
**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**

*Industries du pétrole et du gaz naturel — Matériaux pour utilisation en
présence de H₂S dans la production de pétrole et de gaz naturel —*

*Partie 1: Principes généraux pour le choix des matériaux résistant au
craquage*



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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 3.

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 part of ISO 15156 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 15156-1 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*.

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*
- Part 3: *Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

Introduction

The consequences of sudden failures of metallic components used in the oil and gas field, and associated with their exposure to H₂S-containing production fluids, led to the preparation of the first edition of NACE MR 0175. This standard was published in 1975 by the National Association of Corrosion Engineers, now known as NACE International.

The original and subsequent editions of NACE MR 0175 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 MR 0175 has also provided application limits for some corrosion-resistant alloys, in terms of environmental composition and pH, temperature and H₂S partial pressures. NACE MR 0175 is complemented by NACE TM 0177 and NACE M 284.

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 differ in scope and detail.

With the cooperation of NACE and EFC, ISO/TC 67 formed Working Group 7 to prepare ISO 15156. The Working Group are to promote the collection, review and, where appropriate, publication of field experience and laboratory test data related to the cracking resistance of metallic materials in H₂S-containing environments.

This part of ISO 15156 utilises the above sources to provide requirements and recommendations for materials qualification and selection for safe application in environments containing wet H₂S in oil and gas production systems.

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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

1 Scope

This part of ISO 15156 describes general principles and gives requirements and recommendations for the selection and qualification of metallic materials for service in equipment used in oil and gas production and in natural gas sweetening plants in H₂S-containing environments, where the failure of such equipment could 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 material requirements given in the appropriate design codes, standards or regulations.

This part of ISO 15156 addresses all mechanisms of cracking that can be caused by H₂S, including sulfide stress cracking, stress corrosion cracking, hydrogen-induced cracking and stepwise cracking, stress-oriented hydrogen-induced cracking, soft zone cracking and galvanically induced hydrogen stress cracking.

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.

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

CAUTION — Metallic materials selected or qualified using ISO 15156 are resistant to cracking in defined H₂S-containing environments in oil and gas production, but are not necessarily immune under all service conditions.

Table 1 — List of equipment

ISO 15156-1 is applicable to materials used for the following equipment	Permitted exclusions
Drilling, well construction and well servicing equipment	Equipment only exposed to drilling fluids of controlled composition ^a Drill bits Blowout preventer (BOP) shear blades ^b Drilling riser systems Work strings Wire line and wire line equipment ^c Surface and intermediate casing
Wells, including subsurface equipment, gas lift equipment, wellheads and christmas trees	Sucker rod pumps and sucker rods ^d Electrical submersible pumps Other artificial lift equipment Slips
Flowlines, gathering lines, field facilities and field processing plants	Crude oil storage and handling facilities operating at gauge pressure below 4,3 bar (65 psi)
Sour-water handling equipment	
Natural gas treatment plants	
Transportation pipelines for liquids, gases and multiphase fluids	Lines handling gas prepared for domestic use
<p>^a Given the high strength often needed, drilling equipment may not comply with the requirements of this part of ISO 15156. In such cases the primary means for avoiding SSC is control of the drilling or well-servicing environment. As service stresses and material hardness increase, drilling fluid control becomes increasingly important. Take care to control the drilling environment by maintenance of drilling fluid hydrostatic head and fluid density to minimize formation fluid in-flow and by one or more of the following procedures: 1) maintenance of pH 10 or higher to neutralize H₂S in the drilled formation; 2) use of chemical sulfide scavengers; 3) use of a drilling fluid in which oil is the continuous phase.</p> <p>^b High strength steels used for blowout preventer (BOP) shear blades are highly susceptible to SSC.</p> <p>^c Wireline lubricators and lubricator connecting devices shall comply.</p> <p>^d NACE MR 0176 applies to sucker rod pumps and sucker rods.</p>	

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 15156. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 15156 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 15156-2, *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*

ISO 15156-3, *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*

3 Terms and definitions

For the purposes of this part of ISO 15156, the following terms and definitions apply.

3.1

blowout preventer

BOP

mechanical device capable of containing pressure, used for control of well fluids and drilling fluids during drilling operations

3.2

braze, verb

join metals by flowing a thin layer (of capillary thickness) of a lower-melting-point non-ferrous filler metal in the space between them

3.3

carbon steel

alloy of carbon and iron containing up to 2 % carbon and up to 1,65 % manganese and residual quantities of other elements, except those intentionally added in specific quantities for deoxidation (usually silicon and/or aluminium)

NOTE Carbon steels used in the petroleum industry usually contain less than 0,8 % carbon.

3.4

christmas tree

equipment at a wellhead for the control of fluid production or injection

3.5

cold work, verb

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

3.6

corrosion-resistant alloy

CRA

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

3.7

ferrite

body-centred cubic crystalline phase of iron-based alloys

3.8

ferritic steel

steel whose microstructure at room temperature consists predominantly of ferrite

3.9

hardness

resistance of metal to plastic deformation, usually measured by indentation

3.10

heat-affected zone

HAZ

that portion of the base metal that is not melted during brazing, cutting or welding, but whose microstructure and properties are altered by the heat of these processes

3.11

heat treatment

heating and cooling a solid metal or alloy in such a way as to obtain desired properties

NOTE Heating for the sole purpose of hot working is not considered heat treatment.

3.12

hydrogen-induced cracking

HIC

planar cracking that occurs in carbon and low alloy steels when atomic hydrogen diffuses into the steel and then combines to form molecular hydrogen at trap sites

NOTE Cracking results from the pressurization of trap sites by hydrogen. No externally applied stress is needed for the formation of hydrogen-induced cracks. Trap sites capable of causing HIC are commonly found in steels with high impurity levels that have a high density of planar inclusions and/or regions of anomalous microstructure (e.g. banding) produced by segregation of impurity and alloying elements in the steel. This form of hydrogen-induced cracking is not related to welding.

3.13

hydrogen stress cracking

HSC

cracking that results from the presence of hydrogen in a metal and tensile stress (residual and/or applied)

NOTE HSC describes cracking in metals that are not sensitive to SSC but which may be embrittled by hydrogen when galvanically coupled, as the cathode, to another metal that is corroding actively as an anode. The term galvanically induced HSC has been used for this mechanism of cracking.

3.14

low alloy steel

steel with a total alloying element content of less than about 5 %, but more than specified for carbon steel

3.15

microstructure

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

3.16

partial pressure

pressure that would be exerted by a single component of a gas if present alone, at the same temperature, in the total volume occupied by the mixture

NOTE For a mixture of ideal gases, the partial pressure of each component is equal to the total pressure multiplied by its mole fraction in the mixture, where its mole fraction is equal to the volume fraction of the component.

3.17

residual stress

stress present in a component free of external forces or thermal gradients

3.18

soft zone cracking

SZC

form of SSC that may occur when a steel contains a local "soft zone" of low yield strength material

NOTE Under service loads, soft zones may yield and accumulate plastic strain locally, increasing the SSC susceptibility to cracking of an otherwise SSC-resistant material. Such soft zones are typically associated with welds in carbon steels.

3.19

sour service

exposure to oilfield environments that contain H₂S and can cause cracking of materials by the mechanisms addressed by this part of ISO 15156

3.20**stepwise cracking****SWC**

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

NOTE This term describes the crack appearance. The linking of hydrogen-induced cracks to produce stepwise cracking is dependent upon local strain between the cracks and 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.

3.21**stress corrosion cracking****SCC**

cracking of metal involving anodic processes of localized corrosion and tensile stress (residual and/or applied) in the presence of water and H₂S

NOTE Chlorides and/or oxidants and elevated temperature can increase the susceptibility of metals to this mechanism of attack.

3.22**stress-oriented hydrogen-induced cracking****SOHIC**

staggered small cracks formed approximately perpendicular to the principal stress (residual or applied) resulting in a "ladder-like" crack array linking (sometimes small) pre-existing HIC cracks

NOTE The mode of cracking can be categorized as SSC caused by a combination of external stress and the local strain around hydrogen-induced cracks. SOHIC is related to SSC and HIC/SWC. It has been observed in parent material of longitudinally welded pipe and in the heat-affected zone (HAZ) of welds in pressure vessels. SOHIC is a relatively uncommon phenomenon usually associated with low-strength ferritic pipe and pressure vessel steels.

3.23**sulfide stress cracking****SSC**

cracking of metal involving corrosion and tensile stress (residual and/or applied) in the presence of water and H₂S

NOTE SSC is a form of hydrogen stress cracking (HSC) and involves 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.

3.24**weld, verb**

join two or more pieces of metal by applying heat and/or pressure with or without filler metal, to produce a union through localized fusion of the substrates and solidification across the interfaces

3.25**yield strength**

stress at which a material exhibits a specified deviation from the proportionality of stress to strain

NOTE 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 %).

4 Abbreviated terms

BOP Blowout preventer

CRA Corrosion resistant alloy

HAZ Heat-affected zone

HIC Hydrogen-induced cracking

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HSC	Hydrogen stress cracking
SCC	Stress corrosion cracking
SOHIC	Stress-oriented hydrogen-induced cracking
SWC	Stepwise cracking
SSC	Sulfide stress cracking
SZC	Soft zone cracking.

5 General principles

Users of ISO 15156 (all parts) shall first assess the conditions to which the materials they wish to select may be exposed. Having evaluated, defined and documented these conditions in accordance with ISO 15156-1, materials selection is made following the requirements and recommendations of the appropriate part of ISO 15156.

The use of other parts of ISO 15156 may require exchange of information (for example concerning required or suitable service conditions) between the equipment user and the equipment or materials supplier.

NOTE The equipment supplier may need to exchange information with the equipment manufacturer, the materials supplier, and/or the materials manufacturer.

Qualification, with respect to a particular mode of failure, for use in defined service conditions also qualifies a material for use under other service conditions that are equal to or less severe in all respects than the conditions for which qualification was carried out.

The equipment user shall determine whether or not the service conditions are such that this part of ISO 15156 applies. If necessary the equipment user shall advise other parties of the service conditions.

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-states designs) use of this part of ISO 15156 may not be appropriate and the equipment user shall assess the need for other requirements.

6 Evaluation and definition of service conditions to enable material selection

6.1 Before selecting or qualifying materials using other parts of ISO 15156, the user of the equipment shall define, evaluate and document the service conditions to which materials may be exposed for each application. The defined conditions shall include both intended exposures and unintended exposures which may result from the failure of primary containment or protection methods. Particular attention shall be paid to the quantification of those factors known to affect the susceptibility of materials to cracking caused by H₂S.

Factors, other than material properties, known to affect the susceptibility of metallic materials to cracking in H₂S service include H₂S partial pressure, *in situ* pH, the concentration of dissolved chloride or other halide, the presence of elemental sulfur or other oxidant, temperature, galvanic effects, mechanical stress, and time of exposure to contact with a liquid water phase.

6.2 The documented service conditions shall be used for one or more of the following purposes:

- a) to provide the basis for selection of pre-qualified SSC/SCC resistant materials (see clause 7);
- b) to provide the basis for qualification and selection based upon documented field experience (see 8.2);
- c) to define the laboratory test requirements to qualify a material for H₂S service with respect to one or more of SSC, SCC, HIC, SOHIC, SZC and/or galvanically induced HSC (see 8.3);
- d) to provide the basis for the reassessment of the suitability of existing alloys of construction, using clause 7, 8.2 and/or 8.3, in the event of changes to the actual or intended service conditions.

7 Selection of pre-qualified materials resistant to SSC/SCC in the presence of sulfides

SSC-resistant carbon and low alloy steels may be selected from the pre-qualified materials identified in ISO 15156-2.

SSC, SCC-resistant CRAs and other alloys may be selected from the pre-qualified materials identified in ISO 15156-3.

Generally, no additional laboratory testing of pre-qualified materials selected in these ways is required. The materials listed have given acceptable performance under the stated metallurgical, environmental and mechanical conditions based either on field experience and/or laboratory testing. The equipment user should, nevertheless, give consideration to specific testing of materials for applications where they consider the potential consequences of failure make this justifiable (see clause 1, CAUTION).

NOTE The experience reflected in the requirements of NACE MR 0175 is included in the lists of pre-qualified materials of ISO 15156-2 and ISO 15156-3.

8 Qualification of materials for H₂S service

8.1 Material description and documentation

The material to be qualified shall be described and documented, such that those of its properties likely to affect performance in H₂S-containing media are defined. The tolerances or ranges of properties that can occur within the material shall be described and documented.

Metallurgical properties known to affect performance in H₂S-containing environments include: chemical composition, method of manufacture, product form, strength, hardness, amount of cold work, heat-treatment condition and microstructure.

8.2 Qualification based upon field experience

A material may be qualified by documented field experience. The material description shall meet the requirements of 8.1. The description of the service conditions in which the experience has been gained shall meet the relevant requirements of 6.1. The duration of the documented field experience shall be at least two years, and should preferably involve a full examination of the equipment following field use. The severity of intended service conditions shall not exceed that of the field experience for which documented records are available.

8.3 Qualification based upon laboratory testing

8.3.1 General

Laboratory testing can only approximate field service.

Laboratory testing in accordance with the ISO 15156 (all parts) may be used for the following:

- to qualify metallic materials for their resistance to SSC and/or SCC under service conditions up to the limits that apply to pre-qualified materials of similar types listed in ISO 15156-2 and ISO 15156-3;
- to qualify metallic materials for their resistance to SSC and/or SCC under service conditions with other limits;

EXAMPLE Qualification up to a higher than normally acceptable level of H₂S, to a lower than normally required test stress or to revised temperature limit(s) or to a lower pH.

- to qualify carbon and low alloy steels with respect to their resistance to HIC, SOHIC or SZC,
- to qualify corrosion-resistant or other alloys with respect to their resistance to galvanically induced HSC,
- to provide qualification data for a material not currently shown as pre-qualified in ISO 15156-2 and ISO 15156-3 in such a form that it may be considered for inclusion at a later date.

8.3.2 Sampling of materials for laboratory testing

The method of sampling the material for laboratory testing shall be reviewed and accepted by the equipment user.

The test samples shall be representative of the commercial product.

For multiple batches of a material produced to a single specification, an assessment shall be made of the properties that influence cracking behaviour in H₂S-containing environments (see 8.1). The distributions of these properties shall be considered when selecting samples for testing according to the requirements of ISO 15156-2 and ISO 15156-3. The materials in the metallurgical condition that has the greatest susceptibility to cracking in H₂S service shall be used for the selection of the test samples.

Materials source, method of preparation and surface condition of samples for testing shall be documented.

8.3.3 Selection of laboratory test methods

For carbon and low alloy steels, test methods for SSC, HIC, SOHIC and/or SZC shall be selected from ISO 15156-2 as required.

For CRAs and other alloys, test methods for SSC, SCC and galvanically induced HSC shall be selected from ISO 15156-3 as required.

8.3.4 Conditions to be applied during testing

For qualification of carbon and low alloy steels, for general sour service applications or for more restricted application ranges, standardized test environments and mechanical test conditions shall be chosen from those described in ISO 15156-2.

For qualification of CRAs or other alloys for the restricted application ranges appropriate to each alloy type the standardized test environments and mechanical test conditions shall be chosen from those described in ISO 15156-3.

For qualification of a material for use in application specific service conditions, the equipment user shall take care to ensure that the test conditions and the test results obtained from them are appropriate for those specific service conditions. All the test conditions applied shall be at least as severe, with respect to the potential mode of failure, as those defined to occur in the field service (see 6.1). The pH applied shall represent the service *in situ* pH.

The justification of the selection of the test environment and mechanical test conditions with respect to a specific application shall be documented by the equipment user.

8.3.5 Acceptance criteria

Test acceptance criteria shall be as defined for each test method in ISO 15156-2 and ISO 15156-3.

9 Report of the method of selection or qualification

Materials selected or qualified in accordance with this part of ISO 15156 shall have the method of selection documented by reporting item a) from the following list, together with one other item [b), c) or d)] from the list. The equipment user shall be responsible for ensuring that the required documentation is prepared.

- a) For all materials, evaluation of the service conditions (see 6.1).
- b) For a material selected as pre-qualified with respect to SSC and/or SCC (see clause 7), documentation making reference to the relevant subclauses of ISO 15156-2 or ISO 15156-3.