordance with ISO 6892-1
SOHIC	stress-oriented hydrogen-induced cracking
SMYS	specified minimum yield strength
SSC	sulfide stress cracking
SWC	step-wise cracking
SZC	soft-zone cracking
UT	ultrasonic testing
ε	strain
ε_p	principal strain
υ	poisons ratio
σ	stress
σ_p	principal stress
σ_{res}	residual stress

65 Principle

A short length of pipe (a ‘full ring’) is mechanically loaded to produce a circumferential stress equal to the target hoop stress at two diametrically opposite locations on the inside surface of the test specimen. The test specimen is subjected to a predetermined stress by ovalization and exposed to a sour environment. Testing is undertaken within an enclosure or in a restricted area.

The test specimen may be monitored throughout the test exposure to determine the extent of development of hydrogen damage due to the presence of wet hydrogen sulfide (H_2S). It is then subjected to post-test non-destructive testing and metallographic examination.

~~7~~6 Reagents

6.1 The following reagent grade or higher-purity chemicals shall be used:

— ~~—~~sodium acetate, CH_3COONa;

— ~~—~~sodium chloride, NaCl;

— ~~—~~acetic acid, CH_3COOH;

— ~~—~~hydrochloric acid, HCl;

— ~~—~~sodium hydroxide, NaOH.

6.2 The following gases shall be used:

— ~~—~~hydrogen sulfide, 99,5 % minimum;

— ~~—~~carbon dioxide, 99,995 % minimum;

— ~~—~~inert gas used for the removal of oxygen, such as nitrogen, argon, or other non-reactive gas, 99,998 % minimum.

6.3 Water, distilled or deionized, conforming to the minimum purity requirements of Type IV of ASTM D1193 shall be used.

6.4 Test environment

6.4.1 General

The test solution used shall be reported for each test. All reagents added to the test solution shall be measured to ±1,0 % of the quantities specified.

The test solution shall be prepared in a separate sealed vessel followed by sparging with inert gas prior to transferring the test solution to the test cell, which has been subjected to inert gas purging in advance (see 9.5~~9.5).~~).

The test solution pH before transfer to the test cell shall be measured and verified to conform with requirements.

The H_2S concentration in the solution shall be measured using the iodometric titration method described in Annex C~~Annex C,~~, or other equivalent method (e.g. photometric measurement).

6.4.2 Test solutions

The following test solutions shall be used depending on the specific test requirements:

