
**Petroleum and natural gas industries —
Materials for use in H₂S-containing
environments in oil and gas
production —**

Part 2:

**Cracking-resistant carbon and low-alloy
steels, and the use of cast irons**

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*Industries du pétrole et du gaz naturel — Matériaux pour utilisation dans
des environnements contenant de l'hydrogène sulfuré (H₂S) dans la
production de pétrole et de gaz —*

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*Partie 2: Aciers au carbone et aciers faiblement alliés résistants à la
fissuration, et utilisation de fontes*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15156-2 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

This second edition cancels and replaces the first edition (ISO 15156-2:2003), of which it constitutes a minor revision, specifically by the following:

- inclusion of the requirements for welding-procedure qualification for overlay welding;
- inclusion of changes to the limitations that apply to Table A.1 on weld hardness;
- inclusion of the ISO equivalents of ASTM hardness standards;
- inclusion of a small number of other technical changes;
- inclusion of changes to make the intent of the text clearer and to correct editorial errors.

ISO 15156 consists of the following parts, under the general title *Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production*:

- *Part 1: General principles for selection of cracking-resistant materials*
- *Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons*
- *Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

Introduction

The consequences of sudden failures of metallic oil and gas field components, associated with their exposure to H₂S-containing production fluids, led to the preparation of the first edition of NACE MR0175, which was published in 1975 by the National Association of Corrosion Engineers, now known as NACE International.

The original and subsequent editions of NACE MR0175 established limits of H₂S partial pressure above which precautions against sulfide stress-cracking (SSC) were always considered necessary. They also provided guidance for the selection and specification of SSC-resistant materials when the H₂S thresholds were exceeded. In more recent editions, NACE MR0175 has also provided application limits for some corrosion-resistant alloys, in terms of environmental composition and pH, temperature and H₂S partial pressures.

In separate developments, the European Federation of Corrosion issued EFC Publication 16 in 1995 and EFC Publication 17 in 1996. These documents are generally complementary to those of NACE though they differed in scope and detail.

In 2003, the publication of the three parts of ISO 15156 and NACE MR0175/ISO 15156 was completed for the first time. These technically identical documents utilized the above sources to provide requirements and recommendations for materials qualification and selection for application in environments containing wet H₂S in oil and gas production systems. They are complemented by NACE TM0177 and NACE TM0284 test methods.

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The revision of this part of ISO 15156 involves a consolidation of all changes agreed and published in the Technical Corrigendum 1, ISO 15156-2:2003/Cor 1:2005 and by the Technical Circular 1, ISO 15156-2:2001/Cir 1:2007(E), published by the ISO 15156 maintenance agency secretariat at DIN, Berlin.

The changes were developed by, and approved by the ballot of, representative groups from within the oil and gas production industry. The great majority of these changes stem from issues raised by document users. A description of the process by which these changes were approved can be found at the ISO 15156 maintenance website www.iso.org/iso15156maintenance.

When found necessary by oil and gas production industry experts, future interim changes to this part of ISO 15156 will be processed in the same way and will lead to interim updates to this part of ISO 15156 in the form of Technical Corrigenda or Technical Circulars. Document users should be aware that such documents can exist and can impact the validity of the dated references in this part of ISO 15156.

The ISO 15156 maintenance agency at DIN was set up after approval by the ISO Technical Management Board given in document 34/2007. This document describes the make up of the agency, which includes experts from NACE, EFC and ISO/TC 67/WG 7, and the process for approval of amendments. It is available from the ISO 15156 maintenance website and from the ISO/TC 67 Secretariat. The website also provides access to related documents that provide more detail of ISO 15156 maintenance activities.

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Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production —

Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons

WARNING — Carbon and low-alloy steels and cast irons selected using this part of ISO 15156 are resistant to cracking in defined H₂S-containing environments in oil and gas production but not necessarily immune to cracking under all service conditions. It is the equipment user's responsibility to select the carbon and low alloy steels and cast irons suitable for the intended service.

1 Scope

This part of ISO 15156 gives requirements and recommendations for the selection and qualification of carbon and low-alloy steels for service in equipment used in oil and natural gas production and natural gas treatment plants in H₂S-containing environments, whose failure can pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help to avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the materials requirements of the appropriate design codes, standards or regulations.

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This part of ISO 15156 addresses the resistance of these steels to damage that can be caused by sulfide stress-cracking (SSC) and the related phenomena of stress-oriented hydrogen-induced cracking (SOHIC) and soft-zone cracking (SZC).

This part of ISO 15156 also addresses the resistance of these steels to hydrogen-induced cracking (HIC) and its possible development into stepwise cracking (SWC).

This part of ISO 15156 is concerned only with cracking. Loss of material by general (mass loss) or localized corrosion is not addressed.

Table 1 provides a non-exhaustive list of equipment to which this part of ISO 15156 is applicable, including permitted exclusions.

This part of ISO 15156 applies to the qualification and selection of materials for equipment designed and constructed using conventional elastic design criteria. For designs utilizing plastic criteria (e.g. strain-based and limit-state designs), see ISO 15156-1:2009, Clause 5.

Annex A lists SSC-resistant carbon and low alloy steels, and A.2.4 includes requirements for the use of cast irons.

This part of ISO 15156 is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

Table 1 — List of equipment

ISO 15156 is applicable to materials used for the following equipment	Permitted exclusions
Drilling, well construction and well-servicing equipment	Equipment exposed only to drilling fluids of controlled composition ^a Drill bits Blowout preventer (BOP) shear blades ^b Drilling riser systems Work strings Wireline and wireline equipment ^c Surface and intermediate casing
Wells, including subsurface equipment, gas lift equipment, wellheads and christmas trees	Sucker rod pumps and sucker rods ^d Electric submersible pumps Other artificial lift equipment Slips
Flow-lines, gathering lines, field facilities and field processing plants	Crude oil storage and handling facilities operating at a total absolute pressure below 0,45 MPa (65 psi)
Water-handling equipment	Water-handling facilities operating at a total absolute pressure below 0,45 MPa (65 psi) Water injection and water disposal equipment
Natural gas treatment plants	—
Transportation pipelines for liquids, gases and multiphase fluids	Lines handling gas prepared for general commercial and domestic use
For all equipment above	Components loaded only in compression
^a See A.2.3.2.3 for more information.	ISO 15156-2:2009
^b See A.2.3.2.1 for more information.	https://standards.itech.ai/catalog/standards/sist/9e8baa39-26e1-40b1-9aca-94b808dc340a/iso-15156-2-2009
^c Wireline lubricators and lubricator connecting devices are not permitted exclusions.	
^d For sucker rod pumps and sucker rods, reference can be made to NACE MR0176.	

2 Normative references

The following referenced documents are indispensable for the application 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 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

ISO 6507-1, *Metallic materials — Vickers hardness test — Part 1: Test method*

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)*

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

ISO 10423, *Petroleum and natural gas industries — Drilling and production equipment — Wellhead and christmas tree equipment*

ISO 15156-1:2009, *Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156-3:2009, *Petroleum and natural gas industries — Materials for use in H₂S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

NACE TM0177-05¹⁾, *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H₂S environments*

NACE TM0284, *Evaluation of pipeline and pressure vessel steels for resistance to hydrogen-induced cracking*

EFC Publications Number 16²⁾, *Guidelines on materials requirements for carbon and low alloy steels for H₂S-containing environments in oil and gas production*

SAE AMS-2430P³⁾, *Shot Peening, Automatic*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15156-1 and the following apply.

3.1

Brinell hardness

HBW

hardness value, measured in accordance with ISO 6506-1, normally using a 10 mm diameter tungsten ball and a force of 29,42 kN

NOTE For the purposes of this provision, ASTM E10 is equivalent to ISO 6506-1.

3.2

bubble-point pressure

p_B

pressure under which gas bubbles form in a liquid at a particular operating temperature

See Clause C.2.

3.3

burnish

process of smoothing surfaces using frictional contact between the material and some other hard pieces of material, such as hardened steel balls

3.4

casting

metal that is obtained at or near its finished shape by the solidification of molten metal in a mould

3.5

cast iron

iron-carbon alloy containing approximately 2 % to 4 % mass fraction carbon

3.5.1

grey cast iron

cast iron that displays a grey fracture surface due to the presence of flake graphite

3.5.2

white cast iron

cast iron that displays a white fracture surface due to the presence of cementite

1) NACE International, P.O. Box 2183140, Houston, Texas 77218-8340, USA.

2) European Federation of Corrosion, available from The Institute of Materials, 1 Carlton House Terrace, London SW1Y 5DB, UK [ISBN 0-901716-95-2].

3) Society of Automotive Engineers (SAE), 400 Commonwealth Drive, Warrendale, PA 15096-0001 USA.

3.5.3

malleable cast iron

white cast iron that is thermally treated to convert most or all of the cementite to graphite (temper carbon)

3.5.4

ductile cast iron

nodular cast iron

cast iron that has been treated while molten with an element (usually magnesium or cerium) that spheroidizes the graphite

3.6

cementite

microstructural constituent of steels composed principally of iron carbide (Fe_3C)

3.7

cold working

cold deforming

cold forging

cold forming

deforming metal plastically under conditions of temperature and strain rate that induce strain-hardening, usually, but not necessarily, conducted at room temperature

3.8

fitness-for-purpose

suitability for use under the expected service conditions

3.9

free-machining steel

steel to which elements such as sulfur, selenium and lead have been added intentionally to improve machineability

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3.10

lower critical temperature

temperature of a ferrous metal at which austenite begins to form during heating or at which the transformation of austenite is completed during cooling

3.11

nitriding

case-hardening process in which nitrogen is introduced into the surface of metallic materials (most commonly ferrous alloys)

EXAMPLES Liquid nitriding, gas nitriding, ion nitriding and plasma nitriding.

3.12

normalizing

heating a ferrous metal to a suitable temperature above the transformation range (austenitizing), holding at temperature for a suitable time and then cooling in still air (or protective atmosphere) to a temperature substantially below the transformation range

3.13

plastically deformed

permanently deformed by stressing beyond the limit of elasticity, i.e. the limit of proportionality of stress to strain

3.14

pressure-containing parts

those parts whose failure to function as intended results in a release of retained fluid to the atmosphere

EXAMPLES Valve bodies, bonnets and stems.

3.15**quenched and tempered**

quench hardened and then tempered

3.16**Rockwell C hardness****HRC**

hardness value, measured in accordance with ISO 6508, obtained using a diamond cone indenter and a force of 1 471 N

NOTE For the purposes of this provision, ASTM E18 is equivalent to ISO 6508-1.

3.17**shot peening**

inducing compressive stresses in the surface layer of a material by bombarding it with a selected medium (usually round steel shot) under controlled conditions

3.18**stress relieving**

heating a metal to a suitable temperature, holding at that temperature long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses

3.19**tempering**

heat treatment by heating to a temperature below the lower critical temperature, for the purpose of decreasing the hardness and increasing the toughness of hardened steel, hardened cast iron and, sometimes, normalized steel

3.20**tensile strength**

ultimate strength

ratio of maximum load to original cross-sectional area

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See ISO 6892-1.

3.21**test batch**

group of items representing a production batch whose conformity with a specified requirement can be determined by testing representative samples in accordance with a defined procedure

3.22**tubular component**

cylindrical component (pipe) having a longitudinal hole, used in drilling/production operations for conveying fluids

3.23**Vickers hardness****HV**

hardness value, measured in accordance with ISO 6507-1, obtained using a diamond pyramid indenter and one of a variety of possible applied loads

NOTE For the purposes of this provision, ASTM E92 is equivalent to ISO 6507-1.

3.24**weldment**

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

3.25

weld metal

that portion of a weldment that has been molten during welding

3.26

wrought metal

metal in the solid condition that is formed to a desired shape by working (rolling, extruding, forging, etc.), usually at an elevated temperature

4 Symbols and abbreviated terms

For the purposes of this document, the abbreviated terms given in ISO 15156-1 and the following apply.

AYS	actual yield strength
CLR	crack length ratio
CR	c-ring (test)
CSR	crack surface ratio
CTR	crack thickness ratio
DCB	double cantilever beam (test)
FPB	four-point bend (test)
HBW	Brinell hardness
HIC	hydrogen-induced cracking
HRC	Rockwell hardness (scale C)
HSC	hydrogen stress cracking
HV	Vickers hardness
OCTG	oil country tubular goods, i.e. casing, tubing and drill pipe
p_{H_2S}	partial pressure of H ₂ S
$R_{p0,2}$	0,2 % proof stress in accordance with ISO 6892-1
SMYS	specified minimum yield strength
SOHIC	stress-oriented hydrogen-induced cracking
SSC	sulfide stress-cracking
SWC	stepwise cracking
SZC	soft-zone cracking
T	temperature
UNS	Unified Numbering System (from SAE-ASTM, <i>Metals and alloys in the Unified Numbering System</i>)
UT	uniaxial tensile (test)

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5 Purchasing information

5.1 The preparation of material purchasing specifications can require co-operation and exchange of data between the equipment user, the equipment supplier and the material manufacturer to ensure that the material purchased complies with ISO 15156-1 and this part of ISO 15156.

5.2 The following information shall be provided:

- preferred material types and/or grades (if known);
- equipment type (if known);
- reference to this part of ISO 15156;
- acceptable bases for selection of materials for SSC resistance; see Clause 7;
- requirements for HIC resistance; see Clause 8.

5.3 The equipment user and the equipment supplier/material manufacturer may agree that carbon or low-alloy steels other than those described and/or listed in Annex A may be selected subject to suitable qualification testing in accordance with Annex B and ISO 15156-1. The qualification requirements may be extended to include resistance to SOHIC and SZC.

If the purchaser intends to make use of such agreements, extensions and qualifications, the appropriate additional information shall be clearly indicated in the materials purchasing specification. This information may include

- requirements for SSC testing; see 7.1, 7.2,
- service conditions for specific sour-service application; and
- other special requirements.

5.4 Annex C describes how to calculate the H₂S partial pressure and Annex D gives guidance on how to determine the pH-value of a fluid.

5.5 The information required for material purchasing shall be entered on suitable data sheets. Suggested formats are given in Annex E.

6 Factors affecting the behaviour of carbon and low alloy steels in H₂S-containing environments

The behaviour of carbon and low-alloy steels in H₂S-containing environments is affected by complex interactions of parameters, including the following:

- a) chemical composition, method of manufacture, product form, strength, hardness of the material and its local variations, amount of cold work, heat-treatment condition, microstructure, microstructural uniformity, grain size and cleanliness of the material;
- b) H₂S partial pressure or equivalent concentration in the water phase;
- c) chloride ion concentration in the water phase;
- d) acidity (pH) of the water phase;
- e) presence of sulfur or other oxidants;

- f) exposure to non-production fluids;
- g) exposure temperature;
- h) total tensile stress (applied plus residual);
- i) exposure time.

These factors shall be considered when using this part of ISO 15156 for the selection of materials suitable for environments containing H₂S in oil and gas production systems.

7 Qualification and selection of carbon and low-alloy steels with resistance to SSC, SOHIC and SZC

7.1 Option 1 — Selection of SSC-resistant steels (and cast irons) using Clause A.2

7.1.1 For $p_{\text{H}_2\text{S}} < 0,3 \text{ kPa (0,05 psi)}$

The selection of materials for SSC resistance for $p_{\text{H}_2\text{S}}$ below 0,3 kPa (0,05 psi) is not considered in detail in this part of ISO 15156. Normally, no special precautions are required for the selection of steels for use under these conditions, nevertheless, highly susceptible steels can crack. Additional information on factors affecting susceptibility of steels and attack by cracking mechanisms other than SSC is given in 7.2.1.

7.1.2 For $p_{\text{H}_2\text{S}} \geq 0,3 \text{ kPa (0,05 psi)}$

If the partial pressure of H₂S in the gas is equal to or greater than 0,3 kPa (0,05 psi), SSC-resistant steels shall be selected using Clause A.2.

NOTE 1 The steels described or listed in Clause A.2 are considered resistant to SSC in oil and natural-gas production and natural-gas treatment plants.

NOTE 2 Users concerned with the occurrence of SOHIC and/or SZC can refer to Option 2; see 7.2.2.

NOTE 3 For HIC and SWC, refer to Clause 8.

7.2 Option 2 — Selection of steels for specific sour-service applications or for ranges of sour service

7.2.1 Sulfide stress-cracking

7.2.1.1 General

Option 2 allows the user to qualify and select materials for sulfide stress-cracking (SSC) resistance for specific sour-service applications or for ranges of sour service.

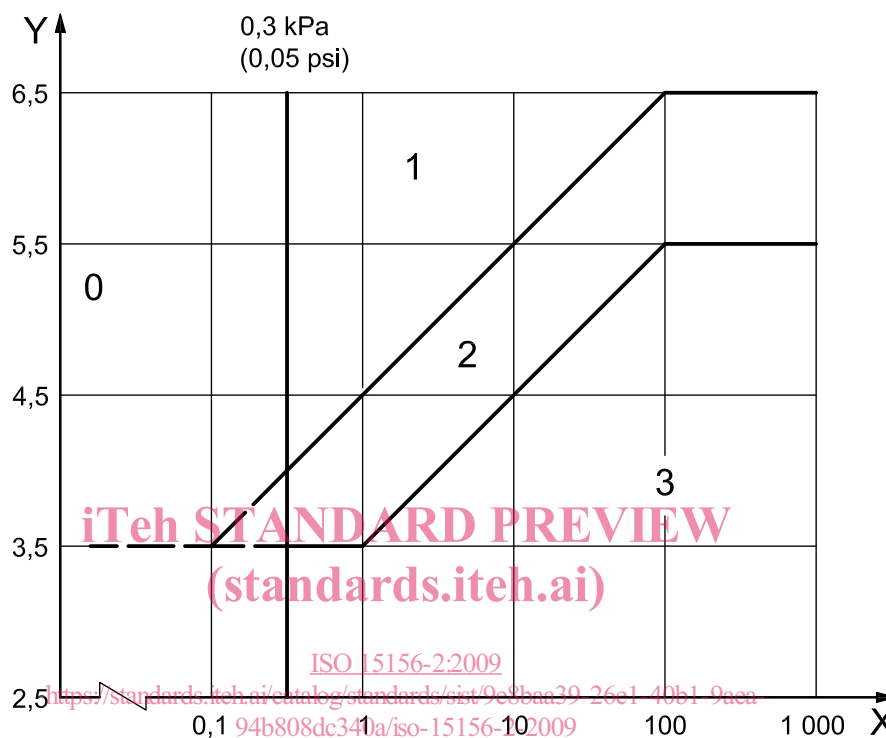
The use of option 2 can require knowledge of both the *in situ* pH and the H₂S partial pressure and their variations with time; see ISO 15156-1.

Option 2 facilitates the purchase of bulk materials, such as OCTG or line pipe, where the economic incentive to use materials not described nor listed in Annex A outweighs the additional qualification and other costs that can be incurred. Steels for other equipment may also be qualified. In some cases, this requires an agreement between the supplier and the equipment user with respect to test and acceptance requirements. Such agreements shall be documented.

Option 2 can also facilitate fitness-for-purpose evaluations of existing carbon or low-alloy steel equipment exposed to sour-service conditions more severe than assumed in the current design.

7.2.1.2 SSC regions of environmental severity

The severity of the sour environment, determined in accordance with ISO 15156-1, with respect to the SSC of a carbon or low-alloy steel shall be assessed using Figure 1. In defining the severity of the H₂S-containing environment, the possibility of exposure to unbuffered, condensed aqueous phases of low pH during upset operating conditions or downtime, or to acids used for well stimulation and/or the backflow of stimulation acid after reaction should be considered.



Key

X H₂S partial pressure, expressed in kilopascals

Y *in situ* pH

0 region 0

1 SSC region 1

2 SSC region 2

3 SSC region 3

NOTE 1 The discontinuities in the figure below 0,3 kPa (0,05 psi) and above 1 MPa (150 psi) partial pressure H₂S reflect uncertainty with respect to the measurement of H₂S partial pressure (low H₂S) and the steel's performance outside these limits (for both low and high H₂S).

NOTE 2 Guidance on the calculation of H₂S partial pressure is given in Annex C.

NOTE 3 Guidance on the calculation of pH is given in Annex D.

Figure 1 — Regions of environmental severity with respect to the SSC of carbon and low-alloy steels