INTERNATIONAL STANDARD

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Third edition
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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

Reference number
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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 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):

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

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.

Annex A
(normative)

Environmental cracking-resistant CRAs and other alloys (including Table A.1 — Guidance on the use of the materials selection tables)

A.1 General

A.1.1 Materials groups

The materials groups used to list CRAs or other alloys (see 6.1) are as follows:

- austenitic stainless steels (identified as material type and as individual alloys) (see A.2);
- highly alloyed austenitic stainless steels (identified as material types and as individual alloys) (see A.3);
- solid-solution nickel-based alloys (identified as material types and as individual alloys) (see A.4);
- ferritic stainless steels (identified as material type) (see A.5);
- martensitic stainless steels (identified as individual alloys) (see A.6);
- duplex stainless steels (identified as material types) (see A.7);
- precipitation-hardened stainless steels (identified as individual alloys) (see A.8);
- precipitation-hardened nickel-based alloys (identified as individual alloys) (see A.9);
- cobalt-based alloys (identified as individual alloys) (see A.10);
- titanium and tantalum (identified as individual alloys) (see A.11);
- copper, aluminium (identified as materials types) (see A.12).

Subject to A.1.2, A.1.3, A.1.4, and A.1.5 below, the CRAs and other alloys listed in Table A.1 to Table A.42 may be used without further testing for SSC, SCC, and GHSC cracking-resistance within the environmental limits shown.

Information on the use of copper and aluminium alloys is contained in A.12.

A.13 contains recommendations on the use of cladding, overlays, and wear-resistant alloys.

NOTE The materials listed and the restrictions shown are those originally listed in NACE MR0175:2003 (no longer available) except for balloted changes introduced since 2003.

A.1.2 Limits of chemical composition

The user of a CRA or other alloy shall ensure that the chemical analysis of the material used meets the material analysis requirements shown for the material in SAE — ASTM, *Metals and alloys in the Unified Numbering System*.

To comply with this part of ISO 15156, the material shall also meet any provision shown in the text and/or tables of its materials group.

A.1.3 Environmental and metallurgical limits for cracking-resistance

A.2.2 to A.11.2 contain materials selection tables showing the environmental limits of the materials when used for any equipment or component. These subclauses also often contain materials selection tables showing the less restrictive environmental limits of the materials when used for named equipment or components.

The tables show the application limits with respect to temperature, pH_2S, Cl^-, pH, S^0. These limits apply collectively. The pH used in the tables corresponds to the minimum *in situ* pH.

NOTE 1 In the tables of this Annex, the SI unit "milligrams per litre" is used for mass concentration. In US Customary units, these are commonly expressed in parts per million (ppm).

NOTE 2 Guidance on the calculation of p_{H2S} is given in ISO 15156-2:2015, Annex C.

NOTE 3 Guidance on the calculation of pH is given in ISO 15156-2:2015, Annex D.

NOTE 4 In preparing the materials selection tables, it is assumed that no oxygen is present in the service environment.

Where no specified limit for a variable can be defined in a table, explanatory remarks that reflect current knowledge have been included in the table.

The environmental limits for an alloy are valid only within any additional metallurgical limits given for the alloy in the text of the same table. Where tempering of a material is required, the tempering time shall be sufficient to ensure the achievement of the required through-thickness hardness.

When purchasing materials, metallurgical properties known to affect the materials' performance in H_2S-containing oil and gas environments in addition to those specifically listed in this Annex should also be considered. ISO 15156-1:2015, 8.1 lists such properties.

A.1.4 Requirements and recommendations on welding

The clauses for the materials groups contain requirements and recommendations for welding the materials of the group to achieve satisfactory cracking-resistance in the weldment produced.

A.1.5 Other requirements and recommendations on CRAs and other alloys

A.1.5.1 Requirements for overlays, surface treatments, plating, coatings, linings, etc.

For the composition, cracking-resistance and use of overlays, see A.13.

Metallic coatings (electroplated and electroless plated), conversion coatings, plastic coatings, or linings may be used, but are not acceptable for preventing cracking.

The effect of their application on the cracking-resistance of the substrate shall be considered.

Nitriding with a maximum case depth of 0,15 mm (0,006 in) is an acceptable surface treatment if conducted at a temperature below the lower critical temperature of the alloy being treated. The use of nitriding as a means of preventing cracking in sour service is not acceptable.

A.1.5.2 Threading

Threads produced using a machine-cutting process are acceptable.

Threads produced by cold forming (rolling) are acceptable on CRAs and other alloys if the material and the limits of its application otherwise comply with this part of ISO 15156.

A.1.5.3 Cold deformation of surfaces

Cold deformation of surfaces is acceptable if caused by processes such as burnishing that do not impart more cold work than that incidental to normal machining operations (such as turning or boring, rolling, threading, drilling, etc.).

Cold deformation by controlled shot-peening is acceptable if applied to base materials that comply with this part of ISO 15156 and if restricted to a maximum shot size of 2,0 mm (0,080 in) and an Almen intensity not exceeding 10C. The process shall be controlled in accordance with SAE AMS-2430.

A.1.5.4 Identification stamping

The use of identification stamping using low-stress (dot, vibratory, and round-V) stamps is acceptable.

The use of conventional sharp V-stamping is acceptable in low-stress areas such as the outside diameter of flanges. Conventional sharp V-stamping shall not be performed in high-stress areas unless agreed with the equipment user.

A.1.6 Use of materials selection tables

Table A.1 provides a guide to the materials selection tables for any equipment or component. It also provides a guide to additional materials selection tables for specific named equipment or components when other, less restrictive, environmental, or metallurgical limits may be applied.

NOTE See Note in introduction of this part of ISO 15156 regarding Annex F of Technical Circular ISO 15156-3:2009/Cir.2:2013 and Technical Circular ISO 15156-3:2009/Cir.3:2014.

A.2 Austenitic stainless steels (identified as material type and as individual alloys)

A.2.1 Materials analyses

Austenitic stainless steels of this material type shall contain the following elements in the following proportions, expressed as mass fractions: C, 0,08 % max; Cr, 16 % min; Ni, 8 % min; P, 0,045 % max; S, 0,04 % max; Mn, 2,0 % max; and Si, 2,0 % max. Other alloying elements are permitted.

Higher carbon contents for UNS S30900 and S31000 are acceptable up to the limits of their respective specifications.

The alloys listed in Table D.1 can, but do not necessarily, meet the requirements above. In some cases, more restrictive chemistries are required to comply with the requirements of this materials group. See also A.3.1.

It is common industry practice to dual certify 300 series stainless steels as standard grade and low carbon grade such as S31600 (316) and S31603 (316L). The environmental limits given for low carbon 300 series stainless steels are acceptable for the dual certified grades.

Free-machining austenitic stainless steel products shall not be used.

Table A.1 — Guidance on the use of the materials selection tables of Annex A based on equipment or component type

Equipment or components	Material selection table numbers for various materials groups									
	Austenitic stainless steel (see A.2)	**Highly-alloyed austenitic stainless steels** (see A.3)	**Solid-solution nickel-based alloys** (see A.4)	**Ferritic stainless steels** (see A.5)	**Martensitic stainless steels** (see A.6)	**Duplex stainless steels** (see A.7)	**Precipitation-hardened stainless steels** (see A.8)	**Precipitation-hardened nickel-based alloys** (see A.9)	**Cobalt-based alloys** (see A.10)	**Titanium and tantalum** (see A.11)
Any equipment or component	A.2	A.8	A.13 A.14	A.17	A.18	A.24	A.26	A.31 A.32 A.33	A.38	A.41 A.42
Additional materials selection tables for casing, tubing and downhole equipment										
Downhole tubular components	—	A.9	—	—	A.19	A.25	—	—	—	—
Packers and other subsurface equipment	—	A.9	—	—	A.20, A.21	A.25	A.27	—	—	—
Gas lift equipment	A.7	A.10	A.16	—	—	—	—	A.37	—	—
Injection tubing and equipment	A.7	—	—	—	—	—	—	—	—	—
Downhole control line tubing and downhole screens	A.7	A.11	—	—	—	—	—	—	—	—
Additional materials selection tables for wellheads, Christmas trees, valves, chokes and level controllers										
Wellhead and tree components (with various specified exclusions)	—	—	A.13	—	A.23	—	A.27	A.34	—	—
Valve and choke components (with various specified exclusions)	—	—	—	—	A.23	—	A.27	A.34	—	—
Shafts, stems and pins	A.3	—	—	—	—	—	—	—	—	—
Non-pressure-containing internal-valve, pressure-regulator, and level-controller components	—	—	—	—	—	—	A.28	A.35	—	—
Additional materials selection tables for process plant										
Compressor components	A.6	—	—	—	A.22	—	A.30	—	—	—
Additional materials selection tables for other equipment										
Instrumentation and control devices	A.6	—	—	—	—	—	—	—	—	—
Instrument tubing and associated compression fittings, surface control line tubing and surface screens	A.4	A.11	—	—	—	—	—	—	—	—
Springs	—	—	—	—	—	—	—	A.36	A.39	—
Diaphragms, pressure measuring devices and pressure seals	—	—	—	—	—	—	—	—	A.40	—
Seal rings and gaskets	A.5	—	—	—	—	—	—	—	—	—
Snap rings	—	—	—	—	—	—	A.29	—	—	—
Bearing pins	—	—	A.15	—	—	—	—	—	—	—
Miscellaneous equipment as named in the tables (including hardware (e.g. set screws, etc.), downhole and surface temporary-service tool applications)	A.7	—	A.16	—	—	—	A.28	A.35	—	—

A.2.2 Environmental and materials limits for the uses of austenitic stainless steels

Table A.2 — Environmental and materials limits for austenitic stainless steels used for any equipment or components

Materials type/ individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Austenitic stainless steel from materials type described in A.2[a]	60 (140)	100 (15)	See “Remarks” column	See “Remarks” column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
	See “Remarks” column	See “Remarks” column	50	See “Remarks” column	No	These materials have been used without restrictions on temperature, pH_2S, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.
S31603[b]	60 (140)	1 000 (145)	50 000	≥4,5	NDS[d]	
	90 (194)	1 000 (145)	1 000	≥3,5	NDS[d]	
	90 (194)	1 (0,145)	50 000	≥4,5	NDS[d]	
	93 (200)	10,2 (1,5)	5 000	≥5,0	NDS[d]	
	120 (248)	100 (14,5)	1 000	≥3,5	NDS[d]	
	149 (300)	10,2 (1,5)	1 000	≥4,0	NDS[d]	
S20910[c]	66 (150)	100 (15)	See “Remarks” column	See “Remarks” column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.

A limit on the martensite content of these austenitic stainless steels should be considered.

The stress corrosion cracking resistance of all austenitic stainless steels of the material type described in A.2 can be adversely affected by cold working.

[a] These materials shall

— be in the solution-annealed and quenched or annealed and thermally-stabilized heat-treatment condition,

— be free of cold work intended to enhance their mechanical properties, and

— have a maximum hardness of 22 HRC.

[b] UNS S31603 shall be in the solution-annealed and quenched condition when used in environments outside the limits imposed for the material type (i.e. in the top two rows), but within those given specifically for S31603. The following conditions shall apply:

— the material shall be free from cold work caused by shaping, forming, cold reducing, tension, expansion, etc. after the final solution annealing and quenching treatment;

— after the final solution annealing and quenching treatment, hardness and cold work incidental to machining or straightening shall not exceed the limits imposed by the appropriate product specification.

[c] UNS S20910 is acceptable for environments inside the limits imposed for the material type and for this alloy, specifically, in the annealed or hot-rolled (hot/cold-worked) condition at a maximum hardness of 35 HRC.

[d] No data submitted (NDS) to ascertain whether these materials are acceptable in service with presence of elemental sulfur in the environment.

Table A.3 — Environmental and materials limits for austenitic stainless steels used as valve stems, pins, and shafts

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
S20910	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	Any combination of temperature, pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.

For these applications, the following material restrictions shall also apply:

— UNS S20910 at a maximum hardness level of 35 HRC may be used in the cold-worked condition provided this cold working is preceded by solution annealing.

[a] No data submitted (NDS) to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.4 — Environmental and materials limits for austenitic stainless steels used in surface applications for control-line tubing, instrument tubing, associated fittings, and screen devices

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur resistant?	Remarks
S31600	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	This material has been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

UNS S31600 stainless steel may be used for compression fittings and instrument tubing even though it might not satisfy the requirements stated for any equipment or component in Table A.2.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.5 — Environmental and materials limits for austenitic stainless steels used as seal rings and gaskets

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} ma kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
J92600, J92900 S30400, S30403 S31600, S31603	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of temperature, pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.

For these applications, the following materials restrictions shall apply;

— J92600, J92900 API compression seal rings and gaskets made of centrifugally cast material in the as-cast or solution-annealed condition shall have a hardness of 160 HBW (83 HRB) maximum;

— S30400, S30403, S31600 or S31603 API compression seal rings and gaskets made of wrought material in the solution-annealed condition shall have a hardness of 160 HBW (83 HRB) maximum.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.6 — Environmental and materials limits for austenitic stainless steels used in compressors and instrumentation and control devices

Materials type	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Compressors						
Austenitic stainless steel from materials type described in A.2	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	Any combination of temperature, pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.
Instrumentation and control devices[b]						
Austenitic stainless steel from materials type described in A.2	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	These materials have been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

For these applications, these materials shall also

— be in the solution-annealed and quenched or annealed and stabilized heat-treatment condition,

— be free of cold work intended to enhance their mechanical properties, and

— have a maximum hardness of 22 HRC.

A limit on the martensite content of these austenitic stainless steels should be considered.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

[b] Instrumentation and control devices include, but are not limited to diaphragms, pressure measuring devices, and pressure seals.

Table A.7 — Environmental and materials limits for austenitic stainless steels used in gas lift service and for special components for subsurface applications such as downhole screens, control-line tubing, hardware (e.g. set screws, etc.), injection tubing, and injection equipment

Materials type	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Austenitic stainless steel from materials group described in A.2	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	These materials have been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.2.3 Welding of austenitic stainless steels of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the HAZ after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective alloy used for the welding consumable.

Austenitic stainless steel, “L”, filler metal shall have a maximum carbon content of 0,03 % mass fraction.

Weldments may be repair-welded if they meet the welding procedure requirements.

A.3 Highly alloyed austenitic stainless steels (identified as material types and as individual alloys)

A.3.1 Materials chemical compositions

Table D.2 lists the chemical compositions of some alloys of this type that can meet the analysis-related requirements shown in the text of Table A.8 and Table A.9. However, in some cases, this requires production within more restricted ranges of chemical analysis than those specified in Table D.2.

Austenitic stainless steels included in Table D.2 that do not meet the restricted ranges of chemical analysis required in Table A.8 and Table A.9, but meet the requirements of A.2.1 may be considered as part of materials group A.2.

Free-machining highly alloyed austenitic stainless steels shall not be used.

A.3.2 Environmental and materials limits for the uses of highly alloyed austenitic stainless steels

Table A.8 — Environmental and materials limits for highly-alloyed austenitic stainless steels used for any equipment or components

Materials type/ individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Materials type 3a, 3b, and J93254	60 (140)	100 (15)	See “Remarks” column	See “Remarks” column	No	Any combinations of chloride concentration, and *in situ* pH occurring in production environments are acceptable.
	See “Remarks” column	See “Remarks” column	50	See “Remarks” column	No	These materials have been used without restrictions on temperature, pH_2S, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.
Materials type 3b	121 (250)	700 (100)	5 000	See “Remarks” column	No	The *in situ* pH values occurring in production environments are acceptable.
	149 (300)	310 (45)	5 000	See “Remarks” column	No	
	171 (340)	100 (15)	5 000	See “Remarks” column	No	
N08926	121 (250)	700 (100)	65 000	≥3,5; See also “Remarks” column	No	pH estimated from laboratory test conditions. UNS N08926 is material type 3b tested to higher limits of chloride concentration than apply for the materials type as a whole.
J95370	150 (302)	700	101 000	See “Remarks” column	No	The *in situ* pH values occurring in production environments are acceptable.

These materials shall also comply with the following:

— materials type 3a shall be highly alloyed austenitic stainless steel with (w_{Ni} + 2w_{Mo}) > 30 (where w_{Mo} has a minimum value of 2 %). The symbol w represents the percentage mass fraction of the element indicated by the subscript;

— materials type 3b shall be highly alloyed austenitic stainless steel with F_{PREN} > 40,0;

— materials types 3a and 3b (including N08926) shall be in the solution-annealed condition;

— UNS J93254 (CK3McuN, cast 254SMO) in accordance with ASTM A351, ASTM A743, or ASTM A744 shall be in the cast, solution heat-treated and water-quenched condition, and shall have a maximum hardness of 100 HRB;

— UNS J95370 shall be in the solution heat-treated and water-quenched condition and shall have a maximum hardness of 94 HRB.

Table A.9 — Environmental and materials limits for highly-alloyed austenitic stainless steels used for downhole tubular components and packers and other subsurface equipment

Materials type/ individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H_2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Materials type 3a and 3b	60 (140)	100 (15)	See “Remarks” column	See “Remarks” column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
Materials type 3a	60 (140)	350 (50)	50	See “Remarks” column	No	The *in situ* pH values occurring in production environments are acceptable.
Materials type 3b	121 (250)	700 (100)	5 000	See “Remarks” column	No	
	149 (300)	310 (45)	5 000	See “Remarks” column	No	
	171 (340)	100 (15)	5 000	See “Remarks” column	No	
N08926	121 (250)	700 (100)	65 000	≥3,5; See also “Remarks” column	No	pH is estimated from laboratory test conditions. UNS N08926 is material type 3b tested to higher limits of chloride concentration than apply for the materials type as a whole.

For these applications, these materials shall also comply with the following:

— highly alloyed austenitic stainless steels used for downhole tubular components shall contain at least these elements, expressed as percentage mass fractions: C, 0,08 % max; Cr, 16 % min; Ni, 8 % min; P, 0,03 % max; S, 0,030 % max; Mn, 2 % max; and Si, 0,5 % max. Other alloying elements may be added;

— materials type 3a shall be highly alloyed austenitic stainless steel with (w_{Ni} + 2w_{Mo}) > 30 (where w_{Mo} has a minimum value of 2 %);

— materials type 3b shall be highly alloyed austenitic stainless steel with a F_{PREN} > 40,0.

All the above alloys shall be in the solution-annealed and cold-worked condition with a maximum hardness of 35 HRC.

Table A.10 — Environmental and materials limits for highly-alloyed austenitic stainless steels used in gas lift service

Materials type	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Highly alloyed austenitic stainless steel from materials group described in A.3	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	These materials have been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.11 — Environmental and materials limits for highly alloyed austenitic stainless steels used as instrument tubing, control-line tubing, compression fittings, and surface and downhole screen devices

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Materials types 3a and 3b	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	These materials have been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.
N08904	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	Any combination of temperature, pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.

Materials type 3a shall be highly alloyed austenitic stainless steel with $(w_{Ni} + 2w_{Mo}) > 30$ (where w_{Mo} has a minimum value of 2 % mass fraction). The symbol w represents the percentage mass fraction of the element indicated by the subscript.

Materials type 3b shall be highly alloyed austenitic stainless steel with a $F_{PREN} > 40,0$.

Wrought N08904 for use as instrument tubing shall be in the annealed condition with a maximum hardness of 180 HV10.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.3.3 Welding highly alloyed austenitic stainless steels of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the HAZ after welding shall not exceed the maximum hardness allowed for the base metal, and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective alloy used for the welding consumable.

Weldments may be repair-welded if they meet the weld procedure requirements.

A.4 Solid-solution nickel-based alloys (identified as material types and as individual alloys)

A.4.1 Materials chemical compositions

Table A.12 provides a breakdown of this materials group into types 4a, 4b, 4c, 4d, and 4e used in Table A.13 and Table A.14.

Table D.4 contains the chemical compositions of some copper-nickel alloys of this group.

Table A.12 — Materials types of solid-solution nickel-based alloys

Materials type	Cr mass fraction min %	Ni + Co mass fraction min %	Mo mass fraction min %	Mo + W mass fraction min %	Metallurgical condition
Type 4a	19,0	29,5	2,5	—	Solution-annealed or annealed
Type 4b	14,5	52	12	—	Solution-annealed or annealed
Type 4c	19,5	29,5	2,5	—	Solution-annealed or annealed and cold-worked
Type 4d	19,0	45	—	6	Solution-annealed or annealed and cold-worked
Type 4e	14,5	52	12	—	Solution-annealed or annealed and cold-worked
Type 4f[a]	20,0	58	15,5	—	a) Solution-annealed or annealed and cold-worked condition b) Solution-annealed or annealed and cold-worked and aged condition

Table D.3 lists the chemical compositions of some alloys that can, but do not necessarily, meet the restrictions of one or more of these types. In some cases, more restrictive compositions than those shown in Table D.3 may be needed.

[a] The type 4f family is currently limited to only UNS N07022.

A.4.2 Environmental and materials limits for the uses of solid-solution nickel-based alloys

Table A.13 — Environmental and materials limits for solid-solution nickel-based alloys used in any equipment or component

Materials type/ individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Annealed alloys of types 4a and 4b	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	Yes	These materials have been used without restriction on temperature, pH_2S, chloride concentration, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.
N04400 N04405	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	

Wrought or cast solid-solution nickel-based products made from alloys of types 4a and 4b shall be in the solution-annealed or annealed condition.

UNS N04400 and UNS N04405 shall have a maximum hardness of 35 HRC.

Wellhead and christmas tree components shall also be in accordance with ISO 10423.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.14 — Environmental and materials limits for annealed and cold-worked, solid-solution nickel-based alloys used as any equipment or component[a]

Materials type	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Cold-worked alloys of types 4c, 4d and 4e	232 (450)	200 (30)	See "Remarks" column	See "Remarks" column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
	218 (425)	700 (100)	See "Remarks" column	See "Remarks" column	No	
	204 (400)	1 000 (150)	See "Remarks" column	See "Remarks" column	No	
	177 (350)	1 400 (200)	See "Remarks" column	See "Remarks" column	No	
	132 (270)	See "Remarks" column	See "Remarks" column	See "Remarks" column	Yes	Any combination of hydrogen sulfide, chloride concentration, and *in situ* pH in production environments is acceptable.
Cold-worked alloys of types 4d and 4e	218 (425)	2 000 (300)	See "Remarks" column	See "Remarks" column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
	149 (300)	See "Remarks" column	See "Remarks" column	See "Remarks" column	Yes	Any combinations of hydrogen sulfide, chloride concentration, and *in situ* pH in production environments are acceptable.

Wrought or cast solid-solution nickel-based products in these applications shall be in the annealed and cold-worked condition or annealed, cold-worked, and aged for type 4f and shall meet all of the following as applicable:

1) the maximum hardness value for types 4c, 4d, and 4e in these applications shall be 40 HRC;

2) the maximum yield strength of the alloys achieved by cold work shall be

— type 4c: 1 034 MPa (150 ksi);

— type 4d: 1 034 MPa (150 ksi);

— type 4e: 1 240 MPa (180 ksi).

3) UNS N10276 (Type 4e) when used at a minimum temperature of 121 °C (250 °F) shall have a maximum hardness of 45 HRC;

4) UNS N07022 (Type 4f) in the annealed and cold-worked condition shall have a maximum hardness of 43 HRC and a maximum yield strength of 1 413 MPa (205 ksi);

5) UNS N07022 (Type 4f) in the annealed and cold-worked and aged condition shall have a maximum hardness of 47 HRC and a maximum yield strength of 1 420 MPa (206 ksi).

[a] The limits of application of the materials types 4c, 4d, and 4e in this table overlap.

[b] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.14 *(continued)*

Materials type	**Temperature** max °C (°F)	**Partial pressure H_2S p_{H2S}** max kPa (psi)	**Chloride conc.** max mg/l	**pH**	**Sulfur-resist-ant?**	**Remarks**
Cold-worked alloys of type 4e	232 (450)	7 000 (1 000)	See “Remarks” column	See “Remarks” column	Yes	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
	204 (400)	See “Remarks” column	See “Remarks” column	See “Remarks” column	Yes	Any combination of hydrogen sulfide, chloride concentration, and *in situ* pH in production environments is acceptable.
Cold-worked alloys of type 4f	204 (400)	3 500 (500)	180 000	See “Remarks” column	Yes	Any *in situ* production environment pH is acceptable for p_{CO2}+ p_{H2S} ≤ 7 000 kpa (1 000 psi)
	288 (550)	7 000 (1000)	180 000	See “Remarks” column	NDS[b]	Any *in situ* production environment pH is acceptable for p_{CO2} such that: For p_{H2S} < 3 000 kPa (450 psi): p_{CO2} + p_{H2S} ≤ 10 000 kPa (1 450 psi). For p_{H2S} from 3 000 kPa to 7 000 kPa: p_{CO2} ≤ 7 000 kPa (1 000 psi).

Wrought or cast solid-solution nickel-based products in these applications shall be in the annealed and cold-worked condition or annealed, cold-worked, and aged for type 4f and shall meet all of the following as applicable:

1) the maximum hardness value for types 4c, 4d, and 4e in these applications shall be 40 HRC;

2) the maximum yield strength of the alloys achieved by cold work shall be

— type 4c: 1 034 MPa (150 ksi);

— type 4d: 1 034 MPa (150 ksi);

— type 4e: 1 240 MPa (180 ksi).

3) UNS N10276 (Type 4e) when used at a minimum temperature of 121 °C (250 °F) shall have a maximum hardness of 45 HRC;

4) UNS N07022 (Type 4f) in the annealed and cold-worked condition shall have a maximum hardness of 43 HRC and a maximum yield strength of 1 413 MPa (205 ksi);

5) UNS N07022 (Type 4f) in the annealed and cold-worked and aged condition shall have a maximum hardness of 47 HRC and a maximum yield strength of 1 420 MPa (206 ksi).

a The limits of application of the materials types 4c, 4d, and 4e in this table overlap.

b No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.15 — Environmental and materials limits for nickel-based alloys used for bearing pins

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N10276	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	Any combination of temperature, pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.

N10276 bearing pins, e.g. core roll pins, shall be in the cold-worked condition with a maximum hardness of 45 HRC.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.16 — Environmental and materials limits for nickel-based alloys used in gas lift service and for downhole running, setting, and service tool applications for temporary service

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N04400 N04405	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	These materials have been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.4.3 Welding solid-solution nickel-based alloys of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the HAZ after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective alloy used for the welding consumable.

There are no hardness requirements for welding solid-solution nickel-based alloys with solid-solution nickel-based weld metal.

A.5 Ferritic stainless steels (identified as material type)

A.5.1 Materials chemical compositions

Table D.5 lists the chemical compositions of some alloys of this type.

A.5.2 Environmental and materials limits for the uses of ferritic stainless steels

Table A.17 — Environmental and materials limits for ferritic stainless steels used for any equipment or components

Materials type	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Ferritic stainless steels from materials type described in A.5	See “Remarks” column	10 (1,5)	See “Remarks” column	≥3,5	NDS[a]	Subject to limitations on pH_2S and pH. These materials have been used without restrictions on temperature or chloride concentration in production environments. No limits on these two parameters are set, but some combinations of their values might not be acceptable.
These materials shall be in the annealed condition and shall have a maximum hardness of 22 HRC.						
[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.						

A.5.3 Welding of ferritic stainless steels of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

Hardness testing of qualification welds shall be carried out and the maximum hardness shall be 250 HV or, if a different hardness test method is permitted, its equivalent.

A.6 Martensitic (stainless) steels (identified as individual alloys)

A.6.1 Materials chemical compositions

Table D.6 lists the chemical compositions of the martensitic steel alloys shown in Table A.18 to Table A.23.

Free-machining martensitic stainless steels shall not be used.

A.6.2 Environmental and materials limits for the uses of martensitic stainless steels

Table A.18 — Environmental and materials limits for martensitic stainless steels used for any equipment or components

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
S41000 S41500 S42000 J91150 J91151 J91540 S42400	See “Remarks” column	10 (1,5)	See “Remarks” column	≥3,5	NDS[a]	Any combination of temperature and chloride concentration occurring in production environments is acceptable
S41425	See “Remarks” column	10 (1,5)	See “Remarks” column	≥3,5	No	

These materials shall also comply with the following:

a) cast or wrought alloys UNS S41000, J91150 (CA15), and J91151 (CA15M) shall have a maximum hardness of 22 HRC and shall be

1) austenitized and quenched or air-cooled;

2) tempered at 621 °C (1 150 °F) minimum, then cooled to ambient temperature;

3) tempered at 621 °C (1 150 °F) minimum, but lower than the first tempering temperature, then cooled to ambient temperature.

b) low-carbon, martensitic stainless steels, either cast J91540 (CA6NM), or wrought S42400 or S41500 (F6NM) shall have a maximum hardness of 23 HRC and shall be

1) austenitized at 1 010 °C (1 850 °F) minimum, then air- or oil-quenched to ambient temperature;

2) tempered at 649 °C to 691 °C (1 200 °F to 1 275 °F), then air-cooled to ambient temperature;

3) tempered at 593 °C to 621 °C (1 100 °F to 1 150 °F), then air-cooled to ambient temperature.

c) cast or wrought alloy UNS S42000 shall have a maximum hardness of 22 HRC and shall be in the quenched and tempered heat-treatment condition;

d) wrought low-carbon UNS S41425 martensitic stainless steel in the austenitized, quenched, and tempered condition shall have a maximum hardness of 28 HRC.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.19 — Environmental and materials limits for martensitic stainless steels used as downhole tubular components and for packers and other subsurface equipment

Specification/ Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
ISO 11960 L-80 Type 13 Cr, S41426, S42500	See "Remarks" column	10 (1,5)	See "Remarks" column	≥3,5	NDS[a]	Any combination of temperature and chloride concentration occurring in production environments is acceptable
S41429	See "Remarks" column	10 (1,5)	See "Remarks" column	≥4,5	NDS[a]	

For these applications, these materials shall also comply with the following:

a) UNS S41426 tubular components shall be quenched and tempered to maximum 27 HRC and maximum yield strength 724 MPa (105 ksi);

b) UNS S42500 (15 Cr) tubing and casing is acceptable as Grade 80 [SMYS 556 MPa (80 ksi)] only and shall be in the quenched and double-tempered condition with a maximum hardness of 22 HRC. The quench and double-temper process shall be as follows:

1) austenitize at minimum 900 °C (1 652 °F), then air- or oil-quench;

2) temper at minimum 730 °C (1 346 °F), then cool to ambient temperature;

3) temper at minimum 620 °C (1 148 °F), then cool to ambient temperature.

c) UNS S41429 tubular components shall be quenched and tempered or normalized and tempered to a maximum hardness of 27 HRC and a maximum yield strength of 827 MPa (120 ksi).

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.20 — Environmental and materials limits for martensitic alloy steel used as subsurface equipment

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
K90941	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	These materials have been used without restrictions on temperature, pH_2S, chloride concentration, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

For these applications, UNS K90941 (martensitic 9Cr 1Mo to ASTM A276 type 9, ASTM A182/A182M grade F9 or ASTM A213/A213M grade T9) shall have a maximum hardness of 22 HRC.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.21 — Environmental and materials limits for martensitic stainless steels used as packers and subsurface equipment

Alloy specification	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
AISI 420 (modified)	See "Remarks" column	10 (1,5)	See "Remarks" column	≥3,5	NDS[a]	Any combination of temperature and chloride concentration occurring in production environments is acceptable
S41427	See "Remarks" column	10 (1,5)	6 100	≥3,5	NDS[a]	Temperatures occurring in production environments are acceptable.

For these applications, AISI 420 (modified) shall have chemical composition in accordance with ISO 11960 L-80 Type 13 Cr and shall be quenched and tempered to 22 HRC maximum.

UNS S41427 shall have a maximum hardness of 29 HRC and shall have been heat-treated in accordance with the following three-step process:

a) austenitize at 900 °C to 980 °C (1 652 °F to 1 796 °F), then air-cool or oil-quench to ambient temperature;

b) tempered at 600 °C to 700 °C (1 112 °F to 1 292 °F), then air-cool to ambient temperature;

c) tempered at 540 °C to 620 °C (1 004 °F to 1 148 °F), then air-cool to ambient temperature.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.22 — Environmental and materials limits for martensitic stainless steels used as compressor components

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
S41000 S41500 S42400 J91150 J91151 J91540	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of temperature, pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.

For these applications, these materials shall also comply with the following:

a) cast or wrought alloys UNS S41000, J91150 (CA15), and J91151 (CA15M) shall have 22 HRC maximum hardness if used for compressor components and shall be

1) austenitized and quenched or air-cooled;

2) tempered at 621 °C (1 150 °F) minimum, then cooled to ambient temperature;

3) tempered at 621 °C (1 150 °F) minimum, but lower than the first tempering temperature, then cooled to ambient temperature.

b) low-carbon, martensitic stainless steels, either cast J91540 (CA6NM) or wrought S42400 or S41500 (F6NM), shall have a maximum hardness of 23 HRC and shall be

1) austenitized at 1 010 °C (1 850 °F) minimum, then air- or oil-quenched to ambient temperature;

2) tempered at 649 °C to 690 °C (1 200 °F to 1 275 °F), then air-cooled to ambient temperature;

3) tempered at 593 °C to 621 °C (1 100 °F to 1 150 °F), then air-cooled to ambient temperature.

c) if used for impellers, cast or wrought alloys UNS S41000, J91150 (CA15) and J91151 (CA15M), cast J91540 (CA6NM) and wrought S42400, or S41500 (F6NM) shall exhibit a threshold stress ≥95 % of actual yield strength in the anticipated service environment.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.23 — Environmental and materials limits for martensitic stainless steels used as wellhead and tree components and valve and choke components (excluding casing and tubing hangers and valve stems)

Individual alloy UNS number	Temperature max. °C (°F)	Partial pressure H_2S p_{H2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
S41000 S41500 S42000 J91150 J91151 J91540 S42400	See "Remarks" column	See "Remarks" column	See "Remarks" column	≥3,5	NDS[a]	Subject to limitations on *in situ* pH, these materials have been used for these components without restriction on temperature, pH_2S, or Cl− in production environments. No limits on these parameters are set, but some combinations of their values might not be acceptable.

For these applications, these materials shall also comply with the following:

a) cast or wrought alloys UNS S41000, J91150 (CA15), and J91151 (CA15M), shall have 22 HRC maximum hardness and shall be

1) austenitized and quenched or air-cooled;

2) tempered at 620 °C (1 150 °F) minimum, then cooled to ambient temperature;

3) tempered at 620 °C (1 150 °F) minimum, but lower than the first tempering temperature, then cooled to ambient temperature.

b) low-carbon, martensitic stainless steels either cast J91540 (CA6NM) or wrought S42400 or S41500 (F6NM) shall have 23 HRC maximum hardness and shall be

1) austenitized at 1 010 °C (1 850 °F) minimum, then air- or oil-quenched to ambient temperature;

2) tempered at 648 °C to 690 °C (1 200 °F to 1 275 °F), then air-cooled to ambient temperature;

3) tempered at 593 °C to 620 °C (1 100 °F to 1 150 °F), then air-cooled to ambient temperature.

c) cast or wrought alloy UNS S42000 shall have a maximum hardness of 22 HRC and shall be in the quenched and tempered heat-treatment condition.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.6.3 Welding of martensitic stainless steels of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the HAZ after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective alloy used for the welding consumable.

Martensitic stainless steels welded with nominally matching consumables shall meet the following requirements.

Weldments in martensitic stainless steels shall undergo a PWHT at 621 °C (1 150 °F) minimum and shall comply with 6.2.2.2.

Weldments in the low-carbon martensitic stainless steels [cast J91540 (CA6NM) or wrought S42400 or S41500 (F6NM)] shall undergo a single- or double-cycle PWHT after first being cooled to 25 °C (77 °F), as follows:

— single-cycle PWHT shall be at 580 °C to 621 °C (1 075 °F to 1 150 °F);

— double-cycle PWHT shall be at 671 °C to 691 °C (1 240 °F to 1 275 °F), then cooled to 25 °C (77 °F) or less, then heated to 580 °C to 621 °C (1 075 °F to 1 150 °F).

A.7 Duplex stainless steels (identified as material types)

A.7.1 Materials chemical compositions

Table D.7 lists the chemical compositions of some duplex stainless steel alloys that can, but do not necessarily, meet the restrictions of this materials group. In some cases, more restrictive chemistries than those shown in Table D.7 are needed.

A.7.2 Environmental and materials limits for the uses of duplex stainless steels

Table A.24 — Environmental and materials limits for duplex stainless steels used for any equipment or component

Materials type/ individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
30 ≤ F_{PREN} ≤ 40,0 Mo ≥ 1,5 %	232 (450)	10 (1,5)	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable
S31803 (HIP)	232 (450)	10 (1,5)	See “Remarks” column	See “Remarks” column	No	
40,0 < F_{PREN} ≤ 45	232 (450)	20 (3)	See “Remarks” column	See “Remarks” column	NDS[a]	
30 ≤ F_{PREN} ≤ 40,0 Mo ≥ 1,5 %	See “Remarks” column	See “Remarks” column	50	See “Remarks” column	NDS[a]	These materials have been used without restrictions on temperature, pH_2S or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.
40,0 < F_{PREN} ≤ 45	See “Remarks” column	See “Remarks” column		See “Remarks” column	NDS[a]	

Wrought and cast duplex stainless steels shall

— be solution-annealed and liquid-quenched or rapidly cooled by other methods[b],

— have a ferrite content (volume fraction) of between 35 % and 65 %, and

— not have undergone ageing heat-treatments.

Hot isostatic pressure-produced (HIP)[15] duplex stainless steel UNS S31803 (30 ≤ F_{PREN} ≤ 40,0 Mo ≥ 1,5 %) shall have a maximum hardness of 25 HRC and shall

— be in the solution-annealed and water-quenched condition,

— have a ferrite content (volume fraction) of between 35 % and 65 %, and

— not have undergone ageing heat-treatments.

NOTE Higher values of F_{PREN} provide higher corrosion resistance; however, they also lead to increased risk of sigma- and alpha-prime phase formation in the materials’ ferrite phase during manufacture depending on product thickness and achievable quench rate. The ranges of F_{PREN} quoted are typical of those found to minimize the problem of sigma- and alpha-prime phase formation.

a No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

b A rapid cooling rate is one sufficiently fast to avoid the formation of deleterious phases such as sigma-phase and precipitates. The presence of deleterious phases can reduce the cracking-resistance of duplex stainless steels.

Table A.25 — Environmental and materials limits for duplex stainless steels used as downhole tubular components and as packers and other subsurface equipment

Materials type	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
$30 \leq F_{PREN} \leq 40,0$ Mo ≥ 1,5 %	See “Remarks” column	2 (0,3)	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of temperature, chloride concentration and *in situ* pH occurring in production environments is acceptable.
$40,0 < F_{PREN} \leq 45$	See “Remarks” column	20 (3)	120 000	See “Remarks” column	NDS[a]	Any combination of temperature and *in situ* pH occurring in production environments is acceptable. Chloride limits have been found to be strongly dependent upon yield strength and the level of cold work.

For these applications, these materials shall

— be in the solution-annealed, liquid-quenched, and cold-worked condition,

— have a ferrite content (volume fraction) of between 35 % and 65 %, and

— have a maximum hardness of 36 HRC.

NOTE Higher values of F_{PREN} provide higher corrosion resistance; however, they also lead to increased risk of sigma- and alpha-prime phase formation in the materials’ ferrite phase during manufacture depending on product thickness and achievable quench rate. The ranges of F_{PREN} quoted are typical of those found to minimize the problem of sigma- and alpha-prime phase formation.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.7.3 Welding of duplex stainless steels of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the HAZ after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective alloy used for the welding consumable.

A cross-section of the weld metal, HAZ, and base metal shall be examined as part of the welding procedure qualification. The microstructure shall be suitably etched and examined at ×400 magnification and shall have grain boundaries with no continuous precipitates. Intermetallic phases, nitrides, and carbides shall not exceed 1,0 % in total. The sigma phase shall not exceed 0,5 %. The ferrite content in the weld metal root and unreheated weld cap shall be determined in accordance with ASTM E562 and shall be in the range of 30 % to 70 % volume fraction.

A.8 Precipitation-hardened stainless steels (identified as individual alloys)

A.8.1 Materials chemical compositions

Table D.8 lists the chemical compositions of the precipitation-hardened stainless steels shown in the tables of A.8.2. Austenitic precipitation-hardened stainless steels are addressed in Table A.26. Martensitic precipitation-hardened stainless steels are addressed in Table A.27 to Table A.30.

A.8.2 Environmental and materials limits for the uses of precipitation-hardened stainless steels

Table A.26 — Environmental and materials limits for austenitic precipitation-hardened stainless steels used for any equipment or component

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
S66286	65 (150)	100 (15)	See “Remarks” column	See “Remarks” column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
UNS S66286 shall have a maximum hardness of 35 HRC and shall be in either the solution-annealed and aged or solution-annealed and double-aged condition.						

Table A.27 — Environmental and materials limits for martensitic precipitation-hardened stainless steels used for wellhead and christmas tree components (excluding bodies and bonnets), valves and chokes (excluding bodies and bonnets), and packers and other subsurface equipment

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
UNS S17400	See “Remarks” column	3,4 (0,5)	See “Remarks” column	≥4,5	NDS[a]	Any combination of temperature and chloride concentration occurring in production environments is acceptable.
UNS S45000	See “Remarks” column	10 (1,5)	See “Remarks” column	≥3,5	NDS[a]	

For these applications, these materials shall also comply with the following:

a) wrought UNS S17400 precipitation-hardening martensitic stainless steels shall have a maximum hardness of 33 HRC and shall have been heat-treated in accordance with either 1) or 2), as follows:

1) double age-hardening process at 620 °C (1 150 °F):

— solution-anneal at (1 040 ± 14) °C [(1 900 ± 25) °F] and air-cool or liquid-quench to below 32 °C (90 °F);

— first precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature, then air-cool or liquid-quench to below 32 °C (90 °F);

— second precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature, then air-cool or liquid-quench to below 32 °C (90 °F).

2) modified double age-hardening process:

— solution-anneal at (1 040 ± 14) °C [(1 900 ± 25) °F], then air-cool or liquid-quench to below 32 °C (90 °F);

— first precipitation-hardening cycle at (760 ± 14) °C [(1 400 ± 25) °F] for 2 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F);

— second precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature, then air-cool or liquid-quench to below 32 °C (90 °F).

b) wrought UNS S45000 molybdenum-modified martensitic precipitation-hardened stainless steel shall have a maximum hardness of 31 HRC (equivalent to 306 HBW for this alloy) and shall have undergone the following two-step heat-treatment procedure:

1) solution-anneal;

2) precipitation-harden at (620 ± 8) °C [(1 150 ± 15) °F] for 4 h minimum at temperature.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.28 — Environmental and materials limits for martensitic precipitation-hardened stainless steels used as non-pressure-containing internal-valve, pressure-regulator, and level-controller components and miscellaneous equipment

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Non-pressure-containing internal-valve, pressure-regulator, and level-controller components						
CB7Cu-1 CB7Cu-2	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	These materials have been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.
S17400 S15500	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	
S45000	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	Any combination of temperature. pH_2S, Cl^-, and *in situ* pH occurring in production environments is acceptable.
Miscellaneous equipment						
S17400	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	This alloy has been used in service tool applications at the surface and for temporary drilling and subsurface well-servicing equipment when stressed at less than 60 % of its specified minimum yield strength under working conditions. Environmental limits for this alloy for these applications have not been established.

For these applications, these materials shall also comply with the following:

a) cast CB7Cu-1 and CB7Cu-2 shall be in the H1150 DBL condition in accordance with ASTM A747/A747M and shall have a maximum hardness of 30 HRC;

b) wrought UNS S17400 and S15500 precipitation-hardening martensitic stainless steels shall have a maximum hardness of 33 HRC and shall have been heat-treated in accordance with either 1) or 2), as follows:

1) double age-hardening process at 620°C (1 150°F):

— solution-anneal at (1 040 ± 14) °C [(1 900 ± 25) °F], then air-cool or liquid-quench to below 32 °C (90 °F);

— first precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F);

— second precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F).

2) modified double age-hardening process:

— solution-anneal at (1 040 ± 14) °C [(1 900 ± 25) °F] and air-cool or liquid-quench to below 32 °C (90 °F);

— first precipitation-hardening cycle at (760 ± 14) °C [(1 400 ± 25) °F] for 2 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F);

— second precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F).

c) for UNS 17400, limits on its ferrite content should be considered;

d) wrought UNS S45000 precipitation-hardening martensitic stainless steel shall have a maximum hardness of 31 HRC (equivalent to 306 HBW for this alloy) and shall be heat-treated using the following two-step process:

1) solution-anneal;

2) precipitation-harden at (621 ± 8) °C [(1 150 ± 14) °F] for 4 h minimum at temperature.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.29 — Environmental and materials limits for martensitic precipitation-hardened stainless steels used as snap rings

Individual alloy UNS number	Tempera-ture max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
S15700	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of temperature. pH_2S, Cl^-, and *in situ* pH occurring in production environments is acceptable.

For this application, UNS S15700 snap rings originally in the RH950 solution-annealed and aged condition shall also be further heat-treated to a hardness of between 30 HRC and 32 HRC using the following three-step process:

a) temper at 620 °C (1 150 °F) for 4 h, 15 min, then cool to room temperature in still air;

b) re-temper at 620 °C (1 150 °F) for 4 h, 15 min, then cool to room temperature in still air;

c) temper at 560 °C (1 050 °F) for 4 h, 15 min, then cool to room temperature in still air.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.30 — Environmental and materials limits for martensitic precipitation-hardened stainless steels used in compressor components

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
S17400 S15500	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of temperature. pH_2S, Cl^-, and *in situ* pH occurring in production environments is acceptable.
S45000	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of temperature. pH_2S, Cl^-, and *in situ* pH occurring in production environments is acceptable.

For these applications, these materials shall also comply with the following:

a) wrought UNS S17400 and S15500 precipitation-hardening martensitic stainless steels shall have a maximum hardness of 33 HRC and shall have been heat-treated in accordance with either 1) or 2), as follows:

1) double age-hardening process at 620 °C (1 150 °F):

— solution-anneal at (1 040 ± 14) °C [(1 900 ± 25) °F] and air-cool or liquid-quench to below 32 °C (90 °F);

— first precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F);

— second precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F).

2) modified double age-hardening process:

— solution-anneal at (1 040 ± 14) °C [(1 900 ± 25) °F] and air-cool or liquid-quench to below 32 °C (90 °F);

— first precipitation-hardening cycle at (760 ± 14) °C [(1 400 ± 25) °F] for 2 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F);

— second precipitation-hardening cycle at (620 ± 14) °C [(1 150 ± 25) °F] for 4 h minimum at temperature and air-cool or liquid-quench to below 32 °C (90 °F).

b) for UNS 17400, limits on its ferrite content should be considered;

c) for use as impellers at higher hardness (strength) levels, these alloys shall be tested in accordance with Annex B at a test stress level of at least 95 % of AYS;

d) wrought UNS S45000 molybdenum-modified martensitic precipitation-hardened stainless steel shall have a maximum hardness of 31 HRC (equivalent to 306 HBW for this alloy) and shall have undergone the following two-step heat-treatment procedure:

1) solution annealing;

2) precipitation hardening at (620 ± 8) °C [1 150 ± 15) °F] for 4 h minimum at temperature.

e) UNS S17400 or S15500 used for impellers at a hardness of >33 HRC shall exhibit a threshold stress ≥95 % of AYS in the anticipated service environment (see B.3.4).

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.8.3 Welding of precipitation-hardened stainless steels of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the base metal after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective metal for the weld alloy.

A.9 Precipitation-hardened nickel-based alloys (identified as individual alloys)

A.9.1 Materials chemical compositions

Table D.9 lists the chemical compositions of the precipitation-hardened nickel-based alloys shown in Table A.31 to Table A.37.

A.9.2 Environmental and materials limits for the uses of precipitation-hardened nickel-based alloys

Table A.31 to Table A.33 give the environmental and materials limits for the uses for any equipment or component of precipitation-hardened nickel-based alloys divided into groups I, II, and III, respectively.

Table A.31 — Environmental and materials limits for precipitation-hardened nickel-based alloys (I) used for any equipment or component

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N07031 N07048 N07773 N09777 (wrought) N07718 (cast) N09925 (cast)	232 (450)	200 (30)	See "Remarks" column	See "Remarks" column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
	204 (400)	1 400 (200)	See "Remarks" column	See "Remarks" column	No	
	149 (300)	2 700 (400)	See "Remarks" column	See "Remarks" column	No	
N07031 N07048 N07773 N09777 (wrought)	135 (275)	See "Remarks" column	See "Remarks" column	See "Remarks" column	Yes	Any combination of hydrogen sulfide, chloride concentration, and *in situ* pH in production environments is acceptable.
N09925 (cast)	135 (275)	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	
N07718 (cast)	135 (275)	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	
N07924 (wrought)	175 (347)	3 500 (500)	139 000	≥3,5, See also "Remarks" column	No	pH estimated from laboratory test conditions.

These materials shall also comply with the following:

a) wrought UNS N07031 shall be in either of the following conditions:

1) solution-annealed to a maximum hardness of 35 HRC;

2) solution-annealed and aged at 760 °C to 871 °C (1 400 °F to 1 600 °F) for a maximum of 4 h to a maximum hardness of 40 HRC.

b) wrought UNS N07048, wrought UNS N07773, and wrought UNS N09777 shall have a maximum hardness of 40 HRC and shall be in the solution-annealed and aged condition;

c) wrought UNS N07924 shall be in the solution-annealed and aged condition at a maximum hardness of 35 HRC;

d) cast UNS N09925 shall be in the solution-annealed and aged condition at a maximum hardness of 35 HRC;

e) cast UNS N07718 shall be in the solution-annealed and aged condition at a maximum hardness of 40 HRC.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.32 — Environmental and materials limits for precipitation-hardened nickel-based alloys (II) used for any equipment or component

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H2S pH2S max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N07718 N09925	232 (450)	200 (30)	See "Remarks" column	See "Remarks" column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
	204 (400)	1 400 (200)	See "Remarks" column	See "Remarks" column	No	
	199 (390)	2 300 (330)	See "Remarks" column	See "Remarks" column	No	
	191 (375)	2 500 (360)	See "Remarks" column	See "Remarks" column	No	
	149 (300)	2 800 (400)	See "Remarks" column	See "Remarks" column	No	
	135 (275)	See "Remarks" column	See "Remarks" column	See "Remarks" column	Yes	Any combination of hydrogen sulfide, chloride concentration, and *in situ* pH in production environments is acceptable.
N09925 (wrought, solution-annealed and aged)	205 (401)	3 500 (500)	180 000	See "Remarks" column	NDS[a]	Any *in situ* production environment pH is acceptable for p_{CO2}+ p_{H2S} ≤ 7 000 kPa (1 000 psi).

These materials shall also comply with the following:

a) wrought UNS N07718 shall be in any one of the following conditions:

1) solution-annealed to a maximum hardness of 35 HRC;
2) hot-worked to a maximum hardness of 35 HRC;
3) hot-worked and aged to a maximum hardness of 35 HRC;
4) solution-annealed and aged to a maximum hardness of 40 HRC.

b) wrought UNS N09925 shall be in any one of the following conditions:

1) cold-worked to a maximum hardness of 35 HRC;
2) solution-annealed to a maximum hardness of 35 HRC;
3) solution-annealed and aged to a maximum hardness of 38 HRC;
4) cold-worked and aged to a maximum hardness of 40 HRC;
5) hot-finished and aged to a maximum hardness of 40 HRC.

c) number-1 wrought UNS N09935 shall be in the solution annealed and aged condition to a maximum hardness of 34 HRC;

d) number-1 wrought UNS N09945 shall be in the solution annealed and aged condition to a maximum hardness of 42 HRC;

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.32 *(continued)*

<table>
<tr><th>Individual alloy UNS number</th><th>Temperature

max
°C (°F)</th><th>Partial pressure H2S pH2S
max
kPa (psi)</th><th>Chloride conc.

max
mg/l</th><th>pH</th><th>Sulfur-resistant?</th><th>Remarks</th></tr>
<tr><td>N09935</td><td>232 (450)</td><td>2 800 (400)</td><td>180 000</td><td>See “Remarks” column</td><td>NDS[a]</td><td>Any in situ production environment pH is acceptable for $p_{CO2} + p_{H2S} \leq$ 8 300 kPa (1 200 psi)</td></tr>
<tr><td rowspan="2">N09945</td><td>232 (450)</td><td>3 500 (508)</td><td>139 000</td><td>See “Remarks” column</td><td>NDS[a]</td><td rowspan="2">Any in situ production environment pH is acceptable for $p_{CO2} + p_{H2S} \leq$ 7 000 kPa (1 000 psi)</td></tr>
<tr><td>205 (401)</td><td>3 500 (508)</td><td>180 000</td><td>See “Remarks” column</td><td>NDS[a]</td></tr>
<tr><td colspan="7">These materials shall also comply with the following:
a) wrought UNS N07718 shall be in any one of the following conditions:
1) solution-annealed to a maximum hardness of 35 HRC;
2) hot-worked to a maximum hardness of 35 HRC;
3) hot-worked and aged to a maximum hardness of 35 HRC;
4) solution-annealed and aged to a maximum hardness of 40 HRC.
b) wrought UNS N09925 shall be in any one of the following conditions:
1) cold-worked to a maximum hardness of 35 HRC;
2) solution-annealed to a maximum hardness of 35 HRC;
3) solution-annealed and aged to a maximum hardness of 38 HRC;
4) cold-worked and aged to a maximum hardness of 40 HRC;
5) hot-finished and aged to a maximum hardness of 40 HRC.
c) number-1 wrought UNS N09935 shall be in the solution annealed and aged condition to a maximum hardness of 34 HRC;
d) number-1 wrought UNS N09945 shall be in the solution annealed and aged condition to a maximum hardness of 42 HRC;
[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.</td></tr>
</table>

Table A.33 — Environmental and materials limits for precipitation-hardened nickel-based alloys (III) used for any equipment or component

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N07626 (powder metal) N07716 N07725 (wrought)	232 (450)	1 000 (150)	See “Remarks” column	See “Remarks” column	No	Any combination of chloride concentration and *in situ* pH occurring in production environments is acceptable.
	220 (425)	2 000 (300)	See “Remarks” column	See “Remarks” column	Yes	
N07626 (powder metal)	204 (400)	4 100 (600)	See “Remarks” column	See “Remarks” column	No	
N07716 N07725 (wrought)	204 (400)	4 100 (600)	See “Remarks” column	See “Remarks” column	Yes	
N07022 (wrought)	204 (400)	3 500 (500)	180 000	See “Remarks” column	Yes	Any *in situ* production environment pH is acceptable for pCO_2 + pH_2S ≤ 7 000 kPa (1 000 psi)
N07626 (powder metal) N07716 N07725 (wrought)	175 (350)	See “Remarks” column	See “Remarks” column	See “Remarks” column	Yes	Any combination of hydrogen sulfide, chloride concentration, and *in situ* pH in production environments is acceptable.

These materials shall also comply with the following:

a) UNS N07626, totally dense hot-compacted by a powder metallurgy process, shall have a maximum hardness of 40 HRC and a maximum tensile strength of 1 380 MPa (200 ksi) and shall be either

1) solution-annealed [927 °C (1 700 °F) minimum] and aged [538 °C to 816 °C (1 000 °F to 1 500 °F)], or

2) direct-aged [538 °C to 816 °C (1 000 °F to 1 500 °F)].

b) wrought UNS N07716 and wrought UNS N07725 shall have a maximum hardness of HRC 43 and shall be in the solution-annealed and aged condition;

c) wrought UNS N07716 and wrought UNS N07725 in the solution-annealed and aged condition can also be used at a maximum hardness of HRC 44 in the absence of elemental sulfur and subject to the other environmental limits shown for the maximum temperature of 204 °C (400 °F);

d) wrought UNS N07022 shall have a maximum hardness of HRC 39 in the annealed and aged condition.

Table A.34 — Environmental and materials limits for precipitation-hardened nickel-based alloys used for wellhead and christmas tree components (excluding bodies and bonnets) and valve and choke components (excluding bodies and bonnets)

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N05500	See "Remarks" column	3,4 (0,5)	See "Remarks" column	≥4,5	NDS[a]	Any combination of temperature and chloride concentration occurring in production environments is acceptable.

For these applications, this material shall also comply with the following.

Wrought UNS N05500 shall have a maximum hardness of 35 HRC and shall be either

a) hot-worked and age-hardened,

b) solution-annealed, or

c) solution-annealed and age-hardened.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.35 — Environmental and materials limits for precipitation-hardened nickel-based alloys used as non-pressure containing internal valve, pressure regulator, and level controller components and miscellaneous equipment

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
Non-pressure-containing internal-valve, pressure-regulator, and level controller components						
N07750 N05500	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	Any combination of temperature. pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.
Miscellaneous equipment						
N05500	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	This alloy has been used in downhole running, setting and service tool applications for temporary service and in temporary surface service tool applications with the exceptions of bodies and bonnets. Environmental limits for this alloy for these applications have not been established.

For these applications, these materials shall also comply with the following:

a) wrought UNS N07750 shall have a maximum hardness of 35 HRC and shall be either

1) solution-annealed and aged,
2) solution-annealed,
3) hot-worked, or
4) hot-worked and aged.

b) wrought UNS N05500 shall have a maximum hardness of 35 HRC and shall be either

1) hot-worked and age-hardened,
2) solution-annealed, or
3) solution-annealed and age-hardened.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.36 — Environmental and materials limits for precipitation-hardened nickel-based alloys used as springs

Individual alloy UNS Number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N07750	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	This material has been used for these components without restriction on temperature, pH_2S, chloride concentration, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters have led to field failures.
N07090	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	This material has been used for these components without restriction on temperature, pH_2S, chloride concentration, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

For this application these materials shall also comply with the following:

— UNS N07750 springs shall be in the cold-worked and age-hardened condition and shall have a maximum hardness of 50 HRC;

— UNS N07090 can be used for springs for compressor valves in the cold-worked and age-hardened condition with a maximum hardness of 50 HRC.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.37 — Environmental and materials limits for precipitation-hardened nickel-based alloys used in gas lift service

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
N05500	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	This material has been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.9.3 Welding of precipitation-hardened nickel-based alloys of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the base metal after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective metal for the weld alloy.

A.10 Cobalt-based alloys (identified as individual alloys)

A.10.1 Materials chemical compositions

Table D.10 lists the chemical compositions of the cobalt-based alloys shown in Table A.38 to Table A.40.

A.10.2 Environmental and materials limits for the uses of cobalt-based alloys

Table A.38 — Environmental and materials limits for cobalt-based alloys used for any equipment or component

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
R30003 R30004 R30035 BS HR.3 R30605 R31233	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	Yes	Any combination of temperature. pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.

These materials shall also comply with the following:

a) alloys UNS R30003, UNS R30004, and BS HR.3 shall have a maximum hardness of 35 HRC;

b) UNS R30035 shall have a maximum hardness of 35 HRC except that it can have a maximum hardness of 51 HRC if it is in the cold-reduced and high-temperature aged heat-treated condition in accordance with the minimum time and the temperature of one of the following ageing treatments:

Minimum time h	Temperature °C (°F)
4	704 (1 300)
4	732 (1 350)
6	774 (1 425)
4	788 (1 450)
2	802 (1 475)
1	816 (1 500)

c) wrought UNS R31233 shall be in the solution-annealed condition and shall have a maximum hardness of 22 HRC;

d) UNS R30605 shall have a maximum hardness of 35 HRC.

Table A.39 — Environmental and materials limits for cobalt-based alloys used as springs

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
R30003 R30035	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	These materials have been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

For this application, these materials shall also comply with the following:

— UNS R30003 shall be in the cold-worked and age-hardened condition and maximum 60 HRC;

— UNS R30035 shall be in the cold-worked and age-hardened condition and maximum 55 HRC when aged for a minimum of 4 h at a temperature no lower than 649 °C (1 200 °F).

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

Table A.40 — Environmental and materials limits for cobalt-based alloys used as diaphragms, pressure measuring devices, and pressure seals

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
R30003, R30004, R30260	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	Any combination of temperature. pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.
R30159	See “Remarks” column	See “Remarks” column	See “Remarks” column	See “Remarks” column	NDS[a]	This material has been used for these components without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments. No limits on individual parameters are set, but some combinations of the values of these parameters might not be acceptable.

For these applications, these materials shall also comply with the following:

a) UNS R30003 and UNS R30004 shall have a maximum hardness of 60 HRC;

b) UNS R30260 shall have a maximum hardness of 52 HRC;

c) wrought UNS R30159 for pressure seals shall have a maximum hardness of 53 HRC and the primary load-bearing or pressure-containing direction shall be parallel to the longitudinal or rolling direction of wrought product.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.10.3 Welding of cobalt-based alloys of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the base metal after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective metal for the weld alloy.

A.11 Titanium and tantalum (individual alloys)

A.11.1 Materials chemical compositions

A.11.1.1 Titanium alloys

Table D.11 lists the chemical compositions of the titanium alloys shown in Table A.41.

A.11.1.2 Tantalum alloys

Table D.12 lists the chemical compositions of the tantalum alloys shown in Table A.42.

A.11.2 Environmental and materials limits for the uses of titanium and tantalum alloys

Table A.41 — Environmental and materials limits for titanium used for any equipment or component

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
R50250 R50400 R56260 R53400 R56323 R56403 R56404 R58640	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	Yes	Any combination of temperature. pH_2S, chloride concentration, and *in situ* pH occurring in production environments is acceptable.

These materials shall also comply with the following:

a) UNS R50250 and R50400 shall have a maximum hardness of 100 HRB;

b) UNS R56260 shall have a maximum hardness of 45 HRC and shall be in one of the three following conditions:

1) annealed;

2) solution-annealed;

3) solution-annealed and aged.

c) UNS R53400 shall be in the annealed condition. Heat treatment shall be annealing at (774 ± 14) °C [(1 425 ± 25) °F] for 2 h followed by air-cooling. Maximum hardness shall be 92 HRB;

d) UNS R56323 shall be in the annealed condition and shall have a maximum hardness of 32 HRC;

e) wrought UNS R56403 shall be in the annealed condition and shall have a maximum hardness of 36 HRC;

f) UNS R56404 shall be in the annealed condition and shall have a maximum hardness of 35 HRC;

g) UNS R58640 shall have a maximum hardness of 42 HRC.

Specific guidelines shall be followed for successful applications of each titanium alloy specified in this part of ISO 15156. For example, hydrogen embrittlement of titanium alloys can occur if these alloys are galvanically coupled to certain active metals (e.g. carbon steel) in H_2S-containing aqueous media at temperatures greater than 80 °C (176 °F). Some titanium alloys can be susceptible to crevice corrosion and/or SSC in chloride environments. Hardness has not been shown to correlate with susceptibility to SSC/SCC. However, hardness has been included for alloys with high strength to indicate the maximum testing levels at which failure has not occurred.

Table A.42 — Environmental and materials limits for tantalum used for any equipment or component

Individual alloy UNS number	Temperature max °C (°F)	Partial pressure H_2S p_{H2S} max kPa (psi)	Chloride conc. max mg/l	pH	Sulfur-resistant?	Remarks
R05200	See "Remarks" column	See "Remarks" column	See "Remarks" column	See "Remarks" column	NDS[a]	Any combination of temperature. pH_2S, chloride concentration, and *in situ* pH occurring in production environments are acceptable.

UNS R05200 shall have a maximum hardness of 55 HRB and shall be either

— annealed, or

— gas tungsten arc-welded and annealed.

[a] No data submitted to ascertain whether these materials are acceptable for service in the presence of elemental sulfur in the environment.

A.11.3 Welding of titanium and tantalum alloys of this materials group

The requirements for the cracking-resistance properties of welds shall apply (see 6.2.2).

The hardness of the base metal after welding shall not exceed the maximum hardness allowed for the base metal and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective metal for the weld alloy.

A.12 Copper- and aluminium-based alloys (identified as materials types)

A.12.1 Copper-based alloys

Copper-based alloys have been used without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments.

NOTE 1 Copper-based alloys can undergo accelerated mass loss corrosion (weight loss corrosion) in sour oil field environments, particularly if oxygen is present.

NOTE 2 Some copper-based alloys have shown sensitivity to GHSC.

A.12.2 Aluminium-based alloys

These materials have been used without restriction on temperature, pH_2S, Cl^-, or *in situ* pH in production environments.

The user should be aware that mass loss corrosion (weight loss corrosion) of aluminium-based alloys is strongly dependent on environmental pH.

A.13 Cladding, overlays, and wear-resistant alloys

A.13.1 Corrosion-resistant claddings, linings and overlays

The materials listed and defined in A.2 to A.11 can be used as corrosion-resistant claddings, linings, or as weld overlay materials.

Unless the user can demonstrate and document the likely long-term in-service integrity of the cladding or overlay as a protective layer, the base material, after application of the cladding or overlay, shall comply with ISO 15156-2 or this part of ISO 15156, as applicable.

This may involve the application of heat or stress-relief treatments that can affect the cladding, lining, or overlay properties.

Factors that can affect the long-term in-service integrity of a cladding, lining, or overlay include environmental cracking under the intended service conditions, the effects of other corrosion mechanisms, and mechanical damage.

Dilution of an overlay during application that can impact on its corrosion resistance or mechanical properties should be considered.

A.13.2 Wear-resistant alloys

A.13.2.1 Wear-resistant alloys used for sintered, cast, or wrought components

Environmental cracking resistance of alloys specifically designed to provide wear-resistant components is not specified in ISO 15156 (all parts). No production limits for temperature, pH_2S, Cl^-, or *in situ* pH have been established.

Some materials used for wear-resistant applications can be brittle. Environmental cracking can occur if these materials are subject to tension. Components made from these materials are normally loaded only in compression.

A.13.2.2 Hard-facing materials

Hard facing may be used.

Environmental cracking resistance of alloys or surface layers specifically designed to provide hard facing is not specified in ISO 15156 (all parts). No production limits for temperature, pH_2S, Cl^-, or *in situ* pH have been established.

Some materials used for hard-facing applications can be brittle. Environmental cracking of the hard facing can occur if these materials are subjected to tension.

Unless the user can demonstrate and document the likely long-term in-service integrity of the hard-facing materials, the base material after application of the hard-facing material shall comply with ISO 15156-2 or this part of ISO 15156, as applicable.

Annex B
(normative)

Qualification of CRAs for H_2S-service by laboratory testing

B.1 General

This Annex specifies minimum requirements for qualifying CRAs for H_2S service by laboratory testing. Requirements are given for qualifying resistance to the following cracking mechanisms:

— SSC at ambient temperature;

— SCC at maximum service temperature in the absence of elemental sulfur, S^0;

— HSC of CRAs when galvanically coupled to carbon or low alloy steel, i.e. GHSC.

Supplementary requirements concern

a) testing at intermediate temperatures when the distinction between SSC and SCC is unclear, and

b) SCC testing in the presence of S^0.

Guidance on the potential for corrosion to cause cracking of CRAs is given in Table B.1. The alloy groups are the same as those used in Annex A.

The test requirements of this Annex do not address the possible consequences of sequential exposure to different environments. For example, the consequence of cooling after hydrogen uptake at a higher temperature is not evaluated.

Table B.1 — Cracking mechanisms that shall be considered for CRA and other alloy groups

Materials groups of Annex A	Potential cracking mechanisms in H_2S service[a, b]			Remarks
	SSC	SCC	GHSC	
Austenitic stainless steels (see A.2)	S	P	S	Some cold-worked alloys contain martensite and can therefore be sensitive to SSC and/or HSC.
Highly-alloyed austenitic stainless steels (see A.3)	—	P	—	These alloys are generally immune to SSC and HSC. Low-temperature cracking tests are not normally required.
Solid-solution nickel-based alloys (see A.4)	S	P	S	Some Ni-based alloys in the cold-worked condition and/or aged conditions contain secondary phases and can be susceptible to HSC when galvanically coupled to steel. In the heavily cold-worked and well-aged condition coupled to steel, these alloys can experience HSC.
Ferritic stainless steels (see A.5)	P	—	P	—
Martensitic stainless steels (see A.6)	P	S	P	Alloys containing Ni and Mo can be subject to SCC whether or not they contain residual austenite.
Duplex stainless steels (see A.7)	S	P	S	Cracking sensitivity can be highest at a temperature below the maximum service temperature and testing over a range of temperatures shall be considered.
Precipitation-hardened stainless steels (see A.8)	P	P	P	—
Precipitation-hardened nickel base alloys (see A.9)	S	P	P	Some Ni-based alloys in the cold-worked condition and/or aged conditions contain secondary phases and can be susceptible to HSC when galvanically coupled to steel.
Cobalt-based alloys (see A.10)	S	P	P	—
Titanium and tantalum (see A.11)	See "Remarks" column			Cracking mechanisms depend upon the specific alloy. The equipment user shall ensure appropriate testing and qualification is carried out.
Copper and aluminium (see A.12)	See "Remarks" column			These alloys are not known to suffer from these cracking mechanisms

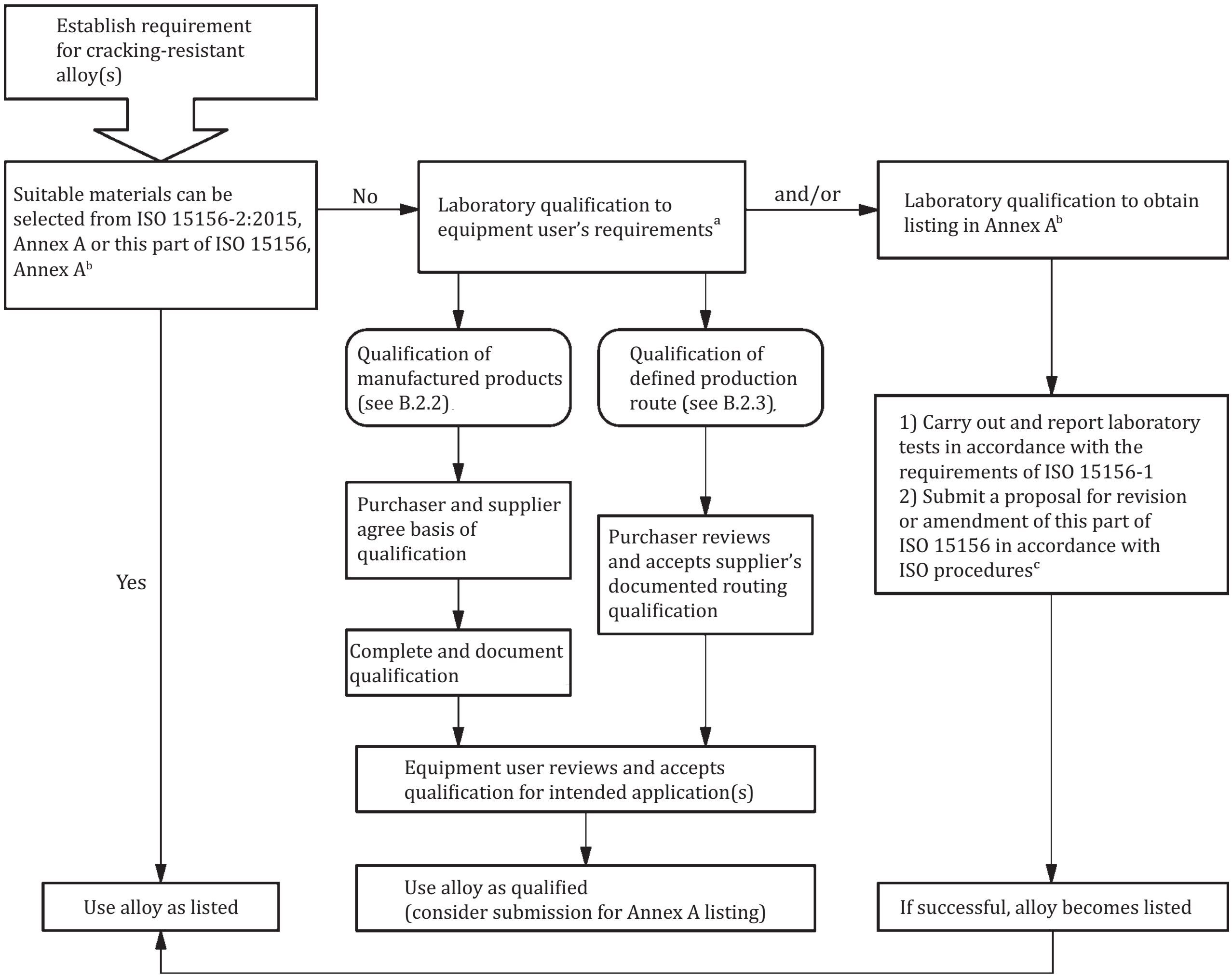
a P indicates primary cracking mechanism.

b S indicates secondary, possible, cracking mechanism.

B.2 Uses of laboratory qualifications

B.2.1 General

An overview of the uses of laboratory qualifications is given in Figure B.1



Key

a This part of ISO 15156 addresses SSC, SCC, and GHSC of CRAs and other alloys. ISO 15156-2 addresses SSC, HIC, SOHIC, and SZC of carbon and low alloy steels.

b Annex A addresses SSC, SCC, and GHSC of CRAs and other alloys. ISO 15156-2:2015, Annex A addresses SSC of carbon and low alloy steels.

c See final paragraphs of "Introduction" for further information regarding document maintenance.

NOTE Flowchart omits qualification by field experience as described in ISO 15156-1.

Figure B.1 — Alternatives for alloy selection and laboratory qualification

B.2.2 Qualification of manufactured products

The user of this part of ISO 15156 shall define the qualification requirements for the material in accordance with ISO 15156-1 and Annex B.

This definition shall include the application of the following:

a) general requirements (see ISO 15156-1:2015, Clause 5);

b) evaluation and definition of service conditions (see ISO 15156-1:2015, Clause 6);

c) material description and documentation (see ISO 15156-1:2015, 8.1);

d) requirements for qualification based upon laboratory testing (see ISO 15156-1:2015, 8.3);

e) report of the method of qualification (see ISO 15156-1:2015, Clause 9).

Appropriate "test batches" and sampling requirements shall be defined having regard to the nature of the product, the method of manufacture, testing required by the manufacturing specification, and the required qualification(s) (see Table B.1).

Samples shall be tested in accordance with Annex B for each cracking mechanism to be qualified. A minimum of three specimens shall be tested per test batch. The test batch shall be qualified if all specimens satisfy the test acceptance criteria.

Retesting is permitted in accordance with the following. If a single specimen fails to meet the acceptance criteria, the cause shall be investigated. If the source material conforms to the manufacturing specification, two further specimens may be tested. These shall be taken from the same source as the failed specimen. If both satisfy the acceptance criteria, the test batch shall be considered qualified. Further retests shall require the purchaser's agreement.

Testing of manufactured products may be carried out at any time after manufacture and before exposure to H_2S service.

Before the products are placed in H_2S service, the equipment user shall review the qualification and verify that it satisfies the defined qualification requirements. Products with a qualification that has been verified by the equipment user may be placed into H_2S service.

B.2.3 Qualification of a defined production route

A defined production route may be qualified for the production of qualified material.

A qualified production route may be followed to avoid order release testing for H_2S cracking resistance.

A materials supplier may propose to a materials purchaser that a qualified production route be used to produce qualified materials. The qualified production route may be used if the materials supplier and materials purchaser agree to its use.

A qualified production route may be used to produce qualified material for more than one materials user.

To qualify a production route, the material supplier shall demonstrate that a defined production route is capable of consistently manufacturing material that satisfies the applicable qualification test requirements of Annex B.

The qualification of a production route requires all of the following:

a) definition of the production route in a written quality plan that identifies the manufacturing location(s), all manufacturing operations, and the manufacturing controls required to maintain the qualification;

b) initial testing of products produced on the defined production route in accordance with B.2.2 and verifying they satisfy the acceptance criteria;

c) periodic testing to confirm that the product continues to have the required resistance to cracking in H_2S service. The frequency of "periodic" testing shall also be defined in the quality plan and shall be acceptable to the purchaser. A record of such tests shall be available to the purchaser;

d) retaining and collating the reports of these tests and making them available to material purchasers and/or equipment users.

A material purchaser may agree additional quality control requirements with the manufacturer.

The accuracy of the quality plan may be verified by site inspection by an interested party.

Changes to a production route that fall outside the limits of its written quality plan require qualification of a new route in accordance with a), b), c), and d) above.

B.2.4 Use of laboratory testing as a basis for proposing additions and changes to Annex A

Changes to Annex A may be proposed (see Introduction). Proposals for changes shall be documented in accordance with ISO 15156-1. They shall also be subject to the following additional requirements.

Representative samples of CRAs and other alloys for qualification by laboratory testing shall be selected in accordance with ISO 15156-1.

Material representing a minimum of three separately processed heats shall be tested for resistance to cracking in accordance with B.3. Test requirements shall be established by reference to the appropriate materials group in Table B.1.

Tests shall be performed for the primary cracking mechanisms listed in Table B.1.

Tests shall also be performed for the secondary cracking mechanisms listed in Table B.1; otherwise, the justification for their omission shall be included in the test report.

For other alloys not covered by Table B.1, the choice of qualification tests used shall be justified and documented.

Sufficient data shall be provided to allow the members of ISO/TC 67 to assess the material and decide on the suitability of the material for inclusion into this part of ISO 15156, by amendment or revision, in accordance with the ISO/IEC Directives, Part 1.

B.3 General requirements for tests

B.3.1 Test method descriptions

The test requirements are based on NACE TM0177 and EFC Publication 17. These documents shall be consulted for details of test procedures. When necessary, suppliers, purchasers, and equipment users may agree variations to these procedures. Such variations shall be documented.

B.3.2 Materials

The materials tested shall be selected in accordance with the requirements found in ISO 15156-1:2015, 8.3.2.

In addition, consideration shall be given to the following:

a) the cracking mechanism for which testing is required (see Table B.1);

b) the testing of appropriately aged samples of alloys that can age in service, particularly HSC testing of downhole materials that can be subject to ageing in service ("well ageing");

c) the directional properties of alloys because cold-worked alloys may be anisotropic with respect to yield strength and for some alloys and products, the susceptibility to cracking varies with the direction of the applied tensile stress and consequent orientation of the crack plane.

B.3.3 Test methods and specimens

Primary test methods use constant load, sustained load (proof-ring), or constant total strain (constant displacement) loading of smooth test specimens.

Uniaxial tensile (UT) tests, four-point bend (FPB) tests, and C-ring (CR) tests may be performed with the above loading arrangements.

Generally, constant load tests using UT specimens are the preferred method of testing homogeneous materials.

Test specimens shall be selected to suit the product form being tested and the required direction of the applied stress. A minimum of three specimens shall be taken from each component tested.

UT specimens may be taken from welded joints in accordance with EFC Publication Number 17, Figure 8.1. Other specimens taken from welded joints may be tested with weld profiles as intended for service.

When double (back-to-back) FPB specimens are used (in accordance with EFC Publication Number 17, Figure 8.2a, or similar), uncracked specimens shall be disqualified as invalid if the opposing specimen cracks.

Alternative test methods or specimens may be used when appropriate. The basis and use of such tests shall be documented and agreed with the equipment user.

Examples of test methods that may be considered are as follows.

— Fracture mechanics tests, e.g. double cantilever beam (DCB) tests, may be used if cracks are unaffected by branching and remain in the required plane. This normally limits DCB tests to SSC and HSC tests.

— Tests involving the application of a slow strain rate, e.g. SSRT in accordance with NACE TM0198, interrupted SSRT in accordance with ISO 7539-7 or RSRT in accordance with the method published as NACE CORROSION/97 Paper 58.

Tests may utilize testing of full-size or simulated components when appropriate.

B.3.4 Applied test stresses/loads for smooth specimens

The yield strengths of CRAs used to derive test stresses shall be determined at the test temperature in accordance with the applicable manufacturing specification. In the absence of an appropriate definition of yield strength in the manufacturing specification, the yield strength shall be taken to mean the 0,2 % proof stress of non-proportional elongation ($R_{p0,2}$ as defined in ISO 6892-1) determined at the test temperature.

Directional properties shall be considered when selecting test specimens and defining test stresses.

For welded specimens, the parent metal yield strength shall normally be used to determine test stresses. For dissimilar joints, the lower parent metal yield strength shall normally be used. When design stresses are based on the yield strength of a weld zone that is lower than the yield strength of either adjoining parent metals, the yield strength of the weld zone may be used to determine test stresses.

For constant-load tests and sustained-load (proof-ring) tests, specimens shall be loaded to 90 % of the AYS of the test material at the test temperature.

For constant total strain (deflection) tests, specimens shall be loaded to 100 % of the AYS of the test material at the test temperature.

NOTE Constant total strain (deflection) tests might not be suitable for materials that can relax by creep when under load.

Lower applied stresses can be appropriate for qualifying materials for specific applications. The use and basis of such tests shall be agreed with the purchaser and documented.

B.3.5 SSC/SCC test environments

B.3.5.1 General

The following environmental test variables shall be controlled and recorded:

— p_{H2S};

— p_{CO2};

— temperature;

— test solution pH, the means of acidification, and pH control (all pH measurements shall be recorded);

— test solution formulation or analysis;

— elemental sulfur, S^0, additions;

— galvanic coupling of dissimilar metals (the area ratio and coupled alloy type shall be recorded).

In all cases, the pH_2S, chloride, and S^0 concentrations shall be at least as severe as those of the intended application. The maximum pH reached during testing shall be no greater than the pH of the intended application.

It can be necessary to use more than one test environment to achieve qualification for a particular service.

The following test environments may be used either to simulate intended service conditions or to simulate a nominated condition when intended applications are insufficiently defined.

Use can be made of nominated test conditions to provide information on the environmental limits within which a CRA or other alloy is resistant to cracking if no specific application is foreseen.

Table E.1 may be used to define the test environments for the standard tests for SSC and GHSC (identified as level II and level III, respectively). For type 1 environments (see B.3.5.2), Table E.1 also provides a number of nominated sets of conditions (for temperature, pCO_2, pH_2S, and chloride concentration) that may be considered. These are identified as levels IV, V, VI, and VII.

When using nominated test conditions, all other requirements of this Annex shall be met.

NOTE 1 The nominated sets of conditions are not intended to limit the freedom of the document user to test using other test conditions of their choice.

The equipment user should be aware that oxygen contamination of the service environment can influence the cracking resistance of an alloy and should be considered when choosing the test environment.

NOTE 2 Reference [15] gives information on the charging of autoclaves.

B.3.5.2 Service simulation at actual H_2S and CO_2 partial pressures — Type 1 environments

In these test environments, the service (*in situ*) pH is replicated by controlling the parameters that determine pH under field conditions. Test environments shall be established in accordance with the following requirements:

a) test limits: the pressure shall be ambient or greater;

b) test solution: synthetic produced water that simulates the chloride and bicarbonate concentrations of the intended service. The inclusion of other ions is optional;

c) test gas: H_2S and CO_2 at the same partial pressures as the intended service;

d) pH measurement: pH is determined by reproduction of the intended service conditions. The solution pH shall be determined at ambient temperature and pressure under the test gas or pure CO_2 immediately before and after the test. This is to identify changes in the solution that influence the test pH. Any pH change detected at ambient temperature and pressure is indicative of a change at the test temperature and pressure.

B.3.5.3 Service simulation at ambient pressure with natural buffering agent — Type 2 environments

In these test environments, the service (*in situ*) pH is replicated by adjusting the buffer capacity of the test solution using a natural buffer to compensate for the reduced pressure of acid gases in the test. Test environments shall be established in accordance with the following requirements:

a) test limits: the pressure shall be ambient, temperature shall be maximum 60 °C and pH shall be 4,5 or greater;

b) test solution: distilled or de-ionized water with sodium bicarbonate ($NaHCO_3$) added to achieve the required pH. Chloride shall be added at the concentration of the intended service. If necessary, a liquid reflux shall be provided to prevent loss of water from the solution;

c) test gas: H_2S at the partial pressure of the intended service and CO_2 as the balance of the test gas. The test gas shall be continuously bubbled through the test solution;

d) pH control: the solution pH shall be measured at the start of the test, periodically during the test and at the end of the test, adjusting as necessary by adding HCl or NaOH. The variation of the test pH shall not exceed ±0,2 pH units.

B.3.5.4 Service simulation at ambient pressure with acetic buffer — Type 3a and Type 3b environments

In these test environments, the service (*in situ*) pH is replicated by adjusting the buffer capacity of the test solution using an artificial buffer and adding HCl to compensate for the reduced pressure of acid gases in the test. Test environments shall be established in accordance with the following requirements:

a) test limits: the pressure shall be ambient, the temperature shall be (24 ± 3) °C;

b) test solution: one of the following test solutions shall be used:

   1) for general use (environment 3a), distilled or de-ionized water containing 4 g/l sodium acetate and chloride at the same concentration as the intended service;

   2) for super-martensitic stainless steels prone to corrosion in solution for environment 3a (environment 3b), de-ionized water containing 0,4 g/l sodium acetate and chloride at the same concentration as the intended service.

   HCl shall be added to both solutions to achieve the required pH;

c) test gas: H_2S at the partial pressure of the intended service and CO_2 as the balance of the test gas. The test gas shall be continuously bubbled through the test solution;

d) pH control: the solution pH shall be measured at the start of the test, periodically during the test and at the end of the test, adjusting as necessary by adding of HCl or NaOH. The variation of the test pH shall not exceed ± 0,2 pH units.

B.3.6 Test duration

Constant-load, sustained-load, and constant-total-strain tests shall have a minimum duration of 720 h. Tests shall not be interrupted.

B.3.7 Acceptance criteria and test report

Specimens exposed in constant-load, sustained-load, and constant-total-strain tests shall be assessed in accordance with NACE TM0177, test methods A, and C. No cracks are permissible.

Specimens exposed in fracture mechanics and slow strain rate tests shall be assessed as required by the test method. Fracture toughness values shall only be valid for substantially unbranched cracks. Acceptance criteria for fracture toughness tests shall be specified by the equipment user.

In all cases, any indication of corrosion causing metal loss including pitting or crevice corrosion shall be reported.

NOTE The occurrence of pitting or crevice corrosion outside the stressed section of a specimen can suppress SCC of the specimen.

A written test report conforming to the requirements in ISO 15156-1:2015, Clause 9, shall be completed and retained.

B.3.8 Validity of tests

Satisfactory test results qualify materials for environmental conditions that are less severe than the test environment. Users shall determine the validity of tests for individual applications. Environmental severity is decreased by the following at any given temperature:

— a lower pH_2S;

— a lower chloride concentration;

— a higher pH;

— the absence of S^0.

B.4 SSC testing

Tests shall be performed in accordance with the general requirements for tests given in B.3.

Tests shall normally be performed at (24 ± 3) °C [(75 ± 5) °F] in accordance with NACE TM0177 and/or EFC Publication 17.

The test temperature may be at the lowest service temperature if this is above 24 °C (75 °F). The use of a test temperature above 24 °C shall be justified in the test report.

B.5 SCC testing without S^0

Tests shall be performed in accordance with the general requirements of B.3.

SCC testing procedures shall be based on NACE TM0177 and/or EFC Publication 17 subject to the following additional requirements, options, and clarifications:

a) the test temperature shall not be less than the maximum intended service temperature. This can require the use of a pressurized test cell;

b) water vapour pressure shall be allowed for in determining gas-phase partial pressures;

c) acetic acid and acetates shall not be used for pH control. The solution pH shall be controlled as described in B.3.5.2;

d) during initial exposure of specimens to the test environment, the applied load and the environmental conditions shall be controlled so that all test conditions are already established when the test temperature is first attained;

e) for constant-total-strain tests, applied stresses shall be verified by measurement;

NOTE It is good practice to verify the deflection calculations in many CRA material specifications.

f) loading procedures used for constant-total-strain tests shall be shown to achieve a stable stress before specimens are exposed to the test environment.

B.6 SSC/SCC testing at intermediate temperatures

Testing at intermediate temperatures, i.e. between (24 ± 3) °C [(75 ± 5) °F] and the maximum intended service temperature, shall meet the requirements of the equipment user. Testing shall be performed at the specified temperature in accordance with the above requirements for SCC testing.

For qualification for inclusion by amendment in A.7, duplex stainless steels shall be tested at (24 ± 3) °C [(75 ± 5) °F], (90 ± 3) °C [(194 ± 5) °F], and at the maximum intended service temperature of the alloy.

B.7 SCC testing in the presence of S^0

Tests shall be performed in accordance with the previous requirements for SCC tests with the addition that the procedure published in NACE CORROSION/95 Paper 47 shall be implemented for control of S^0 additions. The integration of this procedure into CRA test methods is addressed in EFC Publication 17, Appendix S1.

B.8 GHSC testing with carbon steel couple

GHSC tests shall be performed in accordance with the previously stated requirements for SSC testing, subject to the following additional requirements, options, and clarifications:

a) the CRA specimen shall be electrically coupled to unalloyed (i.e. carbon) steel that is fully immersed in the test solution. The ratio of the area of the unalloyed steel to the wetted area of the CRA specimen shall be between 0,5 and 1 as required by NACE TM0177. Loading fixtures shall be electrically isolated from the specimen and the coupled steel. For application-specific qualifications, the CRA may be coupled to a sample of the lower alloyed material to which it will be coupled in service.

b) the test environment shall be NACE TM0177, Solution A under H_2S at a pressure of 100 kPa and at a temperature of (24 ± 3) °C [(75 ± 5) °F]. For application-specific qualifications, SSC test environments described in B.3.5 may be used.

Annex C
(informative)

Information that should be supplied for material purchasing

ISO 15156-1 indicates that cooperation and exchange of information can be necessary between the various users of this part of ISO 15156, e.g. equipment users, purchasers and manufacturers of equipment, purchasers of materials, and manufacturers and suppliers of materials. The following tables can be used to assist this cooperation.

The materials purchaser should indicate the required options in Table C.1 and Table C.2.

Table C.1 and Table C.2 also suggest designations that may be included in markings of materials to show compliance of individual CRAs or other alloys with this part of ISO 15156.

The purchase order details should form part of a material's documentation to ensure its traceability. Where selection of materials is based upon laboratory testing in accordance with Annex B, traceability documentation should also include the details of the conditions derived from Table C.2 that were applied during testing.

Table C.1 — Information for material purchase and marking

Materials selection options and other information		Materials purchaser's requirements	Reference clause in ISO 15156-3	Remarks	Sour service designation for marking[e]
Preferred CRA or other alloy and condition[a]		[b]	—	—	—
Equipment type		[c]	—	—	—
Method of selection/ qualification	CRA or other alloy selected from Annex A?	Option A[d]	6.1	Service exposure conditions as shown in Table C.2 (optional)	A.nn[e]
	CRA or other alloy qualified in accordance with Annex B?	Option B[d]	6.1, Annex B	See also Table C.2	B, B1, B2, etc.[e]
	Either of the above methods of selection/ qualification	Option C[d]	See option A and option B	See option A and option B	See option A and option B

[a] For use when a purchaser requires a known material that is either listed in Annex A or qualified in accordance with Annex B. The purchaser should indicate the method of qualification below.

[b] User may insert material type and condition.

[c] User may insert equipment type for which material is required.

[d] Indicate which option is required.

[e] A suggested scheme for designation of listed CRAs to be included in markings of materials is for manufacturers/suppliers to indicate compliance of individual CRAs or other alloys by reference to the materials group clause number, e.g. A.2. For materials qualified to Annex B, the suggested designations are B, B1, B2, B3 (see Table C.2).

Table C.2 — Additional information for SSC, SCC, and GHSC testing and suggested marking

Cracking qualification test		Materials purchaser's requirements for cracking resistance and service exposure	Reference in this part of ISO 15156	Remarks	Sour service designation for marking[b]
Resistance to SSC		Option 1[a, c]	B.4	—	B1
Resistance to SCC		Option 2[a, c]	B.5 to B.7	—	B2
Resistance to GHSC		Option 3[a, c]	B.8	—	B3
Resistance to SSC, SCC, and GHSC		Option 4[a, c]	B.4 to B.8	—	B
Description of service conditions documented in accordance with ISO 15156-1	CO_2 pressure, kPa	—	B.3	—	—
	H_2S pressure, kPa	—		—	
	Temperature, °C	—		—	
	In situ pH	—		—	
	Cl^- or other halide, mg/l	—		—	
	S^0	Present or absent[a]		—	
Laboratory test requirements		—	B.3	—	—
Non-standard test stress, % AYS		—		—	
Specimen type		—		—	

[a] Indicate which option(s) is (are) required.

[b] For materials qualified to Annex B, the suggested designations for marking are B, B1, B2, and B3 where B1 is SSC, B2 is SCC, B3 is GHSC, and B indicates that the material has been shown to be resistant to all three cracking mechanisms.

[c] Test conditions to be appropriate to the service conditions shown in this table (see also B.2 and B.3).

Annex D
(informative)

Materials chemical compositions and other information

D.1 The tables that follow are included for the convenience of the users of this part of ISO 15156 and are based on the SAE — ASTM standard. Users are encouraged to confirm the accuracy of the information shown using the latest edition of this SAE — ASTM standard.

D.2 These tables provide a link between the UNS numbers used in the tables of Annex A and the chemical compositions of the alloys to which they refer. Document users are encouraged to consult the SAE — ASTM standard which gives a written description of each alloy, its chemical composition, common trade names, and cross references to other industry specifications.

D.3 Alloy acceptability depends upon actual chemical composition within the ranges shown and upon any additional chemical composition, heat treatment, and hardness requirements listed for the alloy in Annex A. Some alloy chemical compositions that comply with the tables do not meet these additional qualification requirements.

NOTE 1 ISO 15510 [2] provides assistance for the cross-referencing for some UNS numbers to other standards. ISO 13680 [1] provides information relating to materials, their chemical compositions, and their availability for use as casing, tubing, and coupling stock.

NOTE 2 Mass fraction, *w*, is often expressed in US customary units as parts per million by weight and in SI units as milligrams per kilogram. The mass fractions given in the tables of this Annex are expressed as percentage mass fractions, 1 % being equal to 1 g per 100 g.

NOTE 3 For Tables D.1, D.2, D.5, D.6, D.7, and D.8, the balance of composition up to 100 % is Fe.

NOTE 4 For Tables D.1, D.2, and D.7, the values of (Ni + 2Mo) and/or F_{PREN} have been rounded to whole numbers. They are provided for guidance only.

Table D.1 — Chemical compositions of some austenitic stainless steels (see A.2 and D.3)

UNS	C max[a] w_C %	Cr w_{Cr} %	Ni w_{Ni} %	Mn max[a] w_{Mn} %	Si max[a] w_{Si} %	P max w_P %	S max w_S %	Mo w_{Mo} %	N max w_N %	Other	F_{PREN}	Ni + 2Mo
J92500	0,03	17,0 to 21,0	8,0 to 12,0	1,50	2,00	0,04	0,04	—	—	—	17 to 21	8 to 12
J92600	0,08	18,0 to 21,0	8,0 to 11,0	1,50	2,00	0,04	0,04	—	—	—	18 to 21	8 to 11
J92800	0,03	17,0 to 21,0	9,0 to 13,0	1,50	1,50	0,04	0,04	2,0 to 3,0	—	—	24 to 31	13 to 19
J92843	0,28 to 0,35	18,0 to 21,0	8,0 to 11,0	0,75 to 1,50	1,00	0,04	0,04	1,00 to 1,75	—	Other[b]	23 to 30	10 to 15
J92900	0,08	18,0 to 21,0	9,0 to 12,0	1,50	2,00	0,04	0,04	2,0 to 3,0	—	—	24 to 31	13 to 18
S20100	0,15	16,0 to 18,0	3,5 to 5,5	5,5 to 7,5	1,00	0,060	0,030	—	0,25	—	20 to 22	4 to 6
S20200	0,15	17,0 to 19,0	4,0 to 6,0	7,5 to 10,0	1,00	0,060	0,030	—	—	—	17 to 19	4 to 6
S20500	0,12 to 0,25	16,0 to 18,0	1,00 to 1,75	14,0 to 15,5	1,00	0,060	0,030	—	—	—	16 to 18	1 to 2
S20910	0,06	20,5 to 23,5	11,5 to 13,5	4,0 to 6,0	1,00	0,040	0,030	1,5 to 3,0	0,20 to 0,40	Other[c]	29 to 38	15 to 20
S30200	0,15	17,0 to 19,0	8,0 to 10,0	2,00	1,00	0,045	0,030	—	—	—	17 to 19	8 to 10
S30400	0,08	18,0 to 20,0	8,0 to 10,5	2,00	1,00	0,045	0,030	—	—	—	18 to 20	8 to 11
S30403	0,03	18,0 to 20,0	8,0 to 12,0	2,00	1,00	0,045	0,030	—	—	—	18 to 20	8 to 12
S30500	0,12	17,0 to 19,0	10,0 to 13,0	2,00	1,00	0,045	0,030	—	—	—	17 to 19	10 to 13
S30800	0,08	19,0 to 21,0	10,0 to 12,0	2,00	1,00	0,045	0,030	—	—	—	19 to 21	10 to 12
S30900	0,20	22,0 to 24,0	12,0 to 15,0	2,00	1,00	0,045	0,030	—	—	—	22 to 24	12 to 15
S31000	0,25	24,0 to 26,0	19,0 to 22,0	2,00	1,50	0,045	0,030	—	—	—	24 to 26	19 to 22
S31600	0,08	16,0 to 18,0	10,0 to 14,0	2,00	1,00	0,045	0,030	2,0 to 3,0	—	—	23 to 28	14 to 20
S31603	0,030	16,0 to 18,0	10,0 to 14,0	2,00	1,00	0,045	0,030	2,0 to 3,0	—	—	23 to 28	14 to 20
S31635	0,08	16 to 18	10 to 14	2,00	1,0	0,045	0,030	2 to 3	0,10	Other[d]	23 to 30	14 to 20

a Where a range is shown, it indicates min to max percentage mass fractions.

b Cu, 0,50 % max; Ti, 0,15 to 0,50 %; W, 1,00 % to 1,75 %; Nb + Ta, 0,30 to 0,70 %.

c Nb, 0,10 % to 0,30 %; V, 0,10 % to 0,30 %.

d Minimum value of Ti shall be five times the percentage mass fraction of carbon.

e Minimum value of Nb shall be 10 times the percentage mass fraction of carbon.

Table D.1 *(continued)*

UNS	C max[a] w_{C} %	Cr w_{Cr} %	Ni w_{Ni} %	Mn max[a] w_{Mn} %	Si max[a] w_{Si} %	P max w_{P} %	S max w_{S} %	Mo w_{Mo} %	N max w_{N} %	Other	F_{PREN}	Ni + 2Mo
S31700	0,08	18,0 to 20,0	11,0 to 15,0	2,00	1,00	0,045	0,030	3,0 to 4,0	—	—	28 to 33	17 to 23
S32100	0,08	17,0 to 19,0	9,0 to 12,0	2,00	1,00	0,045	0,030	—	—	Other[d]	17 to 19	9 to 12
S34700	0,08	17,0 to 19,0	9,0 to 13,0	2,00	1,00	0,045	0,030	—	—	Other[e]	17 to 19	9 to 13
S38100	0,08	17,0 to 19,0	17,5 to 18,5	2,00	1,50 to 2,50	0,03	0,030	—	—	—	17 to 19	18 to 19

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] Cu, 0,50 % max; Ti, 0,15 to 0,50 %; W, 1,00 % to 1,75 %; Nb + Ta, 0,30 to 0,70 %.

[c] Nb, 0,10 % to 0,30 %; V, 0,10 % to 0,30 %.

[d] Minimum value of Ti shall be five times the percentage mass fraction of carbon.

[e] Minimum value of Nb shall be 10 times the percentage mass fraction of carbon.

Table D.2 — Chemical compositions of some highly-alloyed austenitic stainless steels (see A.3 and D.3)

UNS	C max w_C %	Cr w_{Cr} %	Ni w_{Ni} %	Mn max[a] w_{Mn} %	Si max w_{Si} %	P max w_P %	S max w_S %	Mo w_{Mo} %	N w_N %	Cu w_{Cu} %	W w_W %	F_{PREN}	Ni + 2Mo
S31254	0,020	19,5 to 20,5	17,5 to 18,5	1,00	0,80	0,030	0,010	6,0 to 6,5	0,18 to 0,22	0,50 to 1,00	—	42 to 45	30 to 32
J93254	0,025	19,5 to 20,5	17,5 to 19,7	1,20	1,0	0,45	0,010	6,0 to 7,0	0,18 to 0,24	0,50 to 1,00	—	42 to 47	30 to 34
J95370[b]	0,03	24 to 25	17 to 18	8 to 9	0,50	0,030	0,010	4 to 5	0,7 to 0,8	0 to 0,50	0 to 0,10	48 to 54	25 to 28
S31266	0,030	23,0 to 25,0	21,0 to 24,0	2,0	1,00	0,035	0,020	5,0 to 7,0	0,35 to 0,60	0,50 to 3,00	1,00 to 3,00	46 to 62	31 to 38
S32200	0,03	20,0 to 23,0	23,0 to 27,0	1,0	0,5	0,03	0,005	2,5 to 3,5	—	—	—	28 to 35	28 to 34
S32654	0,02	24,0 to 25,0	21,0 to 23,0	2,00 to 4,00	0,50	0,03	0,005	7,00 to 8,00	0,45 to 0,55	0,30 to 0,60	—	54 to 60	35 to 39
N08007	0,07	19,0 to 22,0	27,5 to 30,5	1,50	1,5	—	—	2,00 to 3,00	—	3,00 to 4,00	—	26 to 32	32 to 37
N08020[c]	0,07	19,0 to 21,0	32,0 to 38,0	2,00	1,00	0,045	0,035	2,0 to 3,0	—	3,00 to 4,00	—	25,6 to 30,9	36 to 44
N08320	0,05	21,0 to 23,0	25,0 to 27,0	2,5	1,0	0,04	0,03	4,0 to 6,0	—	—	—	34 to 43	33 to 39
N08367	0,030	20,0 to 22,0	23,5 to 25,5	2,00	1,00	0,04	0,03	6,00 to 7,00	0,18 to 0,25	0,75 max.	—	43 to 49	36 to 40
N08904	0,02	19,0 to 23,0	23,0 to 28,0	2,00	1,00	0,045	0,035	4,00 to 5,00	—	1 to 2	—	32 to 40	31 to 38
N08925	0,02	19,0 to 21,0	24,0 to 26,0	1,00	0,50	0,045	0,030	6,0 to 7,0	0,10 to 0,20	0,50 to 1,50	—	40 to 47	36 to 40
N08926	0,020	19,0 to 21,0	24,0 to 26,0	2,0	0,5	0,03	0,01	6,0 to 7,0	0,15 to 0,25	0,5 to 1,5	—	41 to 48	36 to 40

[a] Where a range is shown, it indicates min. to max. percentage mass fractions.

[b] Additional elements, expressed as percentage mass fractions, are Al, 0,01 % max; A, 0,01 % max; B, 0,003 % to 0,007 %; Co, 0,25 % max; Nb, 0,10 % max; Pb, 0,01 % max; Sn, 0,010 % max; Ti, 0,10 % max; and V, 0,10 % max.

[c] w_{Nb} shall be eight times w_C (% mass fraction) with a maximum of 1 %.

Table D.3 — Chemical compositions of some solid-solution nickel-based alloys (see A.4 and D.3)

UNS	C	Cr	Ni	Fe	Mn	Si	Mo	Co	Cu	P	S	Ti	Nb + Ta	Nb	V	W	N	Al
	max[a]			max[a]	max[a]	max[a]		max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]		max[a]
	w_C	w_{Cr}	w_{Ni}	w_{Fe}	w_{Mn}	w_{Si}	w_{Mo}	w_{Co}	w_{Cu}	w_P	w_S	w_{Ti}	w_{Nb+Ta}	w_{Nb}	w_V	w_W	w_N	w_{Al}
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
N06002	0,05 to 0,15	20,5 to 23,0	bal.[b]	17,0 to 20,0	1,00	1,00	8,0 to 10,0	0,5 to 2,5	—	0,04	0,030	—	—	—	—	0,2 to 1,0	—	—
N06007	0,05	21,0 to 23,5	bal.[b]	18,0 to 21,0	1,0 to 2,0	1,00	5,5 to 7,5	2,5	1,5 to 2,5	0,04	0,03	—	—	1,75 to 2,5	—	1,00	—	—
N06022	0,015	20,0 to 22,5	bal.[b]	2,0 to 6,0	0,50	0,08	12,5 to 14,5	2,5	—	0,02	0,02	—	—	—	0,35	2,5 to 3,5	—	—
N06030	0,03	28,0 to 31,5	bal.[b]	13,0 to 17,0	1,5	0,8	4,0 to 6,0	5,0	1,0 to 2,4	0,04	0,02	—	0,3 to 1,5	0,30 to 1,50	0,04	1,5 to 4,0	—	—
N06059	0,010	22,0 to 24,0	bal.[b]	1,5	0,5	0,10	15,0 to 16,5	0,3	—	0,015	0,005	—	—	—	—	—	—	0,1 to 0,4
N06060	0,03	19,0 to 22,0	54,0 to 60,0	bal.[b]	1,50	0,50	12,0 to 14,0	—	1,00	0,030	0,005	—	—	1,25	—	1,25	—	—
N06110	0,15	27,0 to 33,0	bal. [b]	—	—	—	8,00 to 12,0	12,0	—	—	—	1,50	—	2,00	—	4,00	—	1,50
N06250	0,02	20,0 to 23,0	50,0 to 53,0	bal.[b]	1,0	0,09	10,1 to 12,0	—	1,00	0,030	0,005	—	—	—	—	1,00	—	—
N06255	0,03	23,0 to 26,0	47,0 to 52,0	bal.[b]	1,00	1,0	6,0 to 9,0	—	1,20	0,03	0,03	0,69	—	—	—	3,0	—	—
N06625	0,10	20,0 to 23,0	bal.[b]	5,0	0,50	0,50	8,0 to 10,0	—	—	0,015	0,015	0,40	—	3,15 to 4,15	—	—	—	0,40
N06686	0,010	19,0 to 23,0	bal.[b]	5,0	0,75	0,08	15,0 to 17,0	—	—	0,04	0,02	0,02 to 0,25	—	—	—	3,0–4,4	—	—
N06950	0,015	19,0 to 21,0	50,0 min	15,0 to 20,0	1,00	1,00	8,0 to 10,0	2,5	0,5	0,04	0,015	—	0,50	—	0,04	1,0	—	—
N06952	0,03	23,0 to 27,0	48,0 to 56,0	bal.[b]	1,0	1,0	6,0 to 8,0	—	0,5 to 1,5	0,03	0,003	0,6 to 1,5	—	—	—	—	—	—
N06975	0,03	23,0 to 26,0	47,0 to 52,0	bal.[b]	1,0	1,0	5,0 to 7,0	—	0,70 to 1,20	0,03	0,03	0,70 to 1,50	—	—	—	—	—	—
N06985	0,015	21,0 to 23,5	bal.[b]	18,0 to 21,0	1,00	1,00	6,0 to 8,0	5,0	1,5 to 2,5	0,04	0,03	—	0,50	—	—	1,5	—	—

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] "Bal." is the balance of composition up to 100 %.

[c] w_{Nb} shall be eight times w_C (% mass fraction), with a maximum of 1 %.

[d] Additional elements by mass fraction: w_{Ta} = 0,2 % max and w_B = 0,006 % max.

Table D.3 *(continued)*

UNS	C	Cr	Ni	Fe	Mn	Si	Mo	Co	Cu	P	S	Ti	Nb + Ta	Nb	V	W	N	Al
	max[a]			max[a]	max[a]	max[a]		max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]		max[a]
	w_{C}	w_{Cr}	w_{Ni}	w_{Fe}	w_{Mn}	w_{Si}	w_{Mo}	w_{Co}	w_{Cu}	w_{P}	w_{S}	w_{Ti}	w_{Nb+Ta}	w_{Nb}	w_{V}	w_{W}	w_{N}	w_{Al}
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
N07022[d]	0,010	20,0 to 21,4	bal.[b]	1,8	0,5	0,08	15,5 to 17,4	1,0	0,5	0,025	0,015	—	—	—	—	0,8	—	0,5
N08007	0,07	19,0 to 22,0	27,5 to 30,5	bal.[b]	1,50	1,50	2,00 to 3,00	—	3,00 to 4,00	—	—	—	—	—	—	—	—	—
N08020	0,07	19,0 to 21,0	32,0 to 38,0	bal.[b]	2,00	1,00	2,0 to 3,0	—	3,00 to 4,00	0,045	0,035	—	—	8xC to 1,00[c]	—	—	—	—
N08024	0,03	22,5 to 25,0	35,0 to 40,0	bal.[b]	1,00	0,50	3,5 to 5,0	—	0,50 to 1,50	0,035	0,035	—	—	0,15 to 0,35	—	—	—	—
N08026	0,03	22,0 to 26,0	33,0 to 37,2	bal.[b]	1,00	0,50	5,00 to 6,70	—	2,00 to 4,00	0,03	0,03	—	—	—	—	—	—	—
N08028	0,03	26,0 to 28,0	29,5 to 32,5	bal.[b]	2,50	1,00	3,0 to 4,0	—	0,6 to 1,4	0,030	0,030	—	—	—	—	—	—	—
N08032	0,01	22	32	bal.[b]	0,4	0,3	4,3	—	—	0,015	0,002	—	—	—	—	—	—	—
N08042	0,03	20,0 to 23,0	40,0 to 44,0	bal.[b]	1,0	0,5	5,0 to 7,0	—	1,5 to 3,0	0,03	0,003	0,6 to 1,2	—	—	—	—	—	—
N08135	0,03	20,5 to 23,5	33,0 to 38,0	bal.[b]	1,00	0,75	4,0 to 5,0	—	0,70	0,03	0,03	—	—	—	—	0,2 to 0,8	—	—
N08535	0,030	24,0 to 27,0	29,0 to 36,5	bal.[b]	1,00	0,50	2,5 to 4,0	—	1,50	0,03	0,03	—	—	—	—	—	—	—
N08825	0,05	19,5 to 23,5	38,0 to 46,0	bal.[b]	1,00	0,5	2,5 to 3,5	—	1,5 to 3,0	—	0,03	0,6 to 1,2	—	—	—	—	—	0,2
N08826	0,05	19,5 to 23,5	38,0 to 46,0	22,0 min.	1,00	1,00	2,5 to 3,5	—	1,5 to 3,0	0,030	0,030	—	—	0,60 to 1,20	—	—	—	—
N08932	0,020	24,0 to 26,0	24,0 to 26,0	bal.[b]	2,0	0,50	4,7 to 5,7	—	1,0 to 2,0	0,025	0,010	—	—	—	—	—	0,17 to 0,25	—
N10002	0,08	14,5 to 16,5	bal.[b]	4,0 to 7,0	1,00	1,00	15,0 to 17,0	2,5	—	0,040	0,030	—	—	—	0,35	3,0 to 4,5	—	—
N10276	0,02	14,5 to 16,5	bal.[b]	4,0 to 7,0	1,00	0,08	15,0 to 17,0	2,5	—	0,030	0,030	—	—	—	0,35	3,0 to 4,5	—	—
CW12MW	0,12	15,5 to 17,5	bal.[b]	4,5 to 7,5	1,0	1,0	16,0 to 18,0	—	—	0,040	0,030	—	—	—	0,20 to 0,4	3,75 to 5,25	—	—

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] "Bal." is the balance of composition up to 100 %.

[c] w_{Nb} shall be eight times w_{C} (% mass fraction), with a maximum of 1 %.

[d] Additional elements by mass fraction: w_{Ta} = 0,2 % max and w_{B} = 0,006 % max.

Table D.3 *(continued)*

UNS	C	Cr	Ni	Fe	Mn	Si	Mo	Co	Cu	P	S	Ti	Nb + Ta	Nb	V	W	N	Al
	max[a]			max[a]	max[a]	max[a]		max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]		max[a]
	w_C	w_{Cr}	w_{Ni}	w_{Fe}	w_{Mn}	w_{Si}	w_{Mo}	w_{Co}	w_{Cu}	w_P	w_S	w_{Ti}	w_{Nb+Ta}	w_{Nb}	w_V	w_W	w_N	w_{Al}
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
CW6MC	0,06	20,0 to 23,0	bal.[b]	5,0	1,0	1,0	8,0 to 10,0	—	—	0,015	0,015	—	—	3,15 to 4,5	1,0	—	—	—

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] "Bal." is the balance of composition up to 100 %.

[c] w_{Nb} shall be eight times w_C (% mass fraction), with a maximum of 1 %.

[d] Additional elements by mass fraction: w_{Ta} = 0,2 % max and w_B = 0,006 % max.

Table D.4 — Chemical compositions of some copper nickel alloys (see A.4)

UNS	C max w_C %	Cu max w_{Cu} %	Ni[a] w_{Ni} %	Fe max w_{Fe} %	Mn max w_{Mn} %	Si max w_{Si} %	S[a] max w_S %
N04400	0,3	Bal.[b]	63,0 to 70,0	2,50	2,00	0,50	0,024
N04405	0,30	Bal.[b]	63,0 to 70,0	2,5	2,0	0,50	0,025 to 0,060

[a] Where a range is shown, it indicates min to max percentage mass fractions %.

[b] Bal. is the balance of composition up to 100 %.

Table D.5 — Chemical compositions of some ferritic stainless steels (see A.5)

UNS	C max w_C %	Cr w_{Cr} %	Ni max[a] w_{Ni} %	Mn max w_{Mn} %	Si max w_{Si} %	Mo w_{Mo} %	N max w_N %	P max w_P %	S max w_S %	Other max[a] w %
S40500	0,08	11,5 to 14,5	—	1,00	1,00	—	—	0,040	0,030	Al 0,10 to 0,30
S40900	0,08	10,5 to 11,75	0,50	1,00	1,00	—	—	0,045	0,045	Ti 6 × C to 0,75[b]
S43000	0,12	16,0 to 18,0	—	1,00	1,00	—	—	0,040	0,030	—
S43400	0,12	16,0 to 18,0	—	1,00	1,00	0,75 to 1,25	—	0,040	0,030	—
S43600	0,12	16,0 to 18,0	—	1,00	1,00	0,75 to 1,25	—	0,040	0,030	(Nb + Ta) 5 × C to 0,70[b]
S44200	0,20	18,0 to 23,0	—	1,00	1,00	—	—	0,040	0,030	—
S44400	0,025	17,5 to 19,5	1,00	1,00	1,00	1,75 to 2,50	0,025	0,040	0,030	[Nb + 0,2 × Ti+ 4(C + N)] 0,8[b]
S44500	0,02	19,0 to 21,0	0,60	1,00	1,00	—	0,03	0,040	0,012	Nb 10(C + N) to 0,8[b]; Cu 0,30 to 0,60
S44600	0,20	23,0 to 27,0	—	1,50	1,00	—	0,25	0,040	0,030	—
S44626	0,06	25,0 to 27,0	0,50	0,75	0,75	0,75 to 1,50	0,04	0,040	0,020	Ti 7 × (C + N) min[b] and 0,20 to 1,00, Cu 0,20
S44627	0,010	25,0 to 27,0	0,50	0,40	0,40	0,75 to 1,50	0,015	0,020	0,020	Nb 0,05 to 0,20, Cu 0,20
S44635	0,025	24,5 to 26,0	3,50 to 4,50	1,00	0,75	3,50 to 4,50	0,035	0,040	0,030	[Nb + 0,2 × Ti+ 4(C + N)] 0,8[b]
S44660	0,025	25,0 to 27,0	1,50 to 3,50	1,00	1,00	2,50 to 3,50	0,035	0,040	0,030	[Nb + 0,2 × Ti+ 4(C + N)] 0,8[b]
S44700	0,010	28,0 to 30,0	0,15	0,30	0,20	3,5 to 4,2	0,020	0,025	0,020	(C + N) 0,025 Cu 0,15
S44735	0,030	28,0 to 30,0	1,00	1,00	1,00	3,60 to 4,20	0,045	0,040	0,030	[Nb + Ta – 6 (C + N)] 0,20 to 1,00[b]
S44800	0,010	28,0 to 30,0	2,0 to 2,5	0,30	0,20	3,5 to 4,2	0,020	0,025	0,020	(C + N) 0,025[b], Cu 0,15

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] Expresses value(s) for element(s) by reference to the mass fraction of other elements, e.g. Ti 6 × C to 0,75 indicates a value for Ti between six times w_C (%) and 0,75 %.

Table D.6 — Chemical compositions of some martensitic stainless steels (see A.6)

UNS	Name	C max[a] w_C %	Cr max[a] w_{Cr} %	Ni max[a] w_{Ni} %	Mo max[a] w_{Mo} %	Si max[a] w_{Si} %	P max[a] w_P %	S max[a] w_S %	Mn max[a] w_{Mn} %	N w_N %	Other max[a] w %
S41000	—	0,15	11,5 to 13,5	—	—	1	0,04	0,03	1	—	—
S41425	—	0,05	12 to 15	4 to 7	1,5 to 2	0,5	0,02	0,005	0,5 to 1,0	0,06 to 0,12	Cu 0,3
S41426	—	0,03	11,5 to 13,5	4,5 to 6,5	1,5 to 3	0,5	0,02	0,005	0,5	—	Ti 0,01 to 0,5; V 0,5
S41427	—	0,03	11,5 to 13,5	4,5 to 6,0	1,5 to 2,5	0,50	0,02	0,005	1,0	—	Ti 0,01; V 0,01 to 0,50
S41429	—	0,1	10,5 to 14,0	2,0 to 3,0	0,4 to 0,8	1,0	0,03	0,03	0,75	0,03	b
S41500	—	0,05	11,5 to 14,0	3,5 to 5,5	0,5 to 1,0	0,6	0,03	0,03	0,5 to 1,0	—	—
S42000	—	0,15 min[a]	12 to 14	—	—	1	0,04	0,03	1	—	—
S42400	—	0,06	12,0 to 14,0	3,5 to 4,5	0,3 to 0,7	0,3 to 0,6	0,03	0,03	0,5 to 1,0	—	—
S42500	—	0,08 to 0,2	14 to 16	1 to 2	0,3 to 0,7	1	0,02	0,01	1	0,2	—
J91150	—	0,15	11,5 to 14	1	0,5	1,5	0,04	0,04	1	—	—
J91151	—	0,15	11,5 to 14	1	0,15 to 1	1	0,04	0,04	1	—	—
J91540	—	0,06	11,5 to 14	3,5 to 4,5	0,4 to 1	1	0,04	0,03	1	—	—
—	420 M	0,15 to 0,22	12 to14	0,5	—	1	0,02	0,01	0,25 to 1	—	Cu 0,25
K90941	—	0,15	8 to 10	—	0,9 to 1,1	0,5 to 1	0,03	0,03	0,3 to 0,6	—	—
—	L80 13 Cr	0,15 to 0,22	12 to 14	0,5	—	—	0,02	0,01	0,25 to 1	—	Cu 0,25

[a] Min indicates minimum percentage mass fraction. Where a range is shown, it indicates min to max percentage mass fractions.

[b] Additional elements, expressed as percentage mass fractions, are Al, 0,05 % max; B, 0,01 % max; Nb, 0,02 % max; Co, 1,0 % max; Cu, 0,5 % max; Se, 0,01 % max; Sn, 0,02 % max; Ti, 0,15 % to 0,75 %; V, 0,25 % max.

Table D.7 — Chemical compositions of some duplex stainless steels (see A.7 and D.3)

UNS	C max[a] w_C %	Cr max[a] w_{Cr} %	Ni max[a] w_{Ni} %	Mn max[a] w_{Mn} %	Si max[a] w_{Si} %	Mo max[a] w_{Mo} %	N max[a] w_N %	Cu max[a] w_{Cu} %	W max[a] w_W %	P max[a] w_P %	S max[a] w_S %	F_{PREN}
S31200	0,03	24,0 to 26,0	5,5 to 6,5	2	1	1,2 to 2,0	0,14 to 0,20	—	—	0,045	0,03	30 to 36
S31260	0,03	24,0 to 26,0	5,5 to 7,5	1	0,75	2,5 to 3,5	0,10 to 0,30	0,20 to 0,80	0,10 to 0,50	0,03	0,03	34 to 43
S31803	0,03	21,0 to 23,0	4,5 to 6,5	2	1	2,50 to 3,50	0,08 to 0,20	—	—	0,03	0,02	31 to 38
S32404	0,04	20,5 to 22,5	5,5 to 8,5	2	1	2,0 to 3,0	0,20	1,0 to 2,0	0,030	0,03	0,01	27 to 36
S32520	0,03	24,0 to 26,0	5,5 to 8,0	1,5	0,8	3,0 to 5,0	0,20 to 0,35	0,50 to 3,00	—	0,035	0,02	37 to 48
S32550	0,04	24,0 to 27,0	4,5 to 6,5	1,5	1	2,00 to 4,00	0,10 to 0,25	1,5 to 2,5	—	0,04	0,03	32 to 44
S32750	0,03	24,0 to 26,0	6,0 to 8,0	1,2	0,8	3,0 to 5,0	0,24 to 0,32	—	—	0,035	0,02	38 to 48
S32760	0,03	24,0 to 26,0	6,0 to 8,0	1	1	3,0 to 4,0	0,2 to 0,3	0,5 to 1,0	0,5 to 1,0	0,03	0,01	38 to 46
S32803[b]	0,01	28,0 to 29,0	3,0 to 4,0	0,5	0,5	1,8 to 2,5	0,025	—	—	0,02	0,005	34 to 38
S32900	0,2	23,0 to 28,0	2,5 to 5,0	1	0,75	1,00 to 2,00	—	—	—	0,04	0,03	26 to 35
S32950	0,03	26,0 to 29,0	3,50 to 5,20	2	0,6	1,00 to 2,50	0,15 to 0,35	—	—	0,035	0,01	32 to 43
S39274	0,03	24,0 to 26,0	6,0 to 8,0	1	0,8	2,50 to 3,50	0,24 to 0,32	0,2 to 0,8	1,5 to 2,5	0,03	0,02	39 to 47
S39277	0,025	24,0 to 26,0	6,5 to 8,0		0,8	3,0 to 4,0	0,23 to 0,33	1,2 to 2,0	0,80 to 1,20	0,025	0,002	39 to 46
J93370	0,04	24,5 to 26,5	4,75 to 6,0	1	1	1,75 to 2,25	—	2,75 to 3,25	—	0,04	0,04	30 to 34
J93345	0,08	20,0 to 27,0	8,9 to 11,0	1		3,0 to 4,5	0,10 to 0,30	—	—	0,04	0,025	31 to 47
J93380	0,03	24,0 to 26,0	6,0 to 8,5	1	1	3,0 to 4,0	0,2 to 0,3	0,5 to 1,0	0,5 to 1,0	0,03	0,025	38 to 46
J93404	0,03	24,0 to 26,0	6,0 to 8,0	1,5	1	4,0 to 5,0	0,10 to 0,30	—	—	—	—	39 to 47

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] Ratio Nb/(C + N) = 12 min; (C + N) = 0,030 % max; Nb = 0,15 % to 0,50 %.

Table D.8 — Chemical compositions of some precipitation-hardened stainless steels (see A.8)

UNS	C max w_C %	Cr w_{Cr} %	Ni w_{Ni} %	Mn max w_{Mn} %	Si max w_{Si} %	Mo w_{Mo} %	Nb w_{Nb} %	Ti w_{Ti} %	Cu w_{Cu} %	Al max[a] w_{Al} %	P max w_P %	S max w_S %	B w_B %	V w_V %
S66286	0,08	13,5 to 16,0	24,0 to 27,0	2,00	1,00	1,00 to 1,50	—	1,90 to 2,35	—	0,35	0,040	0,030	0,001 to 0,01	0,10 to 0,50
S15500	0,07	14,0 to 15,5	3,50 to 5,50	1,00	1,00	—	0,15 to 0,45	—	2,50 to 4,50	—	0,040	0,030	—	—
S15700	0,09	14,0 to 16,0	6,50 to 7,75	1,00	1,00	2,00 to 3,00	—	—	—	0,75 to 1,50	0,04	0,03	—	—
S17400	0,07	15,0 to 17,5	3,00 to 5,00	1,00	1,00	—	0,15 to 0,45	—	3,00 to 5,00	—	0,04	0,03	—	—
S45000	0,05	14,0 to 16,0	5,00 to 7,00	1,00	1,00	0,50 to 1,00	8 × C[b]	—	1,25 to 1,75	—	0,030	0,030	—	—

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] Indicates a minimum value for w_{Nb} of eight times the w_C (%).

Table D.9 — Chemical compositions of some precipitation-hardened nickel base alloys (see A.9)

UNS	C max[a] w_C %	Cr w_{Cr} %	Ni w_{Ni} %	Fe max[a] w_{Fe} %	Mn max[a] w_{Mn} %	Mo w_{Mo} %	Si max[a] w_{Si} %	Nb max[a] w_{Nb} %	Ti max[a] w_{Ti} %	Cu max[a] w_{Cu} %	Al max[a] w_{Al} %	Co max[a] w_{Co} %	N max[a] w_N %	B max[a] w_B %	P max[a] w_P %	S max[a] w_S %
N06625	0,10	20,0 to 23,0	Bal.[b]	5,0	0,50	8,0 to 10,0	0,50	3,15 to 4,15	0,40	—	0,40	—	—	—	0,015	0,015
N07022[e]	0,010	20,0 to 21,4	Bal.[b]	1,8	0,5	15,5 to 17,4	0,08	—	—	0,5	0,5	1,0	—	0,006	0,025	0,015
N07031	0,03 to 0,06	22,0 to 23,0	55,0 to 58,0	Bal.[b]	0,20	1,7 to 2,3	0,20	—	2,10 to 2,60	0,60 to 1,20	1,00 to 1,70	—	—	0,003 to 0,007	0,015	0,015
N07048	0,015	21,0 to 23,5	Bal.[b]	18,0 to 21,0	1,0	5,0 to 7,0	0,10	0,5	1,5 to 2,0	1,5 to 2,2	0,4 to 0,9	2,0	—	—	0,02	0,01
N07090	0,13	18,0 to 21,0	Bal.[b]	3,0	1,0	—	—	—	1,8 to 3,0	—	0,8 to 2,0	15,0 to 21,0	—	—	—	—
N07626	0,05	20,0 to 23,0	Bal.[b]	6,0	0,50	8,0 to 10,0	0,50	4,50 to 5,50	0,60	0,50	0,40 to 0,80	1,00	0,05	—	0,02	0,015
N07716	0,03	19,0 to 22,0	57,0 to 63,0	Bal.[b]	0,20	7,0 to 9,5	0,20	2,75 to 4,00	1,00 to 1,60	—	0,35	—	—	—	0,015	0,01
N07718	0,08	17,0 to 21,0	50,0 to 55,0	Bal.[b]	0,35	2,8 to 3,3	0,35	4,75 to 5,50	0,65 to 1,15	0,30	0,20 to 0,80	1,00	—	0,006	0,015	0,015
N07725	0,03	19,0 to 22,5	55,0 to 59,0	Bal.[b]	0,35	7,00 to 9,50	0,20	2,75 to 4,00	1,00 to 1,70	—	0,35	—	—	—	0,015	0,01
N07773	0,03	18,0 to 27,0	45,0 to 60,0	Bal.[b]	1,00	2,5 to 5,5	0,50	2,5 to 6,0	2,0	—	2,0	—	—	—	0,03	0,01
N07924[c]	0,020	20,5 to 22,5	52,0 min	7,0 to 13,0	0,20	5,5 to 7,0	0,20	2,75 to 3,5	1,0 to 2,0	1,0 to 4,0	0,75	3,0	0,20	—	0,030	0,005
N09777	0,03	14,0 to 19,0	34,0 to 42,0	Bal.[b]	1,00	2,5 to 5,5	0,50	0,1	—	—	0,35	—	—	—	0,03	0,01
N09925	0,03	19,5 to 23,5	38,0 to 46,0	22,0 min	1,00	2,50 to 3,50	0,50	0,50	1,90 to 2,40	1,50 to 3,00	0,10 to 0,50	—	—	—	—	0,03

[a] Min indicates minimum percentage mass fraction. Where a range is shown, it indicates min to max percentage mass fractions.

[b] "Bal." is the balance of composition up to 100 %.

[c] Additional elements by mass fraction: w_W = 0,5 % max and w_{Mg} = 0,005 0 % max.

[d] Additional elements by mass fraction: w_W = 1,0 % max.

[e] Additional elements by mass fraction: w_{Ta} = 0,2 % max and w_W = 0,8 % max.

Table D.9 *(continued)*

UNS	C	Cr	Ni	Fe	Mn	Mo	Si	Nb	Ti	Cu	Al	Co	N	B	P	S
	max[a]			max[a]	max[a]		max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]	max[a]
	w_C	w_{Cr}	w_{Ni}	w_{Fe}	w_{Mn}	w_{Mo}	w_{Si}	w_{Nb}	w_{Ti}	w_{Cu}	w_{Al}	w_{Co}	w_N	w_B	w_P	w_S
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
N09935[d]	0,030	19,5 to 22,0	34,0 to 38,0	Bal.[b]	1,0	3,0 to 5,0	0,50	0,20 to 1,0	1,80 to 2,50	1,0 to 2,0	0,50	1,0	—	—	0,025	0,001
N09945	0,005 to 0,04	19,5 to 23,0	45,0 to 55,0	Bal.[b]	1,0	3,0 to 4,0	0,5	2,5 to 4,5	0,5 to 2,5	1,5 to 3,0	0,01 to 0,7	—	—	—	0,03	0,03
N05500	0,25	—	63,0 to 70,0	2,00	1,50	—	0,50	—	0,35 to 0,85	Bal.[b]	2,30 to 3,15	—	—	—	—	—
N07750	0,08	14,0 to 17,0	70,0 min	5,0 to 9,0	1,00	—	0,50	0,70 to 1,20	2,25 to 2,75	0,5	0,40 to 1,00	—	—	—	—	0,01

[a] Min indicates minimum percentage mass fraction. Where a range is shown, it indicates min to max percentage mass fractions.

[b] “Bal.” is the balance of composition up to 100 %.

[c] Additional elements by mass fraction: w_W = 0,5 % max and w_{Mg} = 0,005 0 % max.

[d] Additional elements by mass fraction: w_W = 1,0 % max.

[e] Additional elements by mass fraction: w_{Ta} = 0,2 % max and w_W = 0,8 % max.

Table D.10 — Chemical compositions of some cobalt-based alloys (see A.10)

UNS	C max[a] w_C %	Cr w_{Cr} %	Ni w_{Ni} %	Co w_{Co} %	Fe max[a] w_{Fe} %	Mn max[a] w_{Mn} %	Si max[a] w_{Si} %	Mo w_{Mo} %	B max w_B %	P max[a] w_P %	S max w_S %	Be max w_{Be} %	Ti max[a] w_{Ti} %	W w_W %	N w_N %
R30003	0,15	19,0 to 21,0	15,0 to 16,0	39,0 to 41,0	Bal.[b]	1,5 to 2,5	—	6,0 to 8,0	—	—	—	1,00	—	—	—
R30004	0,17 to 0,23	19,0 to 21,0	12,0 to 14,0	41,0 to 44,0	Bal.[b]	1,35 to 1,80	—	2,0 to 2,8	—	—	—	0,06	—	2,3 to 3,3	—
R30035	0,025	19,0 to 21,0	33,0 to 37,0	Bal.[b]	1,0	0,15	0,15	9,0 to 10,5	—	0,015	0,01	—	1,00	—	—
R30159	0,04	18,0 to 20,0	Bal.[b]	34,0 to 38,0	8,00 to 10,00	0,20	0,20	6,00 to 8,00	0,03	0,02	0,01	—	2,50 to 3,25	—	—
R30260[c]	0,05	11,7 to 12,3	Bal.[b]	41,0 to 42,0	9,8 to 10,4	0,40 to 1,10	0,20 to 0,60	3,70 to 4,30	—	—	—	0,20 to 0,30	0,80 to 1,20	3,60 to 4,20	—
R31233	0,02 to 0,10	23,5 to 27,5	7,0 to 11,0	Bal.[b]	1,0 to 5,0	0,1 to 1,5	0,05 to 1,00	4,0 to 6,0	—	0,03	0,02	—	—	1,0 to 3,0	0,03 to 0,12
R30605	0,05 to 0,15	19,0 to 21,0	9,0 to 11,0	Bal.[b]	3,0	2,0	1,00	—	—	—	—	—	—	13,0 nom.	—

a Where a range is shown, it indicates min to max percentage mass fractions.

b "Bal." is the balance of composition up to 100 %.

c Additional elements, expressed as percentage mass fractions, are Nb, 0,1 % max; and Cu, 0,30 % max.

Table D.11 — Chemical compositions of some titanium alloys (see A.11)

UNS	Al max[a] w_{Al} %	V max[a] w_V %	C max[a] w_C %	Cr max[a] w_{Cr} %	Fe max[a] w_{Fe} %	H max[a] w_H %	Mo max[a] w_{Mo} %	N max[a] w_N %	Ni w_{Ni} %	Sn max[a] w_{Sn} %	Zr max[a] w_{Zr} %	Other max[a] w %	Ti
R50250	—	—	0,10	—	0,20	0,015	—	0,03	—	—	—	O 0,18	Bal.[b]
R50400	—	—	0,10	—	0,30	0,015	—	0,03	—	—	—	O 0,25	Bal.[b]
R56260	6	—		—	—	—	6	—	—	2	4	—	Bal.[b]
R53400	—	—	0,08	—	0,30	0,015	0,2 to 0,4	0,03	0,6 to 0,9	—	—	O 0,25	Bal.[b]
R56323	2,5 to 3,5	2,0 to 3,0	0,08	—	0,25	0,015	—	0,03	—	—	—	O 0,15, Ru 0,08 to 0,14	Bal.[b]
R56403	5,5 to 6,75	3,5 to 4,5	0,10	—	0,40	0,0125	—	0,05	0,3 to 0,8	—	—	O 0,20, Pd 0,04 to 0,08, Residuals[c]	Bal.[b]
R56404	5,5 to 6,5	3,5 to 4,5	0,08	—	0,25	0,015	—	0,03	—	—	—	O 0,13, Ru 0,08 to 0,14	Bal.[b]
R58640	3	8	—	6	—	—	4	—	—	—	4	—	Bal.[b]

[a] Where a range is shown, it indicates min to max percentage mass fractions.

[b] "Bal." is the balance of composition up to 100 %.

[c] Residuals each 0,1 % max mass fraction, total 0,4 % ma. mass fraction.

Table D.12 — Chemical composition of R05200 tantalum alloy (see A.11)

UNS	C max w_C %	Co max w_{Co} %	Fe max w_{Fe} %	Si max w_{Si} %	Mo max w_{Mo} %	W max w_W %	Ni max w_{Ni} %	Ti max w_{Ti} %	Other max w %	Ta
R05200[a]	0,01	0,05	0,01	0,005	0,01	0,03	0,01	0,01	0,015	Bal.[b]

[a] Additional elements, expressed as percentage mass fractions, are Nb, 0,05 % max; H, 0,001 % max; and O, 0,015 % max.

[b] "Bal." is the balance of composition up to 100 %.

Annex E
(informative)

Nominated sets of test conditions

The nominated sets of test conditions shown in Table E.1 can be used to help determine acceptable limits for the application of CRAs and other alloys.

The “levels” shown in the table were previously established in NACE MR0175. These are retained to provide continuity of terminology with that of the data set on which many of the environmental limits for materials types and individual alloys shown in the tables of Annex A are based.

Table E.1 — Test conditions

Environmental factor	Specific test conditions						
	Level I	**Level II**	**Level III**	**Level IV**	**Level V**	**Level VI**	**Level VII**
Temperature °C (°F)	25 ± 3 (77 ± 5)	Test in accordance with B.4	Test in accordance with B.4 and B.8	90 ± 5 (194 ± 9)	150 ± 5 (302 ± 9)	175 ± 5 (347 ± 9)	205 ± 5 (401 ± 9)
p_{CO2} MPa (psi)	Test conditions defined and documented by the user			0,7 (100)	1,4 (200)	3,5 (500)	3,5 (500)
p_{H2S} MPa (psi)				0,003 (0,4)	0,7 (100)	3,5 (500)	3,5 (500)
NaCl minimum percentage mass fraction				15	15	20	25
Calculated Cl^- [a] milligrams per litre				101 000	101 000	139 000	180 000
pH				See B.3.5.1 and B.3.5.2			
S^0				Optional (see B.7)			
Galvanic coupling to steel				Optional; see Clause B.8			
Other				See B.3.5.1			

[a] The equivalent mg/l concentration for ambient temperature used in Tables A.1 to A.42 was calculated from the corresponding percentage mass fraction value.[18]

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