INTERNATIONAL STANDARD

ISO 15156-3

Fourth edition
2020-11

Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production —

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

Industries du pétrole et du gaz naturel — Matériaux pour utilisation dans des environnements contenant de l'hydrogène sulfuré (H_2S) dans la production de pétrole et de gaz —

Partie 3: ARC (alliages résistants à la corrosion) et autres alliages résistants à la fissuration

Reference number
ISO 15156-3:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This fourth edition cancels and replaces the third edition (ISO 15156-3:2015), which has been technically revised. The main changes compared to the previous edition are as follows:

— Table A.27 UNS S17400 (17-4PH SS) has new limits. The use of the alloy at the annotated environmental conditions is now limited to applications where sustained stress is no more than 50 % of SMYS;

— Table A.32 new limits and annotations for UNS N09946 separate from UNS N09945;

— Table A.41 inclusion of UNS R55400 (new a-b Ti alloy);

— Table A.3 UNS S20910 (Nitronic 50) note modifications;

— Tables A.22, A.23, A.26 through A.30, and A.33 temperature conversion corrections;

— Table A.23 new note for maximum design tensile stress for UNS J91540;

— Table A.32 newly added UNS N07718 (high strength Alloy 718, with two-step aging cycle, meeting API 6A CRA composition and a maximum hardness of 45 HRC) and UNS N09955 requirements and note letters designation changes on UNS N09925, N09935, N09945 and N09946;

— Table A.40 title modification and note clarification;

— Clause A.13 Cladding, overlays, and wear-resistant alloys modifications;

— Table A.18 and Table A.19 (Martensitic SS) remarks modifications;

— Table A.24 Duplex SS Hot Isostatically Pressed (HIP) inclusion and remarks modification;

— the informative Annex D, "Materials chemical compositions and other information", has been removed due to copyright reasons;

— additions to the bibliography.

A list of all parts in the ISO 15156 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The consequences of sudden failures of metallic oil and gas field components associated with their exposure to H_2S-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 H_2S 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 H_2S 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 H_2S 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 ISO 15156 series 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 H_2S in oil and gas production systems. They are complemented by NACE TM0177 and NACE TM0284 test methods.

The revision of this document, i.e. ISO 15156, involves a consolidation of all changes agreed and published in the Technical Circular 1, ISO 15156-3:2015/Cir.1:2016, the Technical Circular 2, ISO 15156-3:2015/Cir.2:2018 and the Technical Circular 3, ISO 15156-3:2015/Cir.3:2019, published by the ISO 15156 series Maintenance Agency secretariat at DIN.

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 series maintenance website: www.iso.org/iso15156maintenance.

When found necessary by oil and gas production industry experts, future interim changes to this document will be processed in the same way and will lead to interim updates to this document 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 document.

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

Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production —

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

WARNING — CRAs (corrosion-resistant alloys) and other alloys selected using this document are resistant to cracking in defined H_2S-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 CRAs and other alloys suitable for the intended service.

1 Scope

This document gives requirements and recommendations for the selection and qualification of CRAs (corrosion-resistant alloys) and other alloys for service in equipment used in oil and natural gas production and natural gas treatment plants in H_2S-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 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.

This document addresses the resistance of these materials to damage that can be caused by sulfide stress cracking (SSC), stress corrosion cracking (SCC), and galvanically induced hydrogen stress cracking (GHSC).

This document 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 document is applicable, including exclusions.

This document applies to the qualification and selection of materials for equipment designed and constructed using load controlled design methods. For design utilizing strain-based design methods, see ISO 15156-1:2020, Clause 5.

This document is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

Table 1 — List of equipment

This document is applicable to materials used for the following equipment	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 multi-phase fluids	Lines handling gas prepared for general commercial and domestic use
For all equipment above	Components loaded only in compression

[a] See ISO 15156-2:2020, A.2.3.2.3 for more information.

[b] See ISO 15156-2:2020, A.2.3.2.1 for more information.

[c] Wireline lubricators and lubricator connecting devices are not excluded.

[d] For sucker rod pumps and sucker rods, reference can be made to NACE MR0176.

2 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 6507-1, *Metallic materials — Vickers hardness test — Part 1: Test method*

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method*

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 11960, *Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells*

ISO 15156-1:2020, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156-2:2020, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons*

ASTM A747/A747M[1)], *Standard Specification for Steel Castings, Stainless, Precipitation Hardening*

ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

ASTM E562, *Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count*

EFC Publication 17[2)], *Corrosion resistant alloys for oil and gas production: guidelines on general requirements and test methods for H_2S service*

NACE CORROSION/95 Paper 47, *Test methodology for elemental sulfur-resistant advanced materials for oil and gas field equipment*

NACE TM0177:2016, *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H_2S environments*

SAE AMS-2430[3)], *Shot Peening*

SAE — ASTM, Metals and alloys in the Unified Numbering System

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15156-1, ISO 15156-2 and the following apply.

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

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

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

3.1
ageing
change in metallurgical properties that generally occurs slowly at room temperature (natural ageing) and more rapidly at higher temperature (artificial ageing)

3.2
anneal
heat to and hold at a temperature appropriate for the specific material and then cool at a suitable rate for such purposes as reducing hardness, improving machineability, or obtaining desired properties

3.3
austenite
face-centred cubic crystalline phase of iron-based alloys

1) www.astm.org

2) www.efcweb.org

3) www.sae.org

3.4
duplex stainless steel
austenitic/ferritic stainless steel
stainless steel (3.13) whose microstructure at room temperature consists primarily of a mixture of *austenite* (3.3) and *ferrite* (3.5)

3.5
ferrite
body-centred cubic crystalline phase of iron-based alloys

3.6
ferritic stainless steel
stainless steel (3.13) whose microstructure at room temperature consists predominantly of *ferrite* (3.5)

3.7
galvanically induced hydrogen stress cracking
GHSC
cracking that results due to the presence of hydrogen in a metal induced in the cathode of a galvanic couple and tensile stress (residual and/or applied)

3.8
martensite
hard, supersaturated solid solution of carbon in iron characterized by an acicular (needle-like) microstructure

3.9
martensitic steel
steel in which a microstructure of *martensite* (3.8) can be attained by quenching at a cooling rate fast enough to avoid the formation of other microstructures

3.10
pitting-resistance equivalent number
PREN
F_{PREN}
number developed to reflect and predict the pitting resistance of a CRA based upon the proportions of the elements Cr, Mo, W, and N in the chemical composition of the alloy

Note 1 to entry: See 6.3 for further information.

3.11
production environment
natural occurring produced fluids without contamination from chemicals that will temporarily or continuously reduce the in situ pH

Note 1 to entry: Flow back of chemicals for stimulation and scale removal may temporarily reduce the pH significantly and some continuously injected chemicals, such as scale inhibitors, can continuously reduce pH.

3.12
solid solution
single crystalline phase containing two or more elements

3.13
stainless steel
steel containing 10,5 % mass fraction or more chromium, possibly with other elements added to secure special properties

4 Symbols and abbreviated terms

AYS	actual yield strength
bal	balance of composition up to 100 %
BOP	blowout preventer
CR	c-ring
CRA	corrosion-resistant alloy
DCB	double cantilever beam (test)
FPB	four-point bend (test)
GHSC	galvanically induced hydrogen stress cracking
HAZ	heat-affected zone
HBW	Brinell hardness
HIC	hydrogen-induced cracking
HIP	hot isostatically pressed
HRB	Rockwell hardness (scale B)
HRC	Rockwell hardness (scale C)
HSC	hydrogen stress cracking
HV	Vickers hardness
NDS	no data submitted
pCO_2	partial pressure of CO_2
pH_2S	partial pressure of H_2S
PREN	pitting-resistance equivalent number
PWHT	post-weld heat treatment
RSRT	rippled strain rate test
S^0	elemental sulfur
SCC	stress-corrosion cracking
SMYS	specified minimum yield strength
SOHIC	stress-oriented hydrogen-induced cracking
SSC	sulfide stress cracking
SSRT	slow strain rate test

SZC soft-zone cracking

UNS unified (alloy) numbering system

UT uniaxial tensile (test)

5 Factors affecting the cracking-resistance of CRAs and other alloys in H_2S-containing environments

The cracking behaviour of CRAs and other alloys in H_2S-containing environments can be affected by complex interactions of parameters including the following:

— chemical composition, strength, heat treatment, microstructure, method of manufacture, and finished condition of the material;

— H_2S partial pressure or equivalent dissolved concentration in the water phase;

— acidity (in situ pH) of the water phase;

— chloride or other halide ion concentration;

— presence of oxygen, sulfur, or other oxidants;

— exposure temperature;

— pitting resistance of the material in the service environment;

— galvanic effects;

— total tensile stress (applied plus residual);

— exposure time.

These factors shall be considered when using this document for the selection of materials suitable for environments containing H_2S in oil and gas production systems.

6 Qualification and selection of CRAs and other alloys with respect to SSC, SCC, and GHSC in H_2S-containing environments

6.1 General

CRAs and other alloys shall be selected for their resistance to SSC, SCC, and/or GHSC as required by the intended service.

Conformance of a CRA or other alloy with this document implies cracking-resistance within defined environmental service limits. These limits are dependent on the material type or the individual alloy.

To enable qualification and/or selection of CRAs and other alloys, the equipment purchaser can be required to provide information on the proposed conditions of exposure to the equipment supplier.

In defining the severity of H_2S-containing environments, exposures that can occur during system upsets or shutdowns, etc. shall also be considered. Such exposures can include unbuffered, low pH condensed water. The limits given in the tables in Annex A are for production environments and do not cover conditions occurring during injection or flowback of chemicals that can reduce the in situ pH.

CRAs and other alloys shall be selected using Annex A or following qualification by successful laboratory testing in accordance with Annex B. Qualification based on satisfactory field experience is also acceptable. Such qualification shall conform with ISO 15156-1.

In Annex A, materials are identified by materials groups. Within each group, alloys are identified by materials type (within compositional limits) or as individual alloys. Acceptable metallurgical conditions and environmental limits are given for which alloys are expected to resist cracking. Environmental limits are given for H_2S partial pressure, temperature, chloride concentration, and elemental sulfur.

A CRA or other alloy can be qualified by testing for use under operating conditions that are more severe than the environmental limits given in Annex A. Similarly, a CRA or other alloy can be qualified for use in different metallurgical conditions (higher strength, alternative heat treatment, etc.) to those given in Annex A.

The documentation of qualifications performed in accordance with Annex B shall meet the requirements in ISO 15156-1:2020, Clause 9.

The equipment user shall verify qualifications (see B.2.2) and retain documentation supporting the materials selections made.

6.2 Evaluation of materials properties

6.2.1 Hardness of parent metals

If hardness measurements on parent metal are specified, sufficient hardness tests shall be made to establish the actual hardness of the CRA or other alloy being examined. Individual HRC readings exceeding the value permitted by this document may be considered acceptable if the average of several readings taken within close proximity does not exceed the value permitted by this document and no individual reading is greater than 2 HRC above the specified value. Equivalent requirements shall apply to other methods of hardness measurement when specified in this document or referenced in a manufacturing specification.

The conversion of hardness readings to or from other scales is material-dependent. The user may establish the required conversion tables.

NOTE The number and location of hardness tests on parent metal are not specified in ISO 15156 (all parts).

6.2.2 Cracking-resistance properties of welds

6.2.2.1 General

The metallurgical changes that occur when welding CRAs and other alloys can affect their susceptibility to SSC, SCC, and/or GHSC. Welded joints can have a greater susceptibility to cracking than the parent material(s) joined.

The equipment user may allow the cracking susceptibility of weldments to govern the limits of safe service conditions for a fabricated system.

Processes and consumables used in welding should be selected in accordance with good practice and to achieve the required corrosion and cracking resistances.

Welding shall be carried out in conformance with appropriate codes and standards as agreed between the supplier and the purchaser. Welding procedure specifications (WPSs) and procedure qualification records (PQRs) shall be available for inspection by the equipment user.

Welding PQRs shall include documented evidence demonstrating satisfactory cracking resistance under conditions at least as severe as those of the proposed application. Such evidence shall be based upon one or more of the following:

— conformance with the requirements and recommendations for the specific materials group of Annex A (see also 6.2.2.2 and 6.2.2.3);

— weld cracking-resistance qualification testing in accordance with Annex B;

— documented field experience modelled upon that specified for parent materials in ISO 15156-1.

The requirements and recommendations given in Annex A might not be appropriate for all combinations of parent and weld metals used in the fabrication of equipment and components. The equipment user may require evidence of successful cracking-resistance testing as part of the welding procedure qualification to ensure the weldment produced provides adequate resistance to SSC, SCC, and GHSC for the application.

6.2.2.2 Qualification of welding procedures in accordance with Annex A based upon hardness

6.2.2.2.1 General

The qualification of welding procedures for sour service shall, if specified in Annex A, include hardness testing in accordance with 6.2.2.2.2, 6.2.2.2.3 and 6.2.2.2.4.

6.2.2.2.2 Hardness testing methods for welding procedure qualification

Unless otherwise approved by the user, hardness testing for welding procedure qualification shall be carried out using Vickers HV 10 or HV 5 methods in accordance with ISO 6507-1 or the Rockwell 15N method in accordance with ISO 6508-1.

NOTE For the purposes of this document, ASTM E384 is equivalent to ISO 6507-1 and ASTM E18 is equivalent to ISO 6508-1.

6.2.2.2.3 Hardness surveys for welding procedure qualification

Hardness surveys for butt welds, fillet welds, repair and partial penetration welds and overlay welds shall be carried out as described in ISO 15156-2:2020, 7.3.3.3.

6.2.2.2.4 Hardness acceptance criteria for welds

Weld hardness acceptance criteria for CRAs or other alloys given in Annex A shall apply to alloys selected using Annex A.

Hardness acceptance criteria can also be established from successful cracking-resistance testing of welded samples. Testing shall be in accordance with Annex B.

6.2.2.3 Qualification of welding procedures in accordance with Annex A by other means of testing

Where appropriate, requirements and recommendations to ensure adequate cracking-resistance of welds using other means of testing are provided in the materials groups of Annex A.

6.2.3 Cracking-resistance properties associated with other fabrication methods

For CRAs and other alloys that are subject to metallurgical changes caused by fabrication methods other than welding, cracking-resistance qualification testing of the material affected by fabrication shall be specified as part of the qualification of the fabrication process.

Qualification testing shall be specified as part of the qualification of burning and cutting processes if any HAZ remains in the final product.

The requirements and acceptance criteria of 6.2.2 shall apply to the qualification testing of both fabrication methods and burning/cutting processes subject to the suitable interpretation of the hardness survey requirements of 6.2.2.2.3 for the fabrication method or burning/cutting process.

The form and location of the samples used for evaluation and testing shall be acceptable to the equipment user.

6.3 PREN

For the purpose of determining conformance with the requirements of this document, all F_{PREN} limits specified in this document shall be considered absolute limits as defined in ASTM E29. With the absolute method, an observed value or a calculated value is not to be rounded, but is to be compared directly with the specified limiting value. Conformance or non-conformance with the specification is based on this comparison.

The F_{PREN} calculation is based on actual composition, not nominal composition. Nominal composition is used for general classification only.

The PREN (F_{PREN})shall be calculated as given in Formula (1):

$$F_{PREN} = w_{Cr} + 3{,}3(w_{Mo} + 0{,}5 w_W) + 16 w_N \quad (1)$$

where

w_{Cr} is the mass fraction of chromium in the alloy, expressed as a percentage mass fraction of the total composition;

w_{Mo} is the mass fraction of molybdenum in the alloy, expressed as a percentage mass fraction of the total composition;

w_W is the mass fraction of tungsten in the alloy, expressed as a percentage mass fraction of the total composition;

w_N is the mass fraction of nitrogen in the alloy, expressed as a percentage mass fraction of the total composition.

NOTE There are several variations of the PREN. All were developed to reflect and predict the pitting resistance of Fe/Ni/Cr/Mo CRAs in the presence of dissolved chlorides and oxygen, e.g. in sea water. Though useful, these indices are not directly indicative of corrosion resistance in H_2S-containing oil field environments.

7 Purchasing information and marking

7.1 Information that should be supplied for material purchasing

7.1.1 The preparation of material purchasing specifications can require cooperation and exchange of data between the equipment user, the equipment supplier, and the material manufacturer to ensure that the material purchased conforms with ISO 15156-1 and this document.

7.1.2 The following information shall be provided:

— preferred materials types and/or grades (if known);

— equipment type (if known);

— reference to this document, i.e. ISO 15156-3:2020;

— acceptable bases for selection of materials for cracking-resistance (see Clause 6).

