INTERNATIONAL STANDARD

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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

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 —

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

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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.

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 on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

This third edition cancels and replaces the second edition (ISO 15156-3:2009), which has been technically revised with the following changes:

— replacement in the Scope of the term “conventional elastic design criteria” by the term “load controlled design methods”;

— refinements to 6.3 to require the use of absolute values when F_{PREN} is calculated for use in this part of ISO 15156;

— acceptance of the environmental limits for low carbon 300 series stainless steels also for their dual certified grades;

— changes to some of the tables of Annex A to more conservatively reflect the current knowledge of the limits of use of some materials;

— changes to the definition of acceptable limits to *in situ* production environment pH in some tables of Annex A;

— additions to a number of tables of Annex A of new sets of acceptable environmental limits for (new) materials and their associated metallurgical requirements.

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 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 part of ISO 15156 involves a consolidation of all changes agreed and published in the Technical Circular 1, ISO 15156-3:2009/Cir.1:2011(E), Technical Circular 2, ISO 15156-3:2009/Cir.2:2013(E), Technical Circular 3, ISO 15156-3:2009/Cir.3:2014(E), and Technical Circular 4, ISO 15156-3:2009/Cir.4:2014(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.

Technical Circular ISO 15156-3:2009/Cir.2:2013 and Technical Circular ISO 15156-3:2009/Cir.3:2014 intend that an informative Annex F should be published for this part of ISO 15156 that was to give an alternative presentation of the information contained in the materials selection tables of Annex A.

During final editing of this part of ISO 15156, a number of technical errors were found in the transfer of information between the materials selection tables of Annex A and Table F.1. In order not to delay the publication of the new edition of this part of ISO 15156, the ISO 15156 Maintenance Agency agreed that the proposed Annex F should not be published at this time.

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, 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.

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

WARNING — CRAs (corrosion-resistant alloys) and other alloys selected using this part of ISO 15156 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 part of ISO 15156 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 part of ISO 15156 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 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 load controlled design methods. For design utilizing strain-based design methods, see ISO 15156-1:2015, Clause 5.

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 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 15156-2:2015, A.2.3.2.3 for more information.	
[b] See ISO 15156-2:2015, A.2.3.2.1 for more information.	
[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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 7539-7, *Corrosion of metals and alloys — Stress corrosion testing — Part 7: Method for slow strain rate testing*

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 15156-1:2015, *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 15156-2:2015, *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*

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 Publications Number 17[2)], *Corrosion resistant alloys for oil and gas production: guidelines on general requirements and test methods for H2S service*

NACE CORROSION/95[3)], Paper 47, *Test methodology for elemental sulfur-resistant advanced materials for oil and gas field equipment*

NACE CORROSION/97 Paper 58, *Rippled strain rate test for CRA sour service materials selection*

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

NACE TM0198, *Slow strain rate test method for screening corrosion resistant alloys (CRAs) for stress corrosion cracking in sour oilfield service*

SAE AMS-2430, *Shot Peening, Automatic*

SAE[4)] — ASTM, *Metals and alloys in the Unified Numbering System*, ISBN 0-7680-04074

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.

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

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)

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1) ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, USA.

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

3) NACE International, P.O. Box 2183140, Houston, TX 77218-8340, USA.

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

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

For the purposes of this document, the symbols and abbreviated terms shown in ISO 15156-1 and ISO 15156-2 apply, some of which are repeated for the purpose of convenience, together with the following:

AYS actual yield strength

CR c-ring

CRA corrosion-resistant alloy

HBW	Brinell hardness
HRB	Rockwell hardness (scale B)
HRC	Rockwell hardness (scale C)
pCO_2	partial pressure of CO_2
pH_2S	partial pressure of H_2S
PWHT	post-weld heat treatment
S^0	elemental sulfur
RSRT	rippled strain rate test
SSRT	slow strain rate test
UNS	unified (alloy) numbering system

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 part of ISO 15156 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.

Compliance of a CRA or other alloy with this part of ISO 15156 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 comply 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 15156-1:2015, 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 part of ISO 15156 may be considered acceptable if the average of several readings taken within close proximity does not exceed the value permitted by this part of ISO 15156 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 part of ISO 15156 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 compliance 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:

— compliance 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

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 part of ISO 15156, ASTM E384 is equivalent to ISO 6507-1 and ASTM E18 is equivalent to ISO 6508-1.

The use of other methods shall require explicit user approval.

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 15156-2:2015, 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 part of ISO 15156, all F_{PREN} limits specified in this part of ISO 15156 shall be considered absolute limits as defined in ASTM Practice 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):

$$F_{PREN} = w_{Cr} + 3{,}3\left(w_{Mo} + 0{,}5w_{W}\right) + 16w_{N} \quad (1)$$

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 complies with ISO 15156-1 and this part of ISO 15156.

7.1.2 The following information shall be provided:

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

— equipment type (if known);

— reference to this part of ISO 15156;

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

7.1.3 The equipment user and the equipment supplier/material manufacturer may agree that CRAs and other alloys other than those described and or listed in Annex A may be selected subject to suitable qualification testing.

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 includes the following:

— requirements for SSC, SCC, and/or GHSC testing (see Clause 6 and Annex B);

— service conditions for the specific sour service application.

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

7.2 Marking, labelling, and documentation

Materials complying with this part of ISO 15156 shall be made traceable, preferably by marking, before delivery. Suitable labelling or documentation is also acceptable.

For materials qualified and selected for a special application in accordance with Annex B, traceability shall include reference to the environmental conditions of the special application.

The equipment user may request the equipment or materials supplier to provide documentation of the materials used in equipment or components and their environmental service limits as defined in this part of ISO 15156.

The tables in Annex C provide designations that can be used.