INTERNATIONAL STANDARD

NACE MR0175/ ISO 15156-1

Item No. 21306

First edition

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

Part 1:

General principles for selection of cracking-resistant materials

Reference number
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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

Attention is drawn to the possibility that some of the elements of this part of NACE MR0175/ISO 15156 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard NACE MR0175/ISO 15156-1 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*.

NACE MR0175/ISO 15156 consists of the following parts, under the general title *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production*:

— *Part 1: General principles for selection of cracking-resistant materials*

— *Part 2: Cracking-resistant carbon and low alloy steels*

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

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Introduction

The consequences of sudden failures of metallic components used in the oil and gas field, and associated with their exposure to H_2S-containing production fluids, led to the preparation of the first edition of NACE Standard MR0175. This standard was published in 1975 by the National Association of Corrosion Engineers, now known as NACE International.

The original and subsequent editions of NACE Standard 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. NACE Standard MR0175 is complemented by NACE Standard TM0177 and NACE Standard TM0284.

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

With the cooperation of NACE and EFC, ISO/TC 67 formed Working Group 7 to prepare ISO 15156. The Working Group are to promote the collection, review and, where appropriate, publication of field experience and laboratory test data related to the cracking resistance of metallic materials in H_2S-containing environments.

This part of NACE MR0175/ISO 15156 utilizes the above sources to provide requirements and recommendations for materials qualification and selection for safe application in environments containing wet H_2S in oil and gas production systems.

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INTERNATIONAL STANDARD

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

Part 1:
General principles for selection of cracking-resistant materials

1 Scope

This part of NACE MR0175/ISO 15156 describes general principles and gives requirements and recommendations for the selection and qualification of metallic materials for service in equipment used in oil and gas production and in natural gas sweetening plants in H_2S-containing environments, where the failure of such equipment could pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help to avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the material requirements given in the appropriate design codes, standards or regulations.

This part of NACE MR0175/ISO 15156 addresses all mechanisms of cracking that can be caused by H_2S, including sulfide stress cracking, stress corrosion cracking, hydrogen-induced cracking and stepwise cracking, stress-oriented hydrogen-induced cracking, soft zone cracking and galvanically induced hydrogen stress cracking.

Table 1 provides a non-exhaustive list of equipment to which this part of NACE MR0175/ISO 15156 is applicable, including permitted exclusions.

This part of NACE MR0175/ISO 15156 applies to the qualification and selection of materials for equipment designed and constructed using conventional elastic design criteria.

This part of NACE MR0175/ISO 15156 is not necessarily applicable to equipment used in refining or downstream processes and equipment.

CAUTION—Metallic materials selected or qualified using NACE MR0175/ISO 15156 are resistant to cracking in defined H_2S-containing environments in oil and gas production, but are not necessarily immune under all service conditions.

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Table 1 — List of equipment

NACE MR0175/ISO 15156-1 is applicable to materials used for the following equipment	Permitted exclusions
Drilling, well construction and well servicing equipment	Equipment only exposed to drilling fluids of controlled composition[a] Drill bits Blowout preventer (BOP) shear blades[b] Drilling riser systems Work strings Wire line and wire line equipment[c] Surface and intermediate casing
Wells, including subsurface equipment, gas lift equipment, wellheads and christmas trees	Sucker rod pumps and sucker rods[d] Electrical submersible pumps Other artificial lift equipment Slips
Flowlines, gathering lines, field facilities and field processing plants	Crude oil storage and handling facilities operating at gauge pressure below 4,3 bar (65 psi)
Sour-water handling equipment	
Natural gas treatment plants	
Transportation pipelines for liquids, gases and multiphase fluids	Lines handling gas prepared for domestic use

[a] Given the high strength often needed, drilling equipment may not comply with the requirements of this part of NACE MR0175/ISO 15156. In such cases the primary means for avoiding SSC is control of the drilling or well-servicing environment. As service stresses and material hardness increase, drilling fluid control becomes increasingly important. Take care to control the drilling environment by maintenance of drilling fluid hydrostatic head and fluid density to minimize formation fluid in-flow and by one or more of the following procedures: 1) maintenance of pH 10 or higher to neutralize H_2S in the drilled formation; 2) use of chemical sulfide scavengers; 3) use of a drilling fluid in which oil is the continuous phase.

[b] High strength steels used for blowout preventer (BOP) shear blades are highly susceptible to SSC.

[c] Wireline lubricators and lubricator connecting devices shall comply.

[d] NACE Standard MR0176 applies to sucker rod pumps and sucker rods.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of NACE MR0175/ISO 15156. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of NACE MR0175/ISO 15156 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

NACE MR0175/ISO 15156-2, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low alloy steels*

NACE MR0175/ISO 15156-3, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

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3 Terms and definitions

For the purposes of this part of NACE MR0175/ISO 15156, the following terms and definitions apply.

3.1
blowout preventer
BOP
mechanical device capable of containing pressure, used for control of well fluids and drilling fluids during drilling operations

3.2
braze, verb
join metals by flowing a thin layer (of capillary thickness) of a lower-melting-point non-ferrous filler metal in the space between them

3.3
carbon steel
alloy of carbon and iron containing up to carbon and up to manganese and residual quantities of other elements, except those intentionally added in specific quantities for deoxidation (usually silicon and/or aluminum)

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

3.4
christmas tree
equipment at a wellhead for the control of fluid production or injection

3.5
cold work, verb
deform metal plastically under conditions of temperature and strain rate that induce strain hardening, usually, but not necessarily, conducted at room temperature

3.6
corrosion-resistant alloy
CRA
alloy intended to be resistant to general and localized corrosion of oilfield environments that are corrosive to carbon steels

3.7
ferrite
body-centred cubic crystalline phase of iron-based alloys

3.8
ferritic steel
steel whose microstructure at room temperature consists predominantly of ferrite

3.9
hardness
resistance of metal to plastic deformation, usually measured by indentation

3.10
heat-affected zone
HAZ
that portion of the base metal that is not melted during brazing, cutting or welding, but whose microstructure and properties are altered by the heat of these processes

3.11
heat treatment
heating and cooling a solid metal or alloy in such a way as to obtain desired properties

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

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3.12
hydrogen-induced cracking
HIC
planar cracking that occurs in carbon and low alloy steels when atomic hydrogen diffuses into the steel and then combines to form molecular hydrogen at trap sites

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

3.13
hydrogen stress cracking
HSC
cracking that results from the presence of hydrogen in a metal and tensile stress (residual and/or applied)

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

3.14
low alloy steel
steel with a total alloying element content of less than about 5%, but more than specified for carbon steel

3.15
microstructure
structure of a metal as revealed by microscopic examination of a suitably prepared specimen

3.16
partial pressure
pressure that would be exerted by a single component of a gas if present alone, at the same temperature, in the total volume occupied by the mixture

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

3.17
residual stress
stress present in a component free of external forces or thermal gradients

3.18
soft zone cracking
SZC
form of SSC that may occur when a steel contains a local “soft zone” of low yield strength material

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

3.19
sour service
exposure to oilfield environments that contain H_2S and can cause cracking of materials by the mechanisms addressed by this part of NACE MR0175/ISO 15156

3.20
stepwise cracking
SWC
cracking that connects hydrogen-induced cracks on adjacent planes in a steel

NOTE This term describes the crack appearance. The linking of hydrogen-induced cracks to produce stepwise cracking is dependent upon local strain between the cracks and embrittlement of the surrounding steel by dissolved hydrogen. HIC/SWC is usually associated with low-strength plate steels used in the production of pipes and vessels.

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3.21
stress corrosion cracking
SCC
cracking of metal involving anodic processes of localized corrosion and tensile stress (residual and/or applied) in the presence of water and H_2S

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

3.22
stress-oriented hydrogen-induced cracking
SOHIC
staggered small cracks formed approximately perpendicular to the principal stress (residual or applied) resulting in a “ladder-like” crack array linking (sometimes small) pre-existing HIC cracks

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

3.23
sulfide stress cracking
SSC
cracking of metal involving corrosion and tensile stress (residual and/or applied) in the presence of water and H_2S

NOTE SSC is a form of hydrogen stress cracking (HSC) and involves embrittlement of the metal by atomic hydrogen that is produced by acid corrosion on the metal surface. Hydrogen uptake is promoted in the presence of sulfides. The atomic hydrogen can diffuse into the metal, reduce ductility and increase susceptibility to cracking. High strength metallic materials and hard weld zones are prone to SSC.

3.24
weld, verb
join two or more pieces of metal by applying heat and/or pressure with or without filler metal, to produce a union through localized fusion of the substrates and solidification across the interfaces

3.25
yield strength
stress at which a material exhibits a specified deviation from the proportionality of stress to strain

NOTE The deviation is expressed in terms of strain by either the offset method (usually at a strain of 0,2%) or the total-extension-under-load method (usually at a strain of 0,5%).

4 Abbreviated terms

BOP	Blowout preventer
CRA	Corrosion resistant alloy
HAZ	Heat-affected zone
HIC	Hydrogen-induced cracking
HSC	Hydrogen stress cracking
SCC	Stress corrosion cracking
SOHIC	Stress-oriented hydrogen-induced cracking

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SWC Stepwise cracking

SSC Sulfide stress cracking

SZC Soft zone cracking.

5 General principles

Users of NACE MR0175/SO 15156 (all parts) shall first assess the conditions to which the materials they wish to select may be exposed. Having evaluated, defined and documented these conditions in accordance with NACE MR0175/ISO 15156-1, materials selection is made following the requirements and recommendations of the appropriate part of NACE MR0175/ISO 15156.

The use of other parts of NACE MR0175/ISO 15156 may require exchange of information (for example concerning required or suitable service conditions) between the equipment user and the equipment or materials supplier.

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

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

The equipment user shall determine whether or not the service conditions are such that this part of NACE MR0175/ISO 15156 applies. If necessary the equipment user shall advise other parties of the service conditions.

This part of NACE MR0175/ISO 15156 applies to the qualification and selection of materials for equipment designed and constructed using conventional elastic design criteria. For designs utilizing plastic criteria (e.g. strain-based and limit-states designs) use of this part of NACE MR0175/ISO 15156 may not be appropriate and the equipment user shall assess the need for other requirements.

6 Evaluation and definition of service conditions to enable material selection

6.1 Before selecting or qualifying materials using other parts of NACE MR0175/ISO 15156, the user of the equipment shall define, evaluate and document the service conditions to which materials may be exposed for each application. The defined conditions shall include both intended exposures and unintended exposures which may result from the failure of primary containment or protection methods. Particular attention shall be paid to the quantification of those factors known to affect the susceptibility of materials to cracking caused by H_2S.

Factors, other than material properties, known to affect the susceptibility of metallic materials to cracking in H_2S service include: H_2S partial pressure, *in situ* pH, the concentration of dissolved chloride or other halide, the presence of elemental sulfur or other oxidant, temperature, galvanic effects, mechanical stress, and time of exposure to contact with a liquid water phase.

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

a) to provide the basis for selection of pre-qualified SSC/SCC resistant materials (see clause 7);

b) to provide the basis for qualification and selection based upon documented field experience (see 8.2);

c) to define the laboratory test requirements to qualify a material for H_2S service with respect to one or more of SSC, SCC, HIC, SOHIC, SZC and/or galvanically induced HSC (see 8.3);

d) to provide the basis for the reassessment of the suitability of existing alloys of construction, using clause 7, 8.2 and/or 8.3, in the event of changes to the actual or intended service conditions.

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

SSC-resistant carbon and low alloy steels may be selected from the pre-qualified materials identified in NACE MR0175/ISO 15156-2.

SSC, SCC-resistant CRAs and other alloys may be selected from the pre-qualified materials identified in NACE MR0175/ISO 15156-3.

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

NOTE The experience reflected in the requirements of NACE Standard MR0175 is included in the lists of pre-qualified materials of NACE MR0175/ISO 15156-2 and NACE MR0175ISO 15156-3.

8 Qualification of materials for H_2S service

8.1 Material description and documentation

The material to be qualified shall be described and documented, such that those of its properties likely to affect performance in H_2S-containing media are defined. The tolerances or ranges of properties that can occur within the material shall be described and documented.

Metallurgical properties known to affect performance in H_2S-containing environments include: chemical composition, method of manufacture, product form, strength, hardness, amount of cold work, heat-treatment condition and microstructure.

8.2 Qualification based upon field experience

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

8.3 Qualification based upon laboratory testing

8.3.1 General

Laboratory testing can only approximate field service.

Laboratory testing in accordance with the NACE MR0175/ISO 15156 (all parts) may be used for the following:

— to qualify metallic materials for their resistance to SSC and/or SCC under service conditions up to the limits that apply to pre-qualified materials of similar types listed in NACE MR0175/ISO 15156-2 and NACE MR0175/ISO 15156-3;

— to qualify metallic materials for their resistance to SSC and/or SCC under service conditions with other limits;

EXAMPLE Qualification up to a higher than normally acceptable level of H_2S, to a lower than normally required test stress or to revised temperature limit(s) or to a lower pH.

— to qualify carbon and low alloy steels with respect to their resistance to HIC, SOHIC or SZC,

— to qualify corrosion-resistant or other alloys with respect to their resistance to galvanically induced HSC,

— to provide qualification data for a material not currently shown as pre-qualified in NACE MR0175/ISO 15156-2 and NACE MR0175/ISO 15156-3 in such a form that it may be considered for inclusion at a later date.

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8.3.2 Sampling of materials for laboratory testing

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

The test samples shall be representative of the commercial product.

For multiple batches of a material produced to a single specification, an assessment shall be made of the properties that influence cracking behaviour in H_2S-containing environments (see 8.1). The distributions of these properties shall be considered when selecting samples for testing according to the requirements of NACE MR0175/ISO 15156-2 and NACE MR0175/ISO 15156-3. The materials in the metallurgical condition that has the greatest susceptibility to cracking in H_2S service shall be used for the selection of the test samples.

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

8.3.3 Selection of laboratory test methods

For carbon and low alloy steels, test methods for SSC, HIC, SOHIC and/or SZC shall be selected from NACE MR0175/ISO 15156-2 as required.

For CRAs and other alloys, test methods for SSC, SCC and galvanically induced HSC shall be selected from NACE MR0175/ISO 15156-3 as required.

8.3.4 Conditions to be applied during testing

For qualification of carbon and low alloy steels, for general sour service applications or for more restricted application ranges, standardized test environments and mechanical test conditions shall be chosen from those described in NACE MR0175/ISO 15156-2.

For qualification of CRAs or other alloys for the restricted application ranges appropriate to each alloy type the standardized test environments and mechanical test conditions shall be chosen from those described in NACE MR0175/ISO 15156-3.

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

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

8.3.5 Acceptance criteria

Test acceptance criteria shall be as defined for each test method in NACE MR0175/ISO 15156-2 and NACE MR0175/ISO 15156-3.

9 Report of the method of selection or qualification

Materials selected or qualified in accordance with this part of NACE MR0175/ISO 15156 shall have the method of selection documented by reporting item a) from the following list, together with one other item [b), c) or d)] from the list. The equipment user shall be responsible for ensuring that the required documentation is prepared.

a) For all materials, evaluation of the service conditions (see 6.1).

b) For a material selected as pre-qualified with respect to SSC and/or SCC (see clause 7), documentation making reference to the relevant subclauses of NACE MR0175/ISO 15156-2 or NACE MR0175/ISO 15156-3.

c) For a material selected on the basis of field experience, documentation describing

   1) the mechanism(s) of cracking for which qualification and selection has been made,

   2) the material used (see 8.1),

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3) the field experience (see 8.2).

d) For a material selected on the basis of qualification by laboratory testing, a test report describing

1) the mechanism(s) of cracking for which qualification and selection has been made,

2) the material selected for laboratory testing (see 8.1),

3) the selection, sampling and preparation of test specimens (see 8.3.2),

4) the justification of the test environment and physical test conditions for qualification (see 8.3.3),

5) the test results that demonstrate compliance with NACE MR0175/ISO 15156-2 or NACE MR0175/ISO 15156-3 (see 8.3).

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[1] ANSI NACE[1] Standard MR0175, *Metals for sulfide stress cracking and stress corrosion cracking resistance in sour oilfield environments*

[2] ANSI NACE Standard TM0177, *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H_2S environments*

[3] ANSI NACE Standard TM0284, *Evaluation of pipeline and pressure vessel steels for resistance to hydrogen induced cracking*

[4] NACE Standard MR0176, *Metallic materials for sucker-rod pumps for corrosive oilfield environments*

[5] EFC[2] Publication 16, *Guidelines on materials requirements for carbon and low alloy steels for H_2S containing environments in oil and gas production*

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

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Addendum

The following editorial changes have been made to the NACE version of the original ISO standard:

1. Designations of NACE standards in the Introduction, page v, and in the Bibliography, page 10, have been corrected to read:

NACE Standard MR0175, NACE Standard TM0177, NACE Standard TM0284.

2. The NACE designation has been added for the NACE nationally adopted version, so that “ISO 15156” reads “NACE MR0175/ISO 15156” on the cover page, Foreword, and pages 1-4 and 6-10.

3. In the Bibliography, the designation of NACE Standard MR0176 has been corrected to reflect that is not an ANSI standard.

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

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

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

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

Reference number
NACE MR0175/
ISO 15156-2:2003(E)

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Foreword

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

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

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

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

NACE MR0175/ISO 15156-2 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*.

NACE MR0175/ISO 15156 consists of the following parts, under the general title *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production*:

— *Part 1: General principles for selection of cracking-resistant materials*

— *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*

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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. NACE MR0175 is complemented by NACE TM0177-96 and NACE TM0284 test methods.

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

This part of ISO NACE MR0175/15156 utilizes 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.

Changes will be incorporated into this part of NACE MR0175/ISO 15156 by amendment or revision in accordance with *Interpretation and maintenance of NACE MR0175/ISO 15156* by ISO/TC 67/WG 7, copies of which can be obtained from the ISO/TC 67 Secretariat. Experts from both NACE and EFC are members of ISO/TC 67/WG 7.

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

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

WARNING — Carbon and low alloy steels and cast irons selected using this part of NACE MR0175/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 carbon and low alloy steels and cast irons suitable for the intended service.

1 Scope

This part of NACE MR0175/ISO 15156 gives requirements and recommendations for the selection and qualification of carbon and low alloy steels for service in equipment, used in oil and natural gas production and natural gas treatment plants in H_2S-containing environments, whose failure could pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help to avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the materials' requirements of the appropriate design codes, standards or regulations.

This part of NACE MR0175/ISO 15156 addresses the resistance of these steels to damage that may be caused by sulfide stress-cracking (SSC) and the related phenomena of stress-oriented hydrogen-induced cracking (SOHIC) and soft-zone cracking (SZC).

This part of NACE MR0175/ISO 15156 also addresses the resistance of these steels to hydrogen-induced cracking (HIC) and its possible development into stepwise cracking (SWC).

This part of NACE MR0175/ISO 15156 is only concerned 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 NACE MR0175/ISO 15156 is applicable, including permitted exclusions.

This part of NACE MR0175/ISO 15156 applies to the qualification and selection of materials for equipment designed and constructed using conventional elastic design criteria. For designs utilizing plastic criteria (e.g. strain-based and limit-state designs), see NACE MR0175/ISO 15156-1:2001, Clause 5.

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

This part of NACE MR0175/ISO 15156 is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

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Table 1 — List of equipment

NACE MR0175/ISO 15156 is applicable to materials used for the following equipment	Permitted exclusions
Drilling, well construction and well-servicing equipment	Equipment only exposed to drilling fluids of controlled composition[a] Drill bits Blowout Preventer (BOP) shear blades[b] Drilling riser systems Work strings 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)
Natural gas treatment plants	
Transportation pipelines for liquids, gases and multiphase fluids	Lines handling gas prepared for general commercial and domestic use
For all equipment above	Components loaded only in compression

[a] See A.2.3.2.3 for more information.

[b] See 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 referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

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

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

ISO 6892, *Metallic materials — Tensile testing at ambient temperature*

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

NACE MR0175/ISO 15156-1:2001, Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials

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NACE TM0177-96[1], *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H_2S environments*

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

EFC Publications Number 16[2], *Guidelines on materials requirements for carbon and low alloy steels for H_2S-containing environments in oil and gas production*

SAE AMS-S-13165[3], *Shot peening of metal parts*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in NACE MR0175/ISO 15156-1 and the following apply.

3.1
Brinell hardness
HBW
hardness value, measured in accordance with ISO 6506-1, normally using a 10-mm diameter tungsten ball and a force of 29,42 kN

3.2
bubble-point pressure
p_B
pressure under which gas bubbles will form in a liquid at a particular operating temperature

NOTE See C.2.

3.3
burnish
process of smoothing surfaces using frictional contact between the material and some other hard pieces of material, such as hardened steel balls

3.4
casting
metal that is obtained at or near its finished shape by the solidification of molten metal in a mould

3.5
cast iron
iron-carbon alloy containing approximately 2 % to 4 % carbon

3.5.1
grey cast iron
cast iron that displays a grey fracture surface due to the presence of flake graphite

3.5.2
white cast iron
cast iron that displays a white fracture surface due to the presence of cementite

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1) NACE International, 1440 South Creek Dr., Houston, Texas 77084-4906, USA

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

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

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3.5.3
malleable cast iron
white cast iron that is thermally treated to convert most or all of the cementite to graphite (temper carbon)

3.5.4
ductile cast iron
nodular cast iron
cast iron that has been treated while molten with an element (usually magnesium or cerium) that spheroidizes the graphite

3.6
cementite
microstructural constituent of steels composed principally of iron carbide (Fe_3C)

3.7
cold working
cold deforming
cold forging
cold forming
deforming metal plastically under conditions of temperature and strain rate that induce strain-hardening, usually, but not necessarily, conducted at room temperature

3.8
fitness-for-purpose
suitability for use under the expected service conditions

3.9
free-machining steel
steel to which elements such as sulfur, selenium and lead have been added intentionally to improve machineability

3.10
lower critical temperature
temperature of a ferrous metal at which austenite begins to form during heating or at which the transformation of austenite is completed during cooling

3.11
nitriding
case-hardening process in which nitrogen is introduced into the surface of metallic materials (most commonly ferrous alloys)

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

3.12
normalizing
heating a ferrous metal to a suitable temperature above the transformation range (austenitizing), holding at temperature for a suitable time and then cooling in still air (or protective atmosphere) to a temperature substantially below the transformation range

3.13
plastically deformed
permanently deformed by stressing beyond the limit of elasticity, i.e. the limit of proportionality of stress to strain

3.14
pressure-containing parts
those parts whose failure to function as intended would result in a release of retained fluid to the atmosphere

NOTE Examples are valve bodies, bonnets and stems.

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3.15
quenched and tempered
quench hardened and then tempered

3.16
Rockwell C hardness
HRC
hardness value, measured in accordance with ISO 6508, obtained using a diamond cone indenter and a force of 1 471 N

3.17
shot peening
inducing compressive stresses in the surface layer of a material by bombarding it with a selected medium (usually round steel shot) under controlled conditions

3.18
stress relieving
heating a metal to a suitable temperature, holding at that temperature long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses

3.19
tempering
heat treatment by heating to a temperature below the lower critical temperature, for the purpose of decreasing the hardness and increasing the toughness of hardened steel, hardened cast iron and, sometimes, normalized steel

3.20
tensile strength
ultimate strength
ratio of maximum load to original cross-sectional area

NOTE See ISO 6892.

3.21
test batch
group of items representing a production batch whose conformity with a specified requirement can be determined by testing representative samples in accordance with a defined procedure

3.22
tubular component
cylindrical component (pipe) having a longitudinal hole, used in drilling/production operations for conveying fluids

3.23
Vickers hardness
HV
hardness value, measured in accordance with ISO 6507-1, obtained using a diamond pyramid indenter and one of a variety of possible applied loads

3.24
weldment
that portion of a component on which welding has been performed, including the weld metal, the heat-affected zone (HAZ), and the adjacent parent metal

3.25
weld metal
that portion of a weldment that has been molten during welding

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3.26
wrought metal
metal in the solid condition that is formed to a desired shape by working (rolling, extruding, forging, etc.), usually at an elevated temperature

4 Symbols and abbreviated terms

For the purposes of this document, the abbreviated terms given in NACE MR0175/ISO 15156-1 and the following apply.

AYS actual yield strength

CLR crack length ratio

CR c-ring (test)

CSR crack surface ratio

CTR crack thickness ratio

DCB double cantilever beam (test)

FPB four point bend (test)

HBW Brinell hardness

HIC hydrogen-induced cracking

HRC Rockwell hardness (scale C)

HSC hydrogen stress cracking

HV Vickers hardness

OCTG oil country tubular goods, i.e. casing, tubing and drill pipe

p_{H_2S} partial pressure of H_2S

$R_{p0,2}$ 0,2 % proof stress in accordance with ISO 6892

SMYS specified minimum yield strength

SOHIC stress-oriented hydrogen-induced cracking

SSC sulfide stress-cracking

SWC stepwise cracking

SZCsoft-zone cracking

UNS Unified Numbering System (from SAE-ASTM, *Metals and alloys in the Unified Numbering System*)

UT uniaxial tensile (test)

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5 Purchasing information

5.1 The preparation of material purchasing specifications might require co-operation and exchange of data between the equipment user, the equipment supplier and the material manufacturer to ensure that the material purchased complies with NACE MR0175/ISO 15156-1 and this part of NACE MR0175/ISO 15156.

5.2 The following information shall be provided:

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

— equipment type (if known);

— reference to this part of NACE MR0175/ISO 15156;

— acceptable bases for selection of materials for SSC resistance (see Clause 7);

— requirements for HIC resistance (see Clause 8).

5.3 The equipment user and the equipment supplier/material manufacturer may agree that carbon or low alloy steels other than those described and/or listed in Annex A may be selected subject to suitable qualification testing in accordance with Annex B and NACE MR0175/ISO 15156-1. The qualification requirements may be extended to include resistance to SOHIC and SZC.

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

— requirements for SSC testing (see 7.1, 7.2),

— service conditions for specific sour service application, and

— other special requirements.

5.4 Annex C describes how to calculate the H_2S partial pressure and Annex D gives guidance on how to determine the pH-value of a fluid.

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

6 Factors affecting the behaviour of carbon and low alloy steels in H_2S-containing environments

The behaviour of carbon and low alloy steels in H_2S-containing environments is affected by complex interactions of parameters, including the following:

a) chemical composition, method of manufacture, product form, strength, hardness of the material and its local variations, amount of cold work, heat treatment condition, microstructure, microstructural uniformity, grain size and cleanliness of the material;

b) H_2S partial pressure or equivalent concentration in the water phase;

c) chloride ion concentration in the water phase;

d) acidity (pH) of the water phase;

e) presence of sulfur or other oxidants;

f) exposure to non-production fluids;

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g) exposure temperature;

h) total tensile stress (applied plus residual);

i) exposure time.

These factors shall be considered when using this part of NACE MR0175/ISO 15156 for the selection of materials suitable for environments containing H_2S in oil and gas production systems.

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

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

7.1.1 For p_{H_2S} < 0,3 kPa (0,05 psi)

The selection of materials for SSC resistance for p_{H_2S} below 0,3 kPa (0,05 psi) is not considered in detail in this part of NACE MR0175/ISO 15156. Normally, no special precautions are required for the selection of steels for use under these conditions, nevertheless, highly susceptible steels can crack. Further information on factors affecting susceptibility of steels and attack by cracking mechanisms other than SSC is given in 7.2.1.

7.1.2 For p_{H_2S} ≥ 0,3 kPa (0,05 psi)

If the partial pressure of H_2S in the gas is equal to or greater than 0,3 kPa (0,05 psi), SSC-resistant steels shall be selected using A.2.

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

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

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

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

7.2.1 Sulfide stress-cracking (SSC)

7.2.1.1 General

Option 2 allows the user to qualify and select materials for SSC resistance for specific sour service applications or for ranges of sour service.

The use of Option 2 may require knowledge of both the *in situ* pH and the H_2S partial pressure and their variations with time (see NACE MR0175/ISO 15156-1).

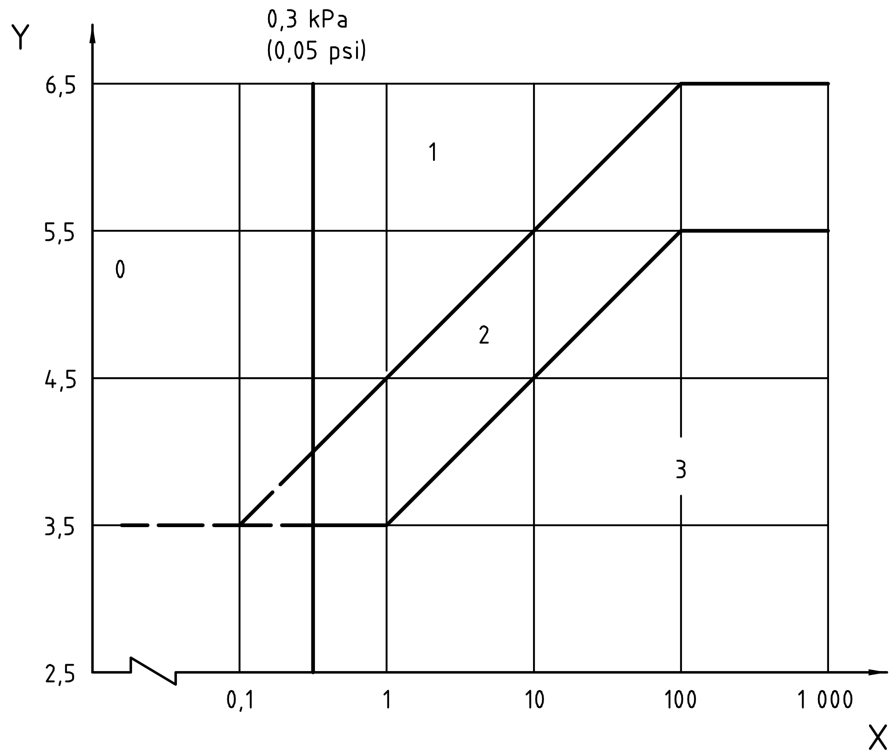
Option 2 facilitates the purchase of bulk materials, such as OCTG or line pipe, where the economic incentive to use materials not described nor listed in Annex A outweighs the additional qualification and other costs that might be incurred. Steels for other equipment may also be qualified. In some cases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

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

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7.2.1.2 SSC Regions of environmental severity

The severity of the sour environment, determined in accordance with NACE MR0175/ISO 15156-1, with respect to SSC of a carbon or low alloy steel shall be assessed using Figure 1.



Key

X H_2S partial pressure, kPa

Y *in situ* pH

0 Region 0
1 SSC Region 1
2 SSC Region 2
3 SSC Region 3

In defining the severity of the H_2S-containing environment, the possibility of exposure to unbuffered condensed aqueous phases of low pH during upset operating conditions or downtime, or to acids used for well stimulation and/or the backflow of stimulation acid, after reaction should be considered.

NOTE 1 The discontinuities in the figure below 0,3 kPa (0,05 psi) and above 1 MPa (150 psi) partial pressure H_2S reflect uncertainty with respect to the measurement of H_2S partial pressure (low H_2S) and steel's performance outside these limits (both low and high H_2S).

NOTE 2 Guidance on the calculation of H_2S partial pressure is given in Annex C.

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

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

7.2.1.3 Region 0, p_{H_2S} < 0,3 kPa (0,05 psi)

Normally, no precautions are required for the selection of steels for use under these conditions. Nevertheless, a number of factors that can affect a steel's performance in this region should be considered, as follows.

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— Steels that are highly susceptible to SSC and HSC may crack.

— A steel's physical and metallurgical properties affect its inherent resistance to SSC and HSC, see Clause 6.

— Very high strength steels can suffer HSC in aqueous environments without H_2S. Above about 965 MPa (140 ksi) yield strength, attention may be required to steel composition and processing to ensure that these steels do not exhibit SSC or HSC in Region 0 environments.

— Stress concentrations increase the risk of cracking.

7.2.1.4 SSC Regions 1, 2 and 3

Referring to the Regions of severity of the exposure as defined in Figure 1, steels for Region 1 may be selected using A.2, A.3 or A.4, steels for Region 2 may be selected using A.2 or A.3 and steels for Region 3 may be selected using A.2.

In the absence of suitable choices from Annex A, carbon and low alloy steels may be tested and qualified for use under specific sour service conditions or for use throughout a given SSC Region. Testing and qualification shall be in accordance with NACE MR0175/ISO 15156-1 and Annex B.

Documented field experience may also be used as the basis for material selection for a specific sour service application (see NACE MR0175/ISO 15156-1).

7.2.2 SOHIC and SZC

The user should consider SOHIC and SZC, as defined in NACE MR0175/ISO 15156-1, when evaluating carbon steels in plate form and their welded products for sour service in H_2S-containing environments.

B.4 provides guidance on test methods and acceptance criteria to evaluate resistance to SOHIC and SZC.

NOTE The occurrence of these phenomena is rare and they are not well understood. They have caused sudden failures in parent steels (SOHIC) and in the HAZ of welds (SOHIC and SZC). Their occurrence is thought to be restricted to carbon steels. The presence of sulfur or oxygen in the service environment is thought to increase the probability of damage by these mechanisms.

7.3 Hardness requirements

7.3.1 General

The hardness of parent materials and of welds and their heat-affected zones play important roles in determining the SSC resistance of carbon and low alloy steels. Hardness control can be an acceptable means of obtaining SSC resistance.

7.3.2 Parent metals

If hardness measurements on parent metal are specified, sufficient hardness tests shall be made to establish the actual hardness of the steel being examined. Individual HRC readings exceeding the value permitted by this part of NACE MR0175/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 NACE MR0175/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 NACE MR0175/ISO 15156 or referenced in a manufacturing specification.

NOTE The number and location of hardness tests on parent metal are not specified in NACE MR0175/ISO 15156.

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For ferritic steels, EFC Publication 16 shows graphs for the conversion of hardness readings, from Vickers (HV) to Rockwell (HRC) and from Vickers (HV) to Brinell (HBW), derived from the tables of ASTM E 140 and BS 860. Other conversion tables also exist. Users may establish correlations for individual materials.

7.3.3 Welds

7.3.3.1 General

The metallurgical changes that occur on welding carbon and low alloy steels affect their susceptibility to SSC, SOHIC and SZC.

Processes and consumables should be selected in accordance with good practice and to achieve the required cracking resistance.

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.

The qualification of welding procedures for sour service shall include hardness testing in accordance with 7.3.3.2, 7.3.3.3 and 7.3.3.4.

7.3.3.2 Hardness testing methods for welding procedure qualification

Hardness testing for welding procedure qualification shall normally be carried out using the Vickers HV 10 or HV 5 method in accordance with ISO 6507-1, or the Rockwell method in accordance with ISO 6508-1 using the 15N scale.

The HRC method may be used for welding procedure qualification if the design stress does not exceed two-thirds of SMYS and the welding procedure specification includes post weld heat treatment. The use of the HRC method for welding procedure qualification in all other cases shall require the agreement of the equipment user.

NOTE Hardness surveys using the Vickers or Rockwell 15N testing method produce a more detailed picture of weld hardness and its variations. Hardness surveys using the HRC testing method might not detect small zones in welds or HAZs where the hardness exceeds the acceptance criteria for the Vickers or Rockwell 15N testing method. The significance of such small hard zones is not well understood.

The use of other hardness testing methods shall require the agreement of the equipment user.

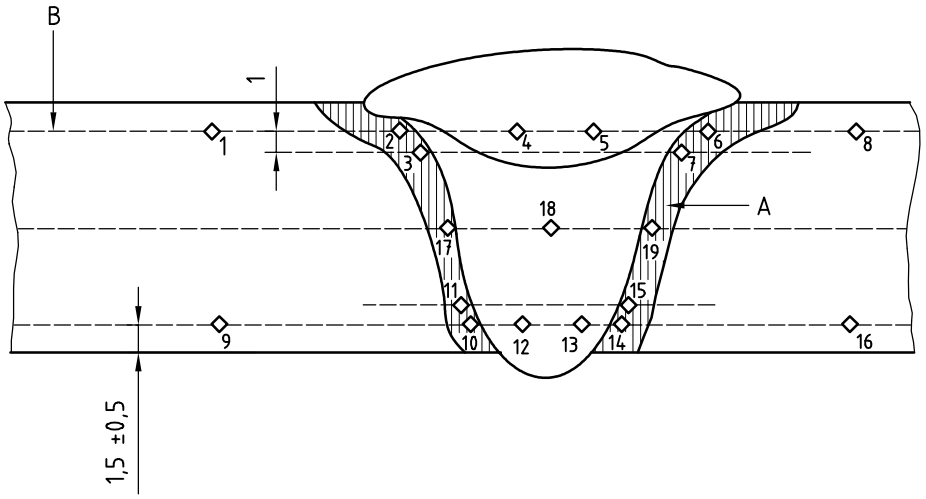
The Vickers or Rockwell 15N hardness testing method shall be used for the qualification of alternative weld hardness acceptance criteria as permitted in 7.3.3.4.

7.3.3.3 Hardness surveys for welding procedure qualification

Vickers hardness surveys shall be in accordance with Figure 2 for butt welds, Figure 3 for fillet welds and Figure 4 for repair and partial penetration welds. HRC surveys of butt welds shall be in accordance with Figure 5. Survey requirements for other joint configurations shall be developed from these figures.

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Dimensions in millimetres



Key

A weld heat-affected zone (visible after etching)

B ———— lines of survey

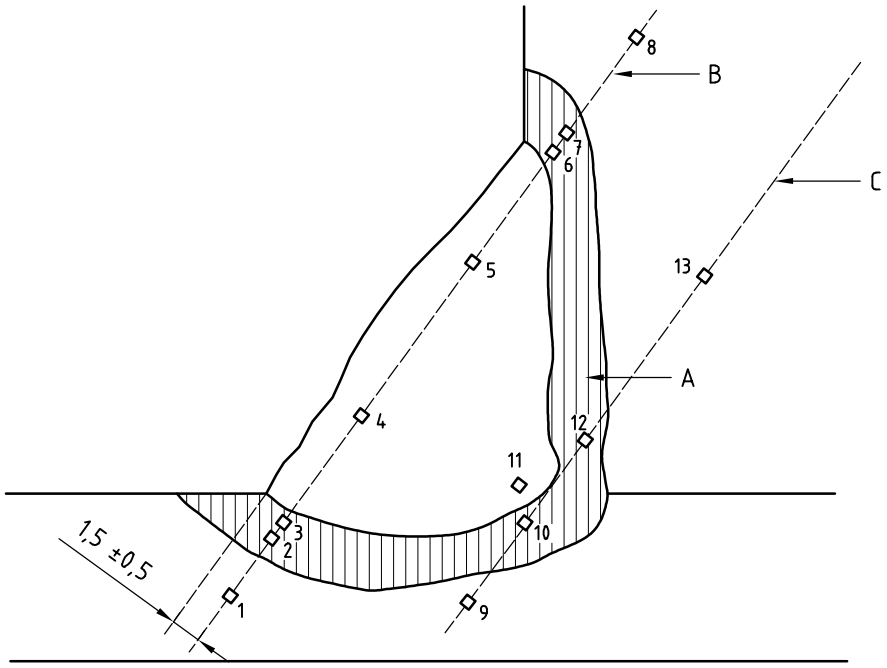
Hardness impressions 2, 3, 6, 7, 10, 11, 14, 15, 17 and 19 should be entirely within the heat-affected zone and located as close as possible to the fusion boundary between the weld metal and the heat-affected zone.

The top line of survey should be positioned so that impressions 2 and 6 coincide with the heat-affected zone of the final run or change of profile of the fusion line associated with the final run.

Figure 2 — Butt weld survey method for Vickers hardness measurement

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Dimensions in millimetres



Key

A weld heat-affected zone (visible after etching)

B ———— line of survey

C ———— line of survey, parallel to line B and passing through the fusion boundary between the weld metal and the heat-affected zone at the throat

Hardness impressions 3, 6, 10 and 12 should be entirely within the heat-affected zone and located as close as possible to the fusion boundary between the weld metal and the heat-affected zone.

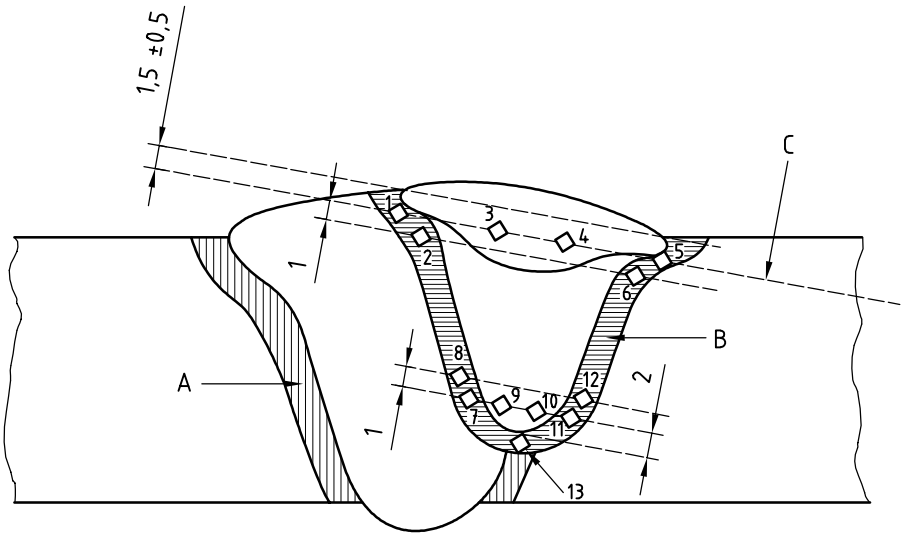
Figure 3 — Fillet weld

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Dimensions in millimetres



Key

A original weld heat-affected zone

B repair weld heat-affected zone

C ———— parallel lines of survey

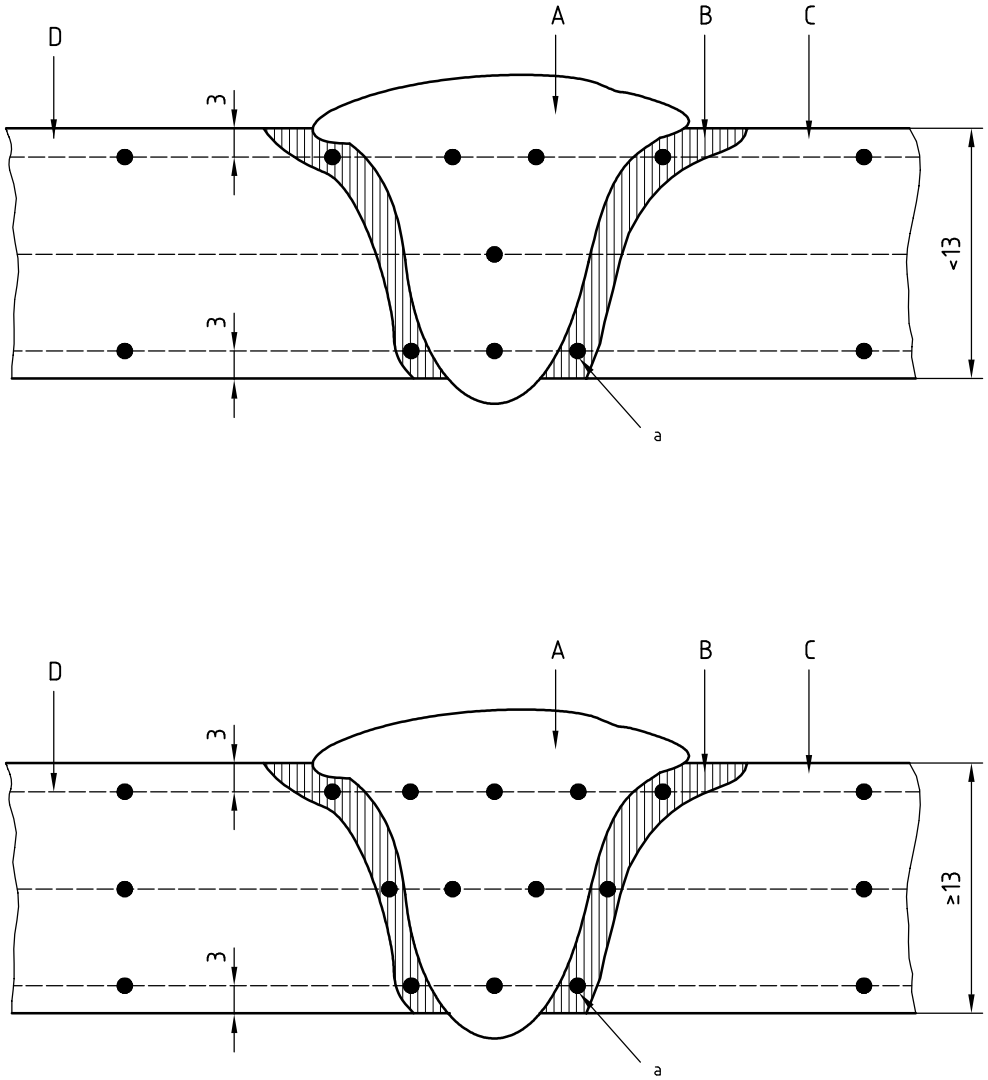
Hardness impressions in the heat-affected zone should be located as close as possible to the fusion boundary.

The top line of survey should be positioned so that the heat-affected zone impressions coincide with the heat-affected zone of the final run or change in profile of the cap of fusion line associated with the final run.

Figure 4 — Repair and partial penetration welds

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Dimensions in millimetres



Key

A weld
B weld heat-affected zone (visible after etching)
C parent metal
D ———— lines of survey

Hardness impressions in the weld heat-affected zone should be located within 2 mm of the fusion boundary.

Figure 5 — Butt weld (survey method for Rockwell hardness measurements)

7.3.3.4 Hardness acceptance criteria for welds

Weld hardness acceptance criteria for steels selected using option 1 (see 7.1) shall be as specified in A.2.1.4. Alternative weld hardness acceptance criteria may be established from successful SSC testing of welded samples. SSC testing shall be in accordance with Annex B.

Weld hardness acceptance criteria for steels qualified and/or selected using option 2 (see 7.2) may be established from successful SSC testing of welded samples. SSC testing shall be in accordance with Annex B.

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7.4 Other fabrication methods

For steels that are subject to hardness change caused by fabrication methods other than welding, hardness testing shall be specified as part of the qualification of the fabrication process. Hardness testing shall be specified as part of the qualification of burning/cutting processes if any HAZ remains in the final product. The requirements, interpreted for the fabrication method, and hardness acceptance criteria of 7.3 shall apply.

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

8 Evaluation of carbon and low alloy steels for their resistance to HIC/SWC

The equipment user shall consider HIC/SWC as defined in NACE MR0175/ISO 15156-1 when evaluating flat-rolled carbon steel products for sour service environments containing even trace amounts of H_2S and shall consider HIC/SWC testing of these products. Annex B provides guidance on test methods and acceptance criteria to evaluate resistance to HIC/SWC.

The probability of HIC/SWC is influenced by steel chemistry and manufacturing route. The level of sulfur in the steel is of particular importance, typical maximum acceptable levels for flat-rolled and seamless products are 0,003 % and 0,01 %, respectively. Conventional forgings with sulfur levels less than 0,025 %, and castings, are not normally considered sensitive to HIC or SOHIC.

NOTE 1 HIC/SWC leading to loss of containment has occurred only rarely in seamless pipe and other products that are not flat-rolled. Furthermore, seamless pipe manufactured using modern technology is much less sensitive to HIC/SWC than older products. Hence there could be benefits in evaluating seamless pipe for HIC/SWC resistance for applications where the potential consequences of failure make this justifiable.

NOTE 2 The presence of rust, sulfur or oxygen, particularly together with chloride, in the service environment is thought to increase the probability of damage.

9 Marking

Materials complying with this part of NACE MR0175/ISO 15156 shall be made traceable, preferably by marking, before delivery. Suitable labelling or documentation is also acceptable.

The tables in Annex E provide designations that may be used to identify materials.

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Annex A
(normative)

SSC-resistant carbon and low alloy steels (and requirements and recommendations for the use of cast irons)

A.1 General

This annex describes and lists SSC-resistant carbon and low alloy steels. Requirements for the use of cast irons are given in A.2.4.

Steels complying with this annex might not resist SOHIC, SZC, HIC or SWC without the specification of additional requirements (see 7.2.2 and/or Clause 8).

NOTE A.2 is consistent with the previously established requirements of NACE MR0175.

At the time of publication of this part of NACE MR0175/ISO 15156, there are no listings of steels approved for SSC Region 2 (A.3) or SSC Region 1 (A.4). Therefore A.3 and A.4 only indicate properties typical of steels that are expected to be suitable for use under the defined conditions.

A.2 SSC-resistant carbon and low alloy steels and the use of cast irons

A.2.1 General requirements for carbon and low alloy steels

A.2.1.1 General

Carbon and low alloy steels shall comply with A.2.1.2 through A.2.1.9.

Carbon and low alloy steels, products and components that comply with A.2 are, with stated exceptions, qualified in accordance with this part of NACE MR0175/ISO 15156 without further SSC testing. Nevertheless, any SSC testing that forms part of a materials manufacturing specification shall be carried out successfully and the results reported.

The majority of steels that comply with the general requirements of A.2 are not individually listed; however, for convenience, some examples of such steels are listed in Table A.2, Table A.3 and Table A.4.

NOTE The carbon and low alloy steels described/listed previously in NACE MR0175 (all revisions) were identified by extensive correlations of field failures/successes and laboratory data. The hardness limit of HRC 22 applied to most carbon and low alloy steels was based upon correlations of heat treatment, chemical composition, hardness and failure experience. The higher hardness limits for the chromium-molybdenum steels were based upon similar considerations.

A.2.1.2 Parent metal composition, heat treatment and hardness

Carbon and low alloy steels are acceptable at 22 HRC maximum hardness provided they contain less than 1 % nickel, are not free-machining steels and are used in one of the following heat-treatment conditions:

a) hot-rolled (carbon steels only);

b) annealed;

c) normalized;

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d) normalized and tempered;

e) normalized, austenitized, quenched, and tempered;

f) austenitized, quenched, and tempered.

A.2.1.3 Carbon steels acceptable with revised or additional restrictions

In addition to the restrictions of A.2.1.2, some carbon steels are acceptable subject to the revised or additional restrictions as follows.

a) Forgings produced in accordance with ASTM A 105 are acceptable if the hardness does not exceed 187 HBW.

b) Wrought pipe fittings to ASTM A 234 grades WPB and WPC are acceptable if the hardness does not exceed 197 HBW.

A.2.1.4 Welding

Welding and weld hardness determinations shall be performed in accordance with 7.3.3.

Acceptable maximum hardness values for carbon steel, carbon manganese steel and low alloy steel welds are given in Table A.1.

As-welded carbon steels, carbon manganese steels and low alloy steels that comply with the hardness requirements of Table A.1 do not require post weld heat treatment.

Tubular products with an SMYS not exceeding 360 MPa (52 ksi), and pressure vessel steels classified as P-No 1, Group 1 or 2, in Section IX of the ASME Boiler and Pressure Vessel Code (see A.2.2.2), are acceptable in the as-welded condition. For these products, hardness testing of welding procedures may be waived if agreed by the equipment user.

Some tubular products with an SMYS exceeding 360 MPa (52 ksi) [see A.2.2.2] may be acceptable in the as-welded condition if suitable qualified welding procedures are used. Table A.1 shall be met.

Carbon steel and low alloy steel weldments that do not comply with other paragraphs of this subclause shall be stress-relieved at a minimum temperature of 620 °C (1 150 °F) after welding. The maximum weld zone hardness, determined in accordance with 7.3, shall be 250 HV (or, subject to the restrictions described in 7.3.3, 22 HRC).

Welding consumables and procedures that produce a deposit containing more than 1 % nickel are acceptable after successful weld SSC qualification by testing in accordance with Annex B.

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Table A.1 — Maximum acceptable hardness values for carbon steel, carbon manganese steel and low alloy steel welds

Hardness test methods	Hardness test locations for welding procedure qualification	Maximum acceptable hardness
Vickers HV 10 or HV 5 or Rockwell HR 15N	Weld root: Base metal, HAZ and weld root metal as shown in Figure 2, Figure 3 or Figure 4	 250 HV 70,6 HR 15N
Vickers HV 10 or HV 5 or Rockwell HR 15N	Weld cap: Base metal, HAZ and weld metal of unexposed weld cap as shown in Figure 2 or Figure 4	 275 HV[a] 73,0 HR 15N
Rockwell HRC (see 7.3.3.2)	As shown in Figure 5	22 HRC

[a] The maximum shall be 250 HV or 70,6 HR 15N unless:

- the equipment user agrees the alternative weld cap hardness limit; and
- the parent material(s) are over 9 mm thick; and
- the weld cap is not exposed directly to the sour environment; and
- the escape of hydrogen is not impeded, e.g. by cathodic protection.

A.2.1.5 Surface treatments, overlays, plating, coatings, linings, etc.

NOTE The composition and cracking resistance of overlays are addressed in NACE MR0175/ISO 15156-3.

Metallic coatings (electroplated and electroless plated), conversion coatings, plastic coatings and linings are not acceptable for preventing SSC.

Overlays applied by thermal processes such as welding, silver brazing, or spray metallizing systems are acceptable if they comply with one of the following requirements.

a) The heat-treated condition of the substrate is unchanged, i.e. it does not exceed the lower critical temperature during application of the overlay.

b) The maximum hardness and final heat-treated condition of the base metal substrate comply with A.2.1.2 and, in the case of welded overlays, A.2.1.4.

Joining of dissimilar materials, such as cemented carbides to steels by silver brazing, is acceptable. The base metal after brazing shall comply with A.2.1.2.

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.

A.2.1.6 Cold deformation and thermal stress relief

Carbon and low alloy steels shall be thermally stress-relieved following any cold deforming by rolling, cold forging, or another manufacturing process that results in a permanent outer fibre deformation greater than 5 %. Thermal stress relief shall be performed in accordance with an appropriate code or standard. The minimum stress-relief temperature shall be 595 °C (1 100 °F). The final maximum hardness shall be 22 HRC except for pipe fittings made from ASTM A 234 grade WPB or WPC, for which the final hardness shall not exceed 197 HBW.

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The above requirement does not apply to cold work imparted by pressure testing according to an applicable code or standard agreed by the equipment user.

Cold-rotary straightened pipe is acceptable only where permitted in the applicable ISO or API product standards, see also A.2.2.3.4.

Cold-worked line pipe fittings of ASTM A 53 Grade B, ASTM A 106 Grade B, API 5L Grade X-42, ISO 3183 L290, or lower-yield strength grades with similar chemical compositions, are acceptable with cold strain equivalent to 15 % or less, provided the hardness in the strained area does not exceed 190 HBW.

SSC testing and qualification in accordance with Annex B may be used to justify other cold deformation limits.

A.2.1.7 Threading

Threads produced using a machine-cutting process are acceptable.

Threads produced by cold forming (rolling) are acceptable in steels that otherwise comply with the heat treatment and hardness requirements of A.2.1.2.

A.2.1.8 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, boring, rolling, threading, drilling, etc.).

Cold deformation by controlled shot-peening is acceptable if applied to base materials that comply with this part of NACE MR0175/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-S-13165.

A.2.1.9 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 subsequently stress-relieved at a minimum temperature of 595 °C (1 100 °F).

A.2.2 Application to product forms

A.2.2.1 General

Except as modified below, the general requirements of A.2.1 shall apply to all product forms.

A.2.2.2 Pipe, plate and fittings

Examples of tubular products that can comply with A.2.1 are shown in Table A.2.

Pressure vessel steels classified as P-No 1, Group 1 or 2, in Section IX of the ASME Boiler and Pressure Vessel Code are acceptable.

Products made from flat-rolled steels might be susceptible to HIC/SWC damage in trace amounts of H_2S [i.e. even if p_{H_2S} is below 0,3 kPa (0,05 psi)].

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Table A.2 — Examples of tubular products that can comply with A.2.1

ISO specifications and grades	Other designations
ISO 3183-3 grades: L245 through L450	API Specification 5L grades: A and B and X-42 through X-65
	ASTM A 53
	ASTM A 106 grades A, B and C
	ASTM A 333 grades 1 and 6
	ASTM A 524 grades 1 and 2
	ASTM A 381 class 1, Y35 to Y65

Pipe seam welds shall comply with A.2.1.

A.2.2.3 Downhole casing, tubing and tubular components

A.2.2.3.1 ISO and API grades of casing, and tubing are acceptable for the temperature ranges given in Table A.3.

A.2.2.3.2 Tubulars and tubular components made of Cr-Mo low alloy steels (UNS G41XX0, formerly AISI 41XX, and modifications), if quenched and tempered in the tubular form, are acceptable if their hardness does not exceed 30 HRC and they have SMYS grades of 690 MPa (100 ksi), 720 MPa (105 ksi), and 760 MPa (110 ksi). The maximum yield strength for each grade shall be no more than 103 MPa (15 ksi) higher than the SMYS. SSC resistance shall be demonstrated by testing each test batch and shall comply with B.1 using the UT test.

A.2.2.3.3 Tubulars and tubular components made of Cr-Mo low alloy steels (UNS G41XX0, formerly AISI 41XX and modifications), if quenched and tempered in the tubular form, are acceptable if the hardness does not exceed 26 HRC. These products should be qualified by SSC testing in accordance with B.1 using the UT test.

A.2.2.3.4 If tubulars and tubular components are cold-straightened at or below 510 °C (950 °F), they shall be stress-relieved at a minimum temperature of 480 °C (900 °F). If tubulars and tubular components are cold-formed (pin-nosed and/or box-expanded) and the resultant permanent outer fibre deformation is greater than 5 %, the cold-formed regions shall be thermally stress-relieved at a minimum temperature of 595 °C (1 100 °F).

If the connections of high-strength tubulars with hardnesses above 22 HRC are cold-formed, they shall be thermally stress-relieved at a minimum temperature of 595 °C (1 100 °F).

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Table A.3 — Environmental conditions for which grades of casing and tubing are acceptable

For all temperatures	For ≥ 65 °C (150 °F)	For ≥ 80 °C (175 °F)	For ≥ 107 °C (225 °F)
ISO 11960[a] grades: H40 J55 K55 M65 L80 type 1 C90 type 1 T95 type 1	ISO 11960[a] grades: N80 type Q C95	ISO 11960[a] grades: N80 P110	ISO 11960[a] grade: Q125[b]
Proprietary grades as described in A.2.2.3.3	Proprietary Q & T grades with 760 MPa (110 ksi) or less maximum yield strength Casings and tubulars made of Cr-Mo low alloy steels as described in A.2.2.3.2.	Proprietary Q & T grades with 965 MPa (140 ksi) or less maximum yield strength	
Temperatures given are minimum allowable service temperatures with respect to SSC. Low temperature toughness (impact resistance) is not considered, equipment users shall determine requirements separately.			
a For the purposes of this provision, API 5CT is equivalent to ISO 11960:2001. b Types 1 and 2 based on Q & T, Cr-Mo chemistry to 1 036 MPa (150 ksi) maximum yield strength. C-Mn steels are not acceptable.			

A.2.2.4 Bolting and fasteners

Bolting that might be exposed directly to a sour environment, or that will be buried, insulated, equipped with flange protectors, or otherwise denied direct atmospheric exposure, shall conform to the general requirements of A.2.1.

Designers and users should be aware that it may be necessary to lower equipment pressure ratings when using SSC-resistant bolting and fasteners. The use of SSC-resistant bolting and fasteners with API flanges shall be in accordance with ISO 10423.

Table A.4 — Acceptable bolting materials

Bolts	Nuts
ASTM A 193 grade B7M ASTM A 320 grade L7M	ASTM A 194 grades 2HM, 7M

A.2.3 Application to equipment

A.2.3.1 General

The general requirements of A.2.1 apply, with the following modifications.

A.2.3.2 Drilling blowout preventers (BOPs)

A.2.3.2.1 Shear blades

The high strength steels used for blowout preventer (BOP) shear blades can be susceptible to SSC. The suitability of shear blades that do not comply with this annex is the responsibility of the equipment user.

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A.2.3.2.2 Shear rams

Rams manufactured in quenched and tempered, Cr-Mo low alloy steels (UNS G41XX0, formerly AISI 4IXX, and modifications) are acceptable if the hardness does not exceed 26 HRC. If the hardness of these alloys exceeds 22 HRC, careful attention shall be paid to chemical composition and heat treatment to ensure their SSC resistance. SSC testing, as agreed with the equipment user, shall demonstrate that the performance of the alloy meets or exceeds that of field proven material.

A.2.3.2.3 Drilling, well construction and well-servicing equipment only exposed to drilling fluids of controlled composition

Given the high strength often needed, drilling equipment might not comply with NACE MR0175/ISO 15156. In such cases the primary means for avoiding SSC is control of the drilling or well-servicing environment. As service stresses and material hardness increase, drilling fluid control becomes increasingly important. Care shall be taken to control the drilling environment by maintenance of drilling fluid hydrostatic head and fluid density to minimize formation fluid in-flow and by the use of one or more of the following:

a) maintenance of pH 10 or higher to neutralize H_2S in the drilled formation;

b) use of chemical sulfide scavengers;

c) use of a drilling fluid in which oil is the continuous phase.

A.2.3.3 Compressors and pumps

A.2.3.3.1 Compressor impellers

UNS G43200 (formerly AISI 4320) and a modified version of UNS G43200 that contains 0,28 % to 0,33 % carbon are acceptable for compressor impellers at a maximum yield strength of 620 MPa (90 ksi) provided they have been heat-treated in accordance with the following three-step procedure.

a) Austenitize and quench.

b) Temper at 620 °C (1 150 °F) minimum temperature, but below the lower critical temperature. Cool to ambient temperature before the second temper.

c) Temper at 620 °C (1 150 °F) minimum, but lower than the first tempering temperature. Cool to ambient temperature.

A.2.3.3.2 Special provisions for compressors and pumps

Soft carbon steel and soft, low carbon, iron are acceptable as gaskets.

Cast irons are acceptable as defined in A.2.4.

A.2.4 Requirements for the use of cast irons

A.2.4.1 General

Grey, austenitic and white cast irons shall not be used for pressure-containing members. These materials may be used for internal components if their use is permitted by the equipment standard and has been approved by the equipment user.

Ferritic ductile iron, in accordance with ASTM A 395, is acceptable for equipment unless otherwise specified by the equipment standard.

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A.2.4.2 Packers and subsurface equipment

Cast irons are acceptable as listed for the following applications.

Table A.5 — Cast irons acceptable for packers and other subsurface equipment

Component	Cast iron
Drillable packer components	Ductile iron (ASTM A 536, ASTM A 571) Malleable iron (ASTM A 220, ASTM A 602)
Compression members	Grey iron (ASTM A 48, ASTM A 278)

A.2.4.3 Compressors and pumps

Grey cast iron (ASTM A 278, Class 35 or 40) and ductile (nodular) cast iron (ASTM A 395) are acceptable as compressor cylinders, liners, pistons and valves.

A.3 SSC-resistant steels for use throughout SSC Region 2

A.3.1 General

Steels listed in A.2 are acceptable.

The properties of steels typical of those that have been shown to meet the requirements for sour service throughout SSC Region 2 are described below. Qualification according to Annex B shall be performed for steels that do not comply with A.2.

A.3.2 Downhole casing, tubing and tubular components

Casing, tubing and tubular components made of Cr-Mo low alloy steels (UNS G41XX0, formerly AISI 41XX, and modifications) have proven acceptable in the quenched and tempered condition. Typically, actual yield strengths of acceptable steels have been no more than 760 MPa (110 ksi) [SMYS approximately 550 MPa (80 ksi)] and their hardness has been no more than 27 HRC. Other requirements shall be in accordance with the applicable manufacturing specification.

A.3.3 Pipeline steels

Pipeline steels require appropriate restricted chemistries to ensure good weldability. Typically, SMYSs of up to 450 MPa (65 ksi) have proven acceptable. Typically, fabrication and field weld hardness should not exceed 280 HV. Other requirements shall be in accordance with the applicable manufacturing specification.

A.4 SSC-resistant steels for use throughout SSC Region 1

A.4.1 General

Steels listed in A.2 and A.3 are acceptable.

The properties of steels typical of those that have been shown to meet the requirements for sour service throughout SSC Region 1 are described below. Qualification according to Annex B shall be performed for steels which do not comply with A.2 or A.3.

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A.4.2 Downhole casing, tubing and tubular components

Casing, tubing and tubular components made of Cr-Mo low alloy steels (UNS G41XX0, formerly AISI 41XX and modifications) have proven acceptable in the quenched and tempered condition. Typically, actual yield strengths of acceptable steels have been no more than 896 MPa (130 ksi) (SMYS approximately 760 MPa (110 ksi)) and their hardnesses have been no more than 30 HRC. Other requirements shall be in accordance with the applicable manufacturing specification.

A.4.3 Pipeline steels

Pipeline steels require appropriate restricted chemistries to ensure good weldability. Typically, SMYSs of up to 550 MPa (80 ksi) have proven acceptable. Typically fabrication and field weld hardness should not exceed 300 HV. Other requirements shall be in accordance with the applicable manufacturing specification.

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Annex B
(normative)

Qualification of carbon and low alloy steels for H_2S service by laboratory testing

B.1 Requirements

This annex specifies requirements for qualifying carbon and low alloy steels for H_2S service by laboratory testing. Requirements are given for qualifying resistance to the following cracking mechanisms.

a) SSC

SSC qualification by laboratory testing shall require one or more of the following:

— SSC testing in accordance with the materials manufacturing specification (see also A.2.1.1);

— testing for specific sour service applications in accordance with B.3;

— testing for SSC Regions 1 or 2 of Figure 1 in accordance with B.3 and Note g of Table B.1;

— testing for sour service in all SSC Regions of Figure 1 in accordance with B.3.

The qualification tests summarized demonstrate varying levels of resistance to SSC in sour environments. Some carbon and low alloy steels described or listed in A.2 might not pass some of the laboratory test requirements listed above, see A.2.1.

b) SZC and SOHIC

Qualification shall require testing in accordance with B.4 using appropriate environmental conditions from those specified for SSC qualification.

c) HIC and SWC

— in any service environment (see B.5 and Table B.3);

— in specific sour service applications (see B.5 and Table B.3).

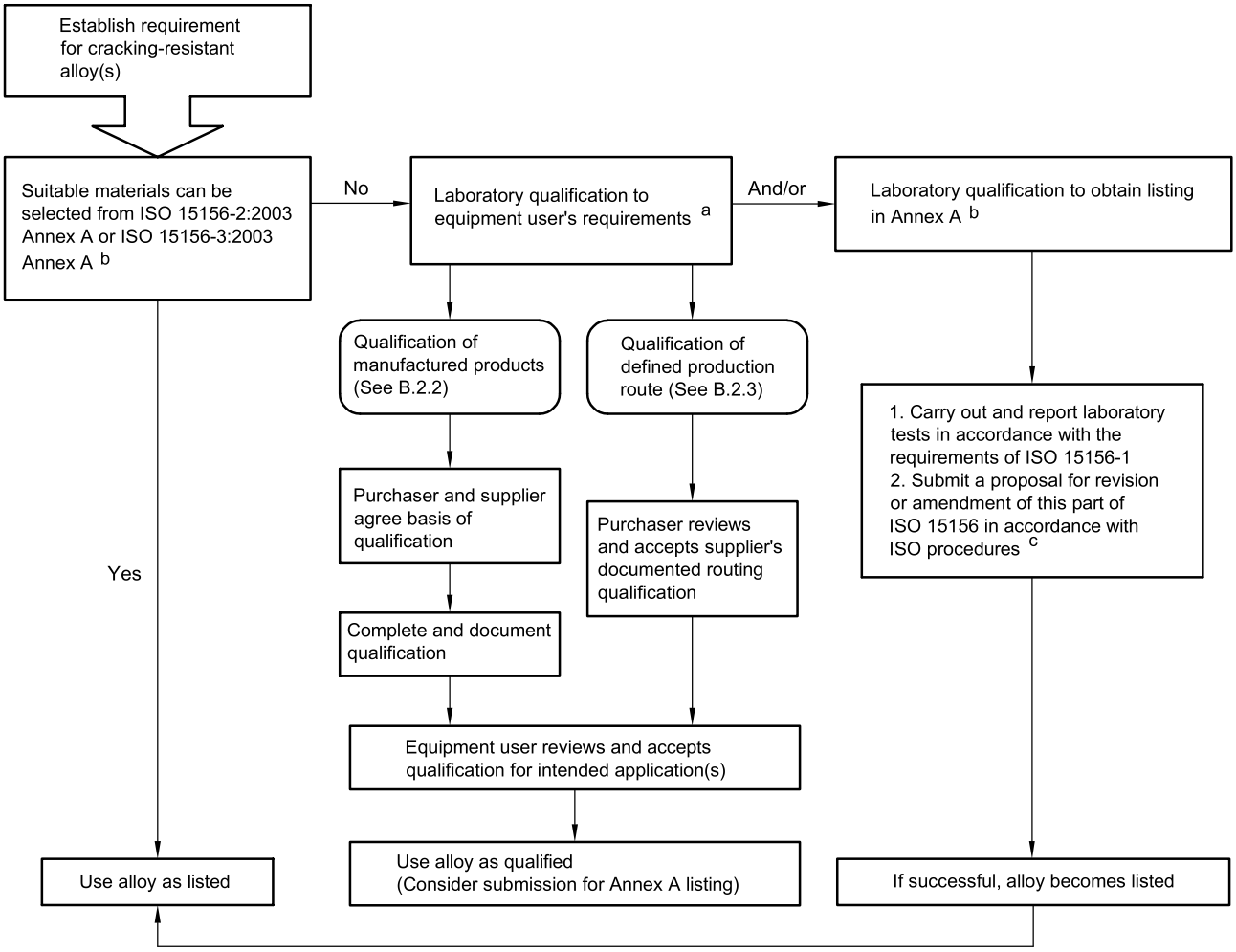
In all cases the equipment user shall ensure that the testing chosen is appropriate to the conditions of the intended service(s). The acceptance of the testing chosen shall be documented.

B.2 Uses of laboratory qualifications

B.2.1 General

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

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a This part of NACE MR0175/ISO 15156 addresses SSC, HIC, SOHIC and SZC of carbon and low alloy steels. NACE MR0175/ISO 15156-3 addresses SSC, SCC and galvanically-induced hydrogen stress-cracking (GHSC) of corrosion-resistant alloys (CRAs) and other alloys.

b Annex A addresses SSC of carbon and low alloy steels. NACE MR0175/ISO 15156-3:2003, Annex A, addresses SSC, SCC and GHSC of CRAs and other alloys.

c See final paragraph of “Introduction” for further information regarding document maintenance.

NOTE Flowchart omits qualification by field experience as described in NACE MR0175/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 NACE MR0175/ISO 15156 shall define the qualification requirements for the material in accordance with NACE MR0175/ISO 15156-1 and this annex.

This definition shall include the application of the following:

a) general requirements (see NACE MR0175/ISO 15156-1:2001, Clause 5);

b) evaluation and definition of service conditions (see NACE MR0175/ISO 15156-1:2001, Clause 6);

c) material description and documentation (see NACE MR0175/ISO 15156-1:2001, 8.1);

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d) requirements for qualification based upon laboratory testing (see NACE MR0175/ISO 15156-1:2001, 8.3);

e) report of the method of qualification (see NACE MR0175/ISO 15156-1:2001, 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) (SSC, SOHIC, SZC, HIC/SWC).

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.

Re-testing is permitted as follows: If a single specimen fails to satisfy 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 manufacturing source and 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 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.

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

Proposals for additions and changes shall be documented in accordance with NACE MR0175/ISO 15156-1. They shall also be subject to the following additional requirements.

Laboratory testing for the evaluation of carbon and low alloy steels for addition to Annex A is for use with steels that do not comply with the general requirements described in A.2.1.

Addition of a carbon or low alloy steel to A.2 requires the testing described in Table B.1 for all SSC Regions of Figure 1 (see 7.2).

Addition of a carbon or low alloy steel to A.3 or A.4 requires the testing described in Table B.1 for the appropriate SSC Region of Figure 1 (see 7.2).

The steel to be qualified by laboratory testing shall be selected in accordance with NACE MR0175/ISO 15156-1.

The product(s) tested shall have been manufactured to a publicly available specification that enables manufacture by more than one supplier.

Material representing a minimum of three separately processed heats shall be tested for SSC resistance in accordance with B.3.

Sufficient data shall be provided to allow the members of ISO/TC 67 to assess the material and decide, in accordance with the ISO/IEC Directives, Part 1, on the suitability of the material for inclusion, by amendment or revision, into this part of NACE MR0175/ISO 15156.

B.3 Test procedures to evaluate the resistance of carbon and low alloy steels to SSC

Qualification shall be in accordance with B.1 and, as appropriate, Table B.1.

Unless otherwise indicated, test requirements shall be in accordance with NACE TM0177-96.

Generally, testing will be performed at ambient temperature [24 °C ± 3 °C (75 °F ± 5 °F)]. For testing at elevated temperatures, use may be made of the guidance on test environments given in NACE MR0175/ISO 15156-3:2003, Annex B.

For materials testing to a materials manufacturing specification, reference should be made to the appropriate specification, and to A.1 and B.1.

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Table B.1 — SSC laboratory testing for sour service

Qualification validity[f]	Test type [a, b, i]	Applied stress[c,d]	Environment	H_2S partial pressure	Acceptance criteria	Remarks
Specific application, or SSC Region 1 or Region 2 of Figure 1	UT	≥ 90 % AYS	5 % mass fraction NaCl + 0,4 % mass fraction CH_3COONa, pH adjusted to required value using HCl or NaOH[e]	Appropriate to intended application or SSC Region	No SSC cracks in accordance with NACE TM0177-96 assessment method	Specific application or less severe environments. Region qualification subject to adequate "coverage"[g]
	FPB[j] or CR					Use as qualification at equipment user's discretion and with documented justification
	DCB[h]	Not applicable			Assessment shall be in accordance with NACE TM0177-96. Acceptance criteria shall be by documented agreement [k]	
All SSC Regions of Figure 1	UT	≥ 80 % AYS	NACE TM0177-96 Environment A (5 % mass fraction NaCl + 0,5 % mass fraction CH_3COOH)	100 kPa (15 psi) in accordance with NACE TM0177-96	No SSC cracks in accordance with NACE TM0177-96 assessment method	Use as qualification at equipment user's discretion and with documented justification
	FPB[j] or CR					
	DCB[h]	Not applicable			Assessment shall be in accordance with NACE TM0177-96. Acceptance criteria shall be by documented agreement [k]	

[a] The test types are as follows:

— UT test in accordance with NACE TM0177-96 Method A;

— FPB test in accordance with EFC Publication 16, Appendix 2;

— CR test in accordance with NACE TM0177-96 Method C;

— DCB test in accordance with NACE TM0177-96 Method D;

— Other test specimens, including full-size components, may be used when appropriate. Their use shall be by agreement between the purchaser and the supplier.

[b] FPB, CR or UT tests are preferred for the qualification of welding and joining procedures (see 7.3 and 7.4). For welded samples: specimens shall normally be taken transverse to welds; testing shall be based upon the actual yield strength of the lowest yield strength parent metal; side 4-point bend testing may be used, subject to the agreement of the equipment user. For details of side bend tests, see NACE publication Corrosion 2000 Paper 128.

[c] For applications where a low service stress level, as a proportion of yield strength, is guaranteed, the test stress may be reduced to the maximum service stress. In such cases, the tests and acceptance criteria shall be agreed with the equipment user. Such agreements shall be documented.

[d] AYS = Actual yield strength of material in finished form at the test temperature. The AYS shall be as defined in the product specification or the 0,2 % proof stress ($R_{p0.2}$) determined as the 'non-proportional elongation' in accordance with ISO 6892.

[e] For SSC tests with pH control, the pH value during tests should be less than or equal to the required value. Control to within a range of 0,1pH units is achievable in practice.

[f] See NACE MR0175/ISO 15156-1:2001, Clause 5 for more information regarding designs utilizing plastic design criteria.

[g] Testing under the conditions listed in Table B.2 provides qualification for use throughout a Region.

[h] For special cases, including components of heavy section or of complex shape, DCB tests may be used to support designs based on fracture mechanics.

[i] Test types are not necessarily equivalent and results may not be directly comparable.

[j] When SOHIC and/or SZC evaluation of a test specimen are carried out, see 7.2.2, the requirements of this table and of B.4 shall be met.

[k] See ISO 11960 for information on tubing and casing grades C90 and T95.

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Table B.2— Test conditions

pH	Required H_2S partial pressures for tests kPa	
	Set of conditions for SSC Region 1	Set of conditions for SSC Region 2
3,5	—	1
4,0	0,3	—
4,5	1	10
5,5	10	100
6,5	100	—

B.4 Test procedures to evaluate the resistance of carbon and low alloy steels to SOHIC and SZC

B.4.1 General

The test methods described in this annex have been used successfully to demonstrate sensitivity to SOHIC or SZC.

Materials shall have been qualified with respect to SSC resistance for the design conditions prior to SOHIC/SZC evaluation.

When evaluating welds, 7.3.3 shall also apply.

The validity of the test results for conditions other than those evaluated is defined in NACE MR0175/ISO 15156-1.

Test methods described for SOHIC and SZC are not standardized. Alternative tests are under development. The equipment user may choose other tests at his discretion. The justification of the use of such tests shall be documented.

B.4.2 Small-scale tests

B.4.2.1 Specimen selection

The test samples used to determine susceptibility to SOHIC/SZC shall be the apparently unfailed UT or FPB test specimens taken from successful SSC qualification testing. Steels selected using A.2 shall also undergo SSC testing according to B.1 prior to the SOHIC/SZC evaluation.

For small-scale testing of welds, specimens shall be taken transverse to the weld.

B.4.2.2 Evaluation and acceptance criteria for UT test specimens

One of the following evaluations and acceptance criteria for UT test specimens shall apply.

a) Heat the specimens to 150 °C and hold at that temperature for 2 h, to remove absorbed hydrogen. Measure the tensile strength of the specimen. The tensile strength shall be not less than 80 % of the actual tensile strength of the material as determined on identical, previously unused, specimens.

b) Make at least two metallographic sections parallel to the sample axis. Examine the sections for possible ladderlike HIC features and other cracks related to SOHIC or to the soft zones of a weld (SZC). No ladderlike HIC indications nor cracks exceeding a length of 0,5 mm in the through thickness direction are allowed.

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B.4.2.3 Evaluation and acceptance criteria for FPB test specimens

A wet magnetic particle examination shall be carried out on the side of the sample that was under tensile stress during H_2S exposure.

Below any magnetic particle indications running perpendicular to the stress axis, metallographic sectioning shall be made perpendicular to the indications or, in the absence of magnetic particle indications, at least two metallographic sections shall be made parallel to the stress axis of the specimen.

Sections produced in these ways shall be examined for possible ladderlike HIC features and other cracks related to SOHIC or to the soft zones of a weld (SZC). No ladderlike HIC features nor cracks exceeding a length of 0,5 mm in the through thickness direction are allowed.

To assist the detection of damage, specimens may be plastically deformed by 5 % in the previous bending direction prior to metallographic sectioning. Prior to deformation, the specimens shall be heated to 150 °C and maintained at that temperature for 2 h, to remove absorbed hydrogen.

Damage developed on the tensile side of a specimen in the form of blisters less than 1 mm below the surface, or on the compression side regardless of the depth of the blister, may be disregarded for the assessment of SOHIC/SZC but shall be reported.

B.4.3 Full pipe ring tests

Full pipe ring tests may be used. The document HSE OTI-95-635 describes a test and acceptance criteria.

NOTE Residual stress has been shown to play an important role in the initiation of SOHIC and SZC. Such stresses in field situations could be better represented in large-scale specimens.

B.5 Test procedures and acceptance criteria to evaluate the resistance of carbon and low alloy steels to HIC/SWC

Test procedures and acceptance criteria shall be in accordance with Table B.3.

Testing shall be performed at ambient temperature [25 °C ± 3 °C (77 °F ± 5 °F)].

Unless otherwise indicated, test requirements shall be in accordance with NACE TM0284.

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Table B.3 —— HIC/SWC test procedure and acceptance criteria

Product type	Applied stress	Environment	H_2S partial pressure	Acceptance criteria[e]	Qualification validity
Flat-rolled steels or their products [a, b]	No applied stress	NACE TM0177-96 Environment A (5 % mass fraction NaCl + 0,5 % mass fraction CH_3COOH)[c]	100 kPa (15 psi)[c]	CLR u 15 % CTR u 5 % CSR u 2 %	Any sour service
		5 % mass fraction NaCl + 0,4 % mass fraction CH_3COONa, pH adjusted to required value using HCl or NaOH[d]	Appropriate to intended application[d]	No cracking[g]	Specific, or less severe duty[f]

[a] Qualification of seamless tubular products may also be appropriate, see Clause 8.

[b] The samples to be taken to represent the general performance of an order should be agreed between the producer and the equipment user. The sampling of materials for testing shall comply with NACE MR0175/ISO 15156-1.

[c] The user is responsible for deciding if this test environment is adequate to represent the severity of the intended application.

[d] Application-specific tests of steel for new or existing installations may be carried out. In such cases tests of longer duration than the standard 96 h (see NACE TM0284) may be applied at the equipment user's discretion. Such tests may be required to improve confidence in the results obtained.

[e] At the request of the equipment user, ultrasonic evaluation of coupons may be used to find and evaluate areas of cracking prior to the selection of locations for metallurgical sectioning. See also EFC Publication 16, Section B7. Other acceptance criteria may be agreed between the supplier and the equipment user. Such agreements shall be documented.

[f] See NACE MR0175/ISO 15156-1:2001, Clause 5 for further information regarding designs utilizing plastic design criteria.

[g] Other acceptance criteria may be used subject to the documented approval of the equipment user.

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Annex C
(informative)

Determination of H_2S partial pressure

C.1 Calculation of partial pressure of H_2S for systems with a gas phase

The partial pressure of H_2S may be calculated by multiplying the system total pressure by the mole fraction of H_2S in the gas phase i.e.

$$p_{H_2S} = p \times \frac{x_{H_2S}}{100}$$

where

p_{H_2S} is the partial pressure of H_2S, expressed in MPa (psi);

p is the system total absolute pressure, expressed in MPa (psi);

x_{H_2S} is the mole fraction of H_2S in the gas, expressed in %.

For example, in a 70 MPa (10 153 psi) gas system, where the mole fraction of H_2S in the gas is 10 %, the H_2S partial pressure is 7 MPa (1 015 psi).

If the system total pressure and concentration of H_2S are known, H_2S partial pressures can also be estimated using Figure C.1.

C.2 Calculations of effective H_2S partial pressure for gas free liquid systems

For liquid systems (for which no equilibrium gas composition is available), the effective thermodynamic activity of H_2S is defined by a virtual partial pressure of H_2S that may be determined in the following way.

a) Determine the bubble-point pressure (p_B) of the fluid at operating temperature by any suitable method.

NOTE For a liquid-full pipeline downstream of gas separation units, a good approximation for bubble-point pressure is the total pressure of the last gas separator.

b) Determine the mole fraction of H_2S in the gas phase at bubble-point conditions by any suitable method.

c) Calculate the partial pressure of H_2S in the gas at the bubble point from the following formula:

$$p_{H_2S} = p_B \times \frac{x_{H_2S}}{100}$$

where

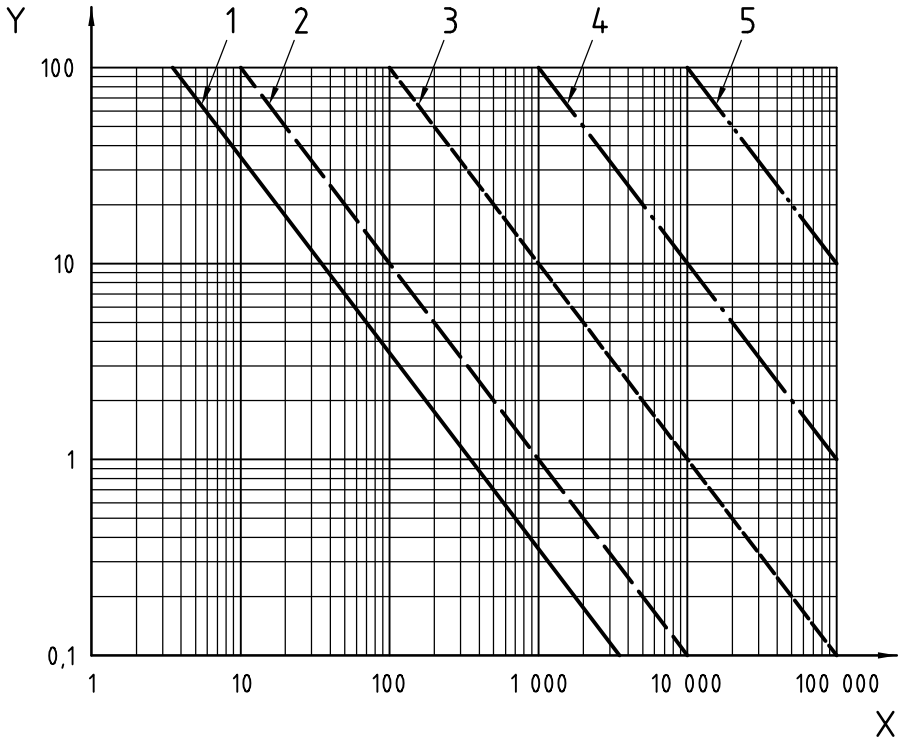
p_{H_2S} is the partial pressure H_2S, expressed in MPa (psi);

p_B is the bubble-point pressure, expressed in MPa (psi);

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x_{H_2S} is the mole fraction of H_2S in the gas, expressed in %.

d) Use this as the H_2S partial pressure for the liquid system. This value can be used to determine if a system is sour in accordance with Option 1 (see 7.1) or to determine its degree of sourness in accordance with Option 2 (see 7.2).



Key

X mole fraction H_2S in gas, % $\times 10^4$ (parts per million by volume)

Y total absolute pressure, MPa

1 p_{H_2S} = 0,3 kPa

2 p_{H_2S} = 1 kPa

3 p_{H_2S} = 10 kPa

4 p_{H_2S} = 100 kPa

5 p_{H_2S} = 1 000 kPa

Figure C.1 — Sour gas systems: H_2S partial pressure isobars

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Annex D
(informative)

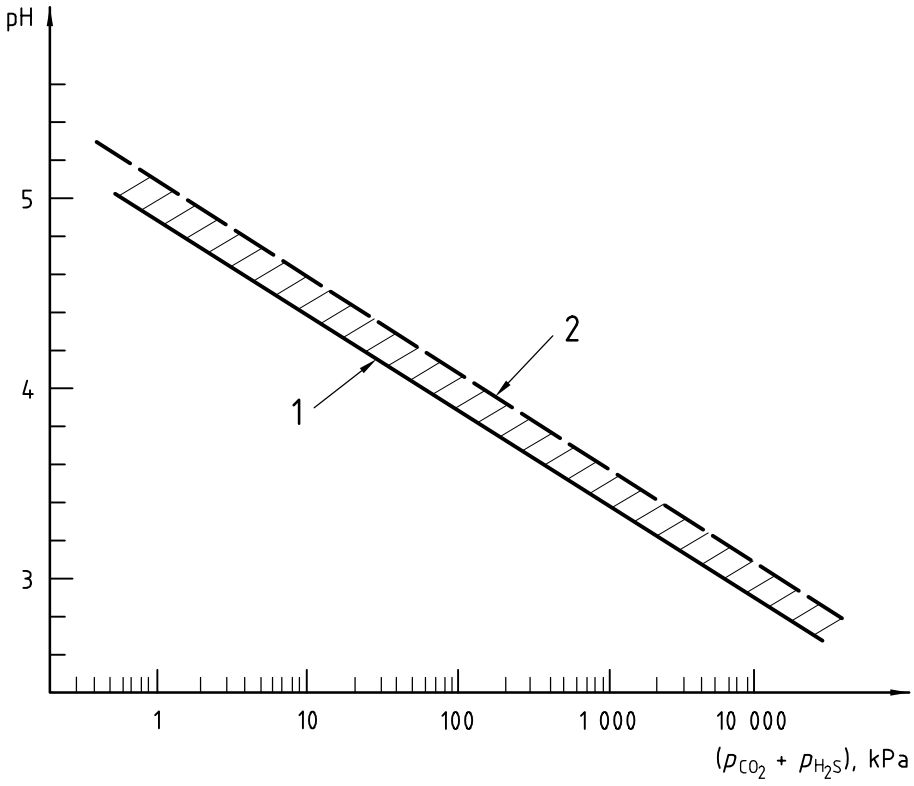
Recommendations for determining pH

Use of Figure 1 requires the determination of *in situ* pH for the production conditions. Figure D.1, Figure D.2, Figure D.3, Figure D.4 and Figure D.5 give a general guide to the determination of an approximate value of the pH of the water phase for various conditions. pH determined in this way may be used if no proven calculation or reliable *in situ* measuring techniques are available. The likely error band may be taken as +0,5 to 0,0 pH units.

In Figures D.1 to D.5, the ordinate axis is *in situ* pH. pH values routinely reported for depressurized water samples should not be mistaken as valid *in situ* pH values.

The *in situ* pH may also be influenced by the presence of organic acids, such as acetic acid, propionic acid, etc. (and their salts), that are not considered in Figures D.1 to D.5. The importance of the influences of these acids on *in situ* pH and on the results of conventional water analyses are described in EFC Publication 17, Appendix 2. Analysis for these components should be made in order to make the necessary adjustments to the calculated *in situ* pH.

NOTE Figures D.1 to D.5 are adapted from reference [25] in the Bibliography.

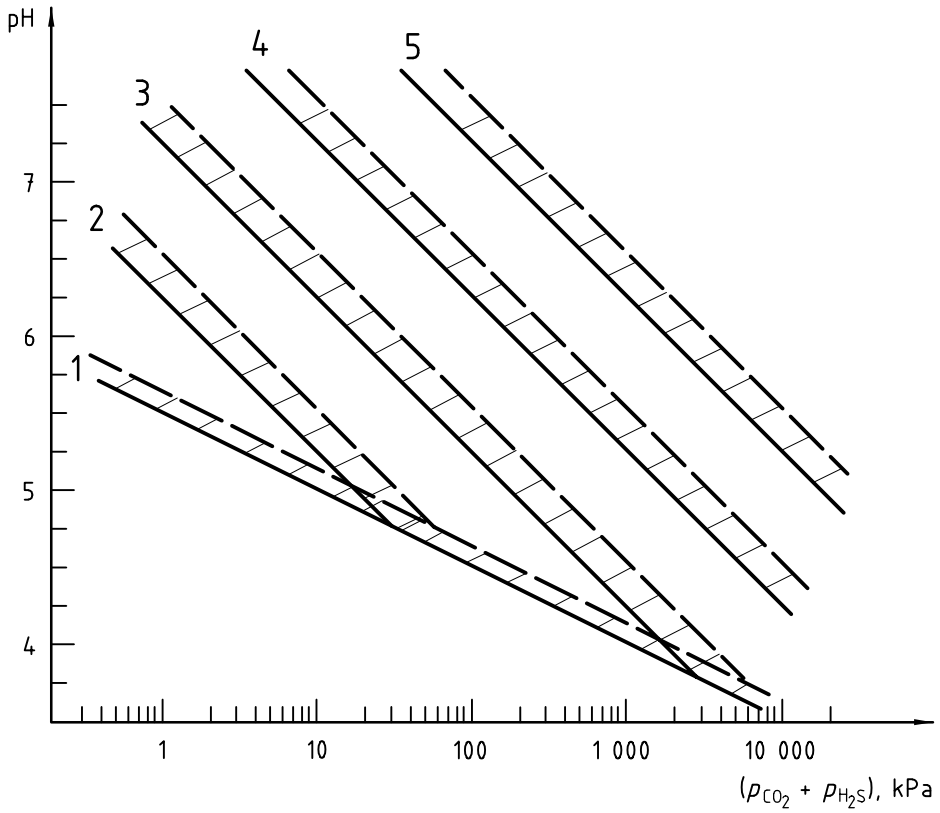


Key

1 temperature = 20 °C
2 temperature = 100 °C

Figure D.1 — The pH of condensed water under CO_2 and H_2S pressure

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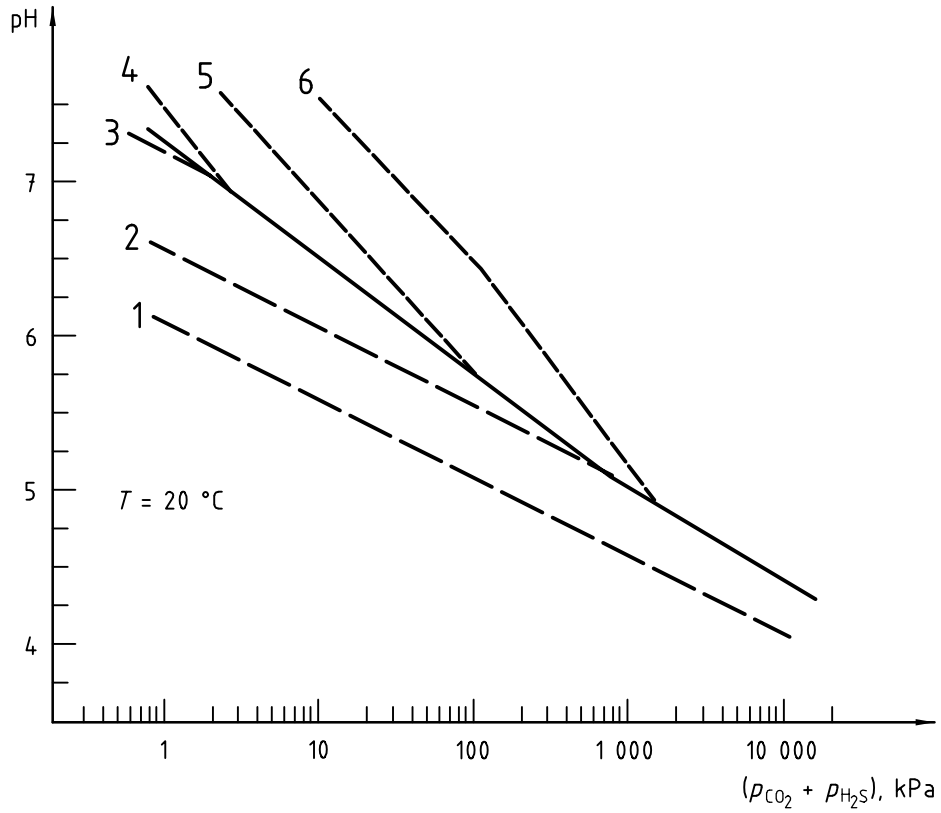


Key

1 HCO_3^- = 0 meq/l
2 HCO_3^- = 0,1 meq/l
3 HCO_3^- = 1 meq/l
4 HCO_3^- = 10 meq/l
5 HCO_3^- = 100 meq/l
– – – – T = 100 °C
——— T = 20 °C

Figure D.2 — The pH of condensate water (wet gas) or formation waters containing bicarbonate (undersaturated in $CaCO_3$) under CO_2 and H_2S pressure

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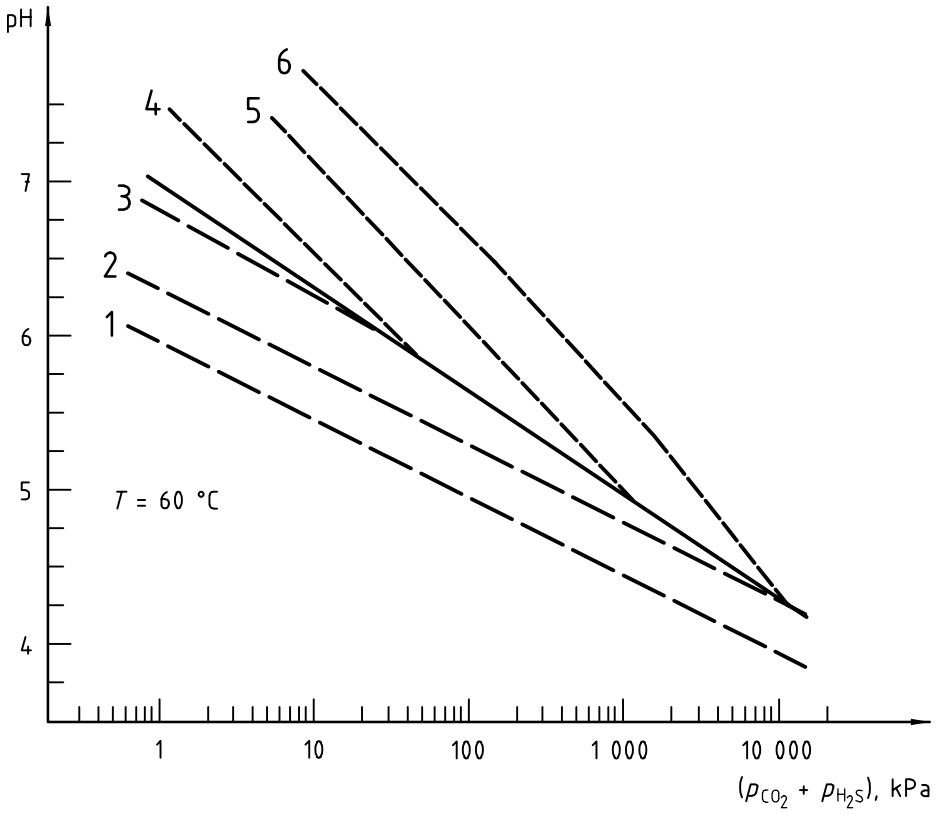


Key

1 Ca^{2+} = 1 000 meq/l
2 Ca^{2+} = 100 meq/l
3 Ca^{2+} = 10 meq/l
4 HCO_3^- = 10 meq/l
5 HCO_3^- = 30 meq/l
6 HCO_3^- = 100 meq/l
– – – – $Ca^{2+} < HCO_3^-$
——— $Ca^{2+} = HCO_3^-$
— — $Ca^{2+} > HCO_3^-$

Figure D.3 — The pH of formation waters (super)saturated in $CaCO_3$ (stoichiometric or non-stoichiometric) under CO_2 and H_2S pressure at 20 °C

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Key

1 Ca^{2+} = 1 000 meq/l
2 Ca^{2+} = 100 meq/l
3 Ca^{2+} = 10 meq/l
4 HCO_3^- = 10 meq/l
5 HCO_3^- = 30 meq/l
6 HCO_3^- = 100 meq/l
– – – – $Ca^{2+} < HCO_3^-$
——— $Ca^{2+} = HCO_3^-$
— — $Ca^{2+} > HCO_3^-$

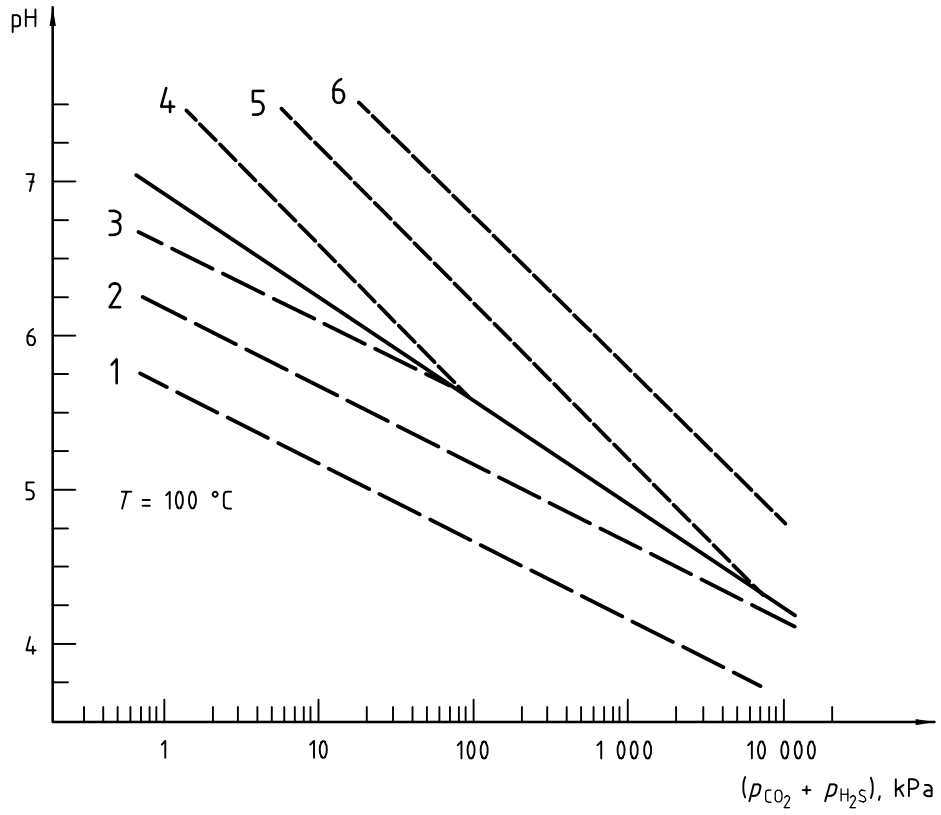
Figure D.4 — The pH of formation waters (super)saturated in $CaCO_3$ (stoichiometric or non-stoichiometric) under CO_2 and H_2S pressure at 60 °C

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Key

1 Ca^{2+} = 1 000 meq/l
2 Ca^{2+} = 100 meq/l
3 Ca^{2+} = 10 meq/l
4 HCO_3^- = 10 meq/l
5 HCO_3^- = 30 meq/l
6 HCO_3^- = 100 meq/l
– – – – $Ca^{2+} < HCO_3^-$
——— $Ca^{2+} = HCO_3^-$
— — $Ca^{2+} > HCO_3^-$

Figure D.5 — The pH of formation waters (super) saturated in $CaCO_3$ (stoichiometric or non-stoichiometric) under CO_2 and H_2S pressure at 100 °C

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Annex E
(informative)

Information to be supplied for material purchasing

Column 2 of Table E.1 and Table E.2 should be completed by the materials purchaser. Acceptable/required options should be indicated.

NOTE The designation NACE MR0175/ISO 15156-2A, in column 5, is generally equivalent to previously specifying carbon steels, low alloy steels or cast irons in accordance with NACE MR0175.

Table E.1 — Minimum information for material purchasing

Purchaser's reference				
Equipment type				
Preferred steel (or cast iron) type and/or grade				
Governing sour service specification: NACE MR0175/ISO 15156 **Materials requirements for this purchase order**		**Reference clause in NACE MR0175/ISO 15156-2**	**Remarks**	**Sour service designation NACE MR0175/ISO 15156-xx, (multiple codes may be required)**
SSC resistance Option 1: Carbon steel, low alloy steel or cast iron for sour service selected from A.2	Yes/No	7.1		2A
SSC resistance Option 2: Carbon or low alloy steel for specific sour service applications or for ranges of sour service	Yes/No	7.2	If selected, see also 5.3 and Table E.2	
HIC resistance: (a) Material for any sour service? (b) Material for specific sour service applications or for ranges of sour service?	 Yes/No Yes/No	Clause 8 and B.5	 If selected, see also 5.3 and Table E.2	2H

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Table E.2 — Additional information for SSC testing and other special cases

Purchaser's reference				
Materials requirements for this purchase order		**Reference clause in NACE MR0175/ISO 15156-2**	**Remarks**	**Sour service designation NACE MR0175/ISO 15156-xxx, (multiple codes may be required)**
Resistance to SSC following Option 2	Indicate preferred options	7.2		
a) Sour service for any SSC Region? Test specimen type	Yes/No	7.2.1.4, Fig. 1, Table B.1 and its Notes	UT test specimens by default	2R3
b) Sour service for SSC Region 2 and 1? Test specimen type	Yes/No	7.2.1.4, Fig. 1 Table B.1 and its Notes	UT test specimens by default	2R2
c) Sour service for SSC Region 1? Test specimen type	Yes/No	7.2.1.4, Fig. 1 Table B.1 and its Notes	UT test specimens by default	2R1
d) Specific sour service application required? Test specimen type	Yes/No	7.2.1.4, Table B.1 and its Notes	Test condition data below required. UT test specimens by default	2S
Resistance to HIC for specific sour service application?	Yes/No	Clause 8 and Table B.3	Test condition data below required	2HS
Description of test conditions		Table B.1 and/or Table B.3	Default values per Table B.1, other values require documented justification according to NACE MR0175/ISO 15156-1	
Test stress for SSC testing			% AYS (or as appropriate)	
CO_2			MPa (psi)	
H_2S			MPa (psi)	
Temperature			°C	
In situ pH			For calculation of pH see Annex D.	
Cl^- or other halide			mg/l	
Elemental sulfur (S^0)			Present or absent	
Special requirements				
SOHIC and SZC resistance requirements	Yes/No	7.2.2 and B.4	SSC testing always required before SOHIC/SZC testing	2Z with SSC designation from above

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[1] ISO 3183-3, *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 3: Pipes of requirement class C*

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

[3] NACE MR0175/ISO 15156-3:2003, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

[4] API Spec 5CT[4], *Specification for Casing and tubing*

[5] API Spec 5L, *Line pipe*

[6] ASME Boiler and pressure vessel code, Section IX[5] — *Qualification standard for welding and brazing procedures, welders, brazers, and welding and brazing operators*

[7] ASTM A 48/A 48M[6], *Standard specification for gray iron castings*

[8] ASTM A 53/A 53M, *Standard specification for pipe, steel, black and hot-dipped, zinc-coated, welded and seamless*

[9] ASTM A 105/A 105M, *Standard specification for carbon steel forgings for piping applications*

[10] ASTM A 106, *Standard specification for seamless carbon steel pipe for high-temperature service*

[11] ASTM A 193/A 193M, *Standard specification for alloy-steel and stainless steel bolting materials for high-temperature service*

[12] ASTM A 194/A 194M, *Standard specification for carbon and alloy steel nuts for bolts for high pressure or high temperature service, or both*

[13] ASTM A 220/A 220M, *Standard specification for pearlitic malleable iron*

[14] ASTM A 234/A 234M, *Standard specification for piping fittings of wrought carbon steel and alloy steel for moderate and high temperature service*

[15] ASTM A 278/A 278M, *Standard specification for gray iron castings for pressure-containing parts for temperatures up to 650 °F (350 °C)*

[16] ASTM A 320/A 320M, *Standard specification for alloy/steel bolting materials for low-temperature service*

[17] ASTM A 333/A 333M, *Standard specification for seamless and welded steel pipe for low-temperature service*

[18] ASTM A 381, *Standard specification for metal-arc-welded steel pipe for use with high-pressure transmission systems*

---

4) American Petroleum Institute, 1220 L Street NW, Washington, DC 20005-4070, USA

5) ASME International, Three Park Avenue, New York, NY 10016-5990, USA

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

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[19] ASTM A 395/A 395M, *Standard specification for ferritic ductile iron pressure-retaining castings for use at elevated temperatures*

[20] ASTM A 524, *Standard specification for seamless carbon steel pipe for atmospheric and lower temperatures*

[21] ASTM A 536, *Standard specification for ductile iron castings*

[22] ASTM A 571/A 571, *Standard specification for austenitic ductile iron castings for pressure-containing parts suitable for low-temperature service*

[23] ASTM A 602, *Standard specification for automotive malleable iron castings*

[24] ASTM E 140, *Standard hardness conversion tables for metals relationship among Brinell hardness, Vickers hardness, Rockwell hardness, Rockwell superficial hardness, Knoop hardness, and scleroscope hardness*

[25] BONIS M. and CROLET J-L., Practical aspects of the influence of *in situ* pH on H_2S- induced cracking, *Corrosion Science*, 1987, 27, pp. 1059-70

[26] BS 860[7], *Tables for comparison of hardness scales*

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

[28] HSE OTI-95-635[8], *A test method to determine the susceptibility to cracking of linepipe steels in sour service*

[29] NACE CORROSION/2000, Paper 128, *A new device for side bend testing on pipe seam welds*

[30] NACE MR0176, *Metallic materials for sucker-rod pumps for corrosive oilfield environments*

[31] NACE MR0175, *Sulfide stress cracking resistant metallic materials for oilfield equipment*

[32] SAE – ASTM, *Metals and alloys in the unified numbering system*, ISBN 0-7680-0407

7) British Standards Institution, 389 Chiswick High Road, London W4 4AL, UK

8) UK Health and Safety Executive, HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA, UK [ISBN 0-7176-1216-3]

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INTERNATIONAL STANDARD

NACE MR0175/ ISO 15156-3

First edition
2003-12-15

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

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

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

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

Reference number
NACE MR0175/
ISO 15156-3:2003(E)

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Foreword

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

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

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

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

NACE MR0175/ISO 15156-3 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*.

NACE MR0175/ISO 15156 consists of the following parts, under the general title *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production*:

— *Part 1: General principles for selection of cracking-resistant materials*

— *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*

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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. NACE MR0175 is complemented by NACE TM0177-96 and NACE TM0284 test methods.

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

This part of NACE MR0175/ISO 15156 utilises 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.

Changes will be incorporated into this International Standard by amendments or revisions in accordance with *Interpretation and maintenance of NACE MR0175/ISO 15156* by ISO/TC 67/WG 7, copies of which can be obtained from the ISO/TC 67 Secretariat. Experts from both NACE and EFC are members of ISO/TC 67/WG 7.

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

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

WARNING — CRAs (corrosion-resistant alloys) and other alloys selected using this part of NACE MR0175/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 NACE MR0175/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 could pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help to avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the materials' requirements of the appropriate design codes, standards or regulations.

This part of NACE MR0175/ISO 15156 addresses the resistance of these materials to damage that may be caused by sulfide stress-cracking (SSC), stress-corrosion cracking (SCC) and galvanically-induced hydrogen stress-cracking (GHSC).

This part of NACE MR0175/ISO 15156 is only concerned 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 NACE MR0175/ISO 15156 is applicable, including permitted exclusions.

This part of NACE MR0175/ISO 15156 applies to the qualification and selection of materials for equipment designed and constructed using conventional elastic design criteria. For designs utilizing plastic criteria (e.g. strain-based and limit-state designs), see NACE MR0175/ISO 15156-1:2001, Clause 5.

This part of NACE MR0175/ISO 15156 is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

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Table 1 — List of equipment

NACE MR0175/ISO 15156 is applicable to materials used for the following equipment	Permitted exclusions
Drilling, well construction and well-servicing equipment	Equipment only exposed to drilling fluids of controlled composition[a] Drill bits Blowout Preventer (BOP) shear blades[b] Drilling riser systems Work strings 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)
Natural gas treatment plants	
Transportation pipelines for liquids, gases and multiphase fluids	Lines handling gas prepared for general commercial and domestic use
For all equipment above	Components loaded only in compression

[a] See NACE MR0175/ISO 15156-2:2003, A.2.3.2.3 for more information.

[b] See NACE MR0175/ISO 15156-2:2003, 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 referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

ISO 6892, *Metallic materials — Tensile testing at ambient temperature*

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

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

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NACE MR0175/ISO 15156-1:2001, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

NACE MR0175/ISO 15156-2:2003, *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons*

ASTM A 747/A 747M[1)] , *Standard specification for steel castings, stainless, precipitation hardening*

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

NACE CORROSION/95[3)] , Paper 47, (Houston), 1995, *Test methodology for elemental sulfur-resistant advanced materials for oil and gas field equipment,* by G. Steinbeck, W. Bruckhoff, M. Köhler, H. Schlerkmann, G. Schmitt

NACE TM0177-96, *Laboratory testing of metals for resistance to sulfide stress cracking and stress corrosion cracking in H_2S environments*

SAE[4)] – ASTM, *Metals and alloys in the Unified Numbering System, ISBN 0-7680-0407*4

3 Terms and definitions

For the purposes of this document, the terms and definitions given in NACE MR0175/ISO 15156-1 and NACE MR0175/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-base alloys

3.4
duplex stainless steel
austenitic/ferritic stainless steel
stainless steel whose microstructure at room temperature consists primarily of a mixture of austenite and ferrite

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, 1440 South Creek Dr., Houston, TX 77084-4906, USA

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

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

3.6
ferritic stainless steel
stainless steel whose microstructure, at room temperature, consists predominantly of ferrite

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 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 Cr, Mo, W and N in the chemical composition of the alloy

NOTE See 6.3 for further information.

3.11
solid solution
single crystalline phase containing two or more elements

3.12
stainless steel
steel containing 10,5 % 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 NACE MR0175/ISO 15156-1 and NACE MR0175/ISO 15156-2 apply, some of which are repeated for the purpose of convenience, together with the following:

AYS actual yield strength

CRA corrosion-resistant alloy

HBW Brinell hardness

HRB Rockwell hardness (scale B)

HRC Rockwell hardness (scale C)

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p_{CO_2} partial pressure of CO_2

p_{H_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 behavior 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 NACE MR0175/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.

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Compliance of a CRA or other alloy with this part of NACE MR0175/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 may 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 might occur during system upsets or shutdowns, etc. shall also be considered. Such exposures can include unbuffered, low pH, condensed water and acids used for well stimulation. In the case of stimulation acids, conditions occurring during backflow shall be considered.

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 NACE MR0175/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 may 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 may 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 Clause 9 of NACE MR0175/ISO 15156-1:2001.

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 NACE MR0175/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 NACE MR0175/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 NACE MR0175/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 NACE MR0175/ISO 15156.

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 may have a greater susceptibility to cracking than the parent material(s) joined.

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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 (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 NACE MR0175/ISO 15156-1.

The requirements and recommendations given in Annex A may 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.

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, and repair and partial penetration welds shall be carried out as described in 7.3.3.3 of NACE MR0175/ISO 15156-2:2003.

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

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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

The PREN (F_{PREN}) shall be calculated as follows:

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

where

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

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

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

w_{N} is the mass fraction of nitrogen in the alloy, expressed as a percentage 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 to be supplied for material purchasing

7.1.1 The preparation of material purchasing specifications might require co-operation and exchange of data between the equipment user, the equipment supplier and the material manufacturer to ensure that the material purchased complies with NACE MR0175/ISO 15156-1 and this part of NACE MR0175/ISO 15156.

7.1.2 The following information shall be provided:

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

— equipment type (if known);

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— reference to this part of NACE MR0175/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:

— 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

Materials complying with this part of NACE MR0175/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 tables in Annex C provide designations that may be used to identify materials.

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Annex A
(normative)

Environmental cracking-resistant CRAs and other alloys

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) (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 Tables A.1 to 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.

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,* (see Annex D).

To comply with this part of NACE MR0175/ISO 15156, the material shall also meet any provision shown in the text and/or tables of its materials group.

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A.1.3 Environmental and metallurgical limits for cracking resistance

Subclauses 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, p_{H_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 it is commonly expressed in parts per million (ppm).

NOTE 2 Guidance on the calculation of p_{H_2S}, is given in NACE MR0175/ISO 15156-2:2003, Annex C.

NOTE 3 Guidance on the calculation of pH is given in NACE MR0175/ISO 15156-2:2003, 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 could be defined in a table, explanatory remarks that reflect current knowledge have been included in the table.

The environmental limits for an alloy are only valid 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. NACE MR0175/ISO 15156-1:2001, 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.

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 NACE MR0175/ISO 15156.

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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 NACE MR0175/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-S-13165.

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 Locating named equipment or components in the 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.

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 will be required to comply with the requirements of this materials group. See also A.3.1.

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

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Table A.1 — Guide to the use of the materials selection tables of Annex A

Equipment or components	Materials groups										Material selection table numbers
	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)	**Matensitic 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.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.14		A.19	A.25					
Packers and other subsurface equipment		A.9	A.14		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**											
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			

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
Austenitic stainless steel from materials type described in A.2	60 (140)	100 (15)	See remarks	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
	60 (140)	350 (50)	50	See remarks	NDS [a]	*In situ* pH values occurring in production environments are acceptable.
S20910	66 (150)	100 (15)	See remarks	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.

These materials shall also

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.

However, S20910 is acceptable in the annealed or hot-rolled (hot/cold-worked) condition at a maximum hardness of 35 HRC.

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

[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.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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
S20910	See remarks	See remarks	See remarks	See remarks	NDS [a]	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH occurring in production environments are 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.

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

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
S31600	See remarks	See remarks	See remarks	See remarks	NDS [a]	This material has been used for these components without restriction on temperature, p_{H_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 may not be acceptable.
UNS S31600 stainless steel may be used for compression fittings and instrument tubing even though it may 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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
J92600, J92900	See remarks	See remarks	See remarks	See remarks	NDS [a]	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH occurring in production environments are acceptable.
For these applications, the following materials restrictions shall apply. — J92600 or J92900 API compression seal rings and gaskets made of wrought or centrifugally cast material, in the as-cast or 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.						

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

Materials type	Temperature max. °C (°F)	Partial pressure H_2S, p_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
Austenitic stainless steel from materials type described in A.2	See remarks	See remarks	See remarks	See remarks	NDS [a]	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH occurring in production environments are 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.						

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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
Austenitic stainless steel from materials group described in A.2	See remarks	See remarks	See remarks	See remarks	NDS [a]	These materials have been used for these components without restriction on temperature, p_{H_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 may 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 (mass fraction) of 0,03 %.

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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.

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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 types/ 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	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
Materials type 3a	60 (140)	350(50)	< 50	See remarks	No	The *in situ* pH values occurring in production environments are acceptable.
Materials type 3b	121 (250)	700 (100)	5 000	See remarks	No	
	149 (300)	310 (45)	5 000	See remarks	No	
	171 (340)	100 (15)	5 000	See remarks	No	
N08926	121 (250)	700 (100)	60 700	W 3,5, see also remarks	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	90 000	See remarks	No	The *in situ* pH values occurring in production environments are acceptable.
J93254	See remarks	See remarks	See remarks	See remarks	No	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH 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 (Ni + 2Mo) > 30 (where Mo has a minimum value of 2 %).

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

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

— Cast UNS J93254 (CK3McuN, cast 254SMO) in accordance with ASTM A 351, A 743 or A 744 shall be in the cast, solution heat-treated condition and shall have a maximum hardness of 100 HRB.

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

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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 types/ 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	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
Materials type 3a	60 (140)	350 (50)	50	See remarks	No	The *in situ* pH values occurring in production environments are acceptable.
Materials type 3b	121 (250)	700 (100)	5 000	See remarks	No	
	149 (300)	310 (45)	5 000	See remarks	No	
	171 (340)	100 (15)	5 000	See remarks	No	
N08926	121 (250)	700 (100)	60 700	W 3,5, see also remarks	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

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 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 (Ni + 2 Mo) > 30 (where Mo has a minimum value of 2 %).

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

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

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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_{H_2S} 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	See remarks	See remarks	See remarks	NDS[a]	These materials have been used for these components without restriction on temperature, p_{H_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 may 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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
Materials types 3a and 3b	See remarks	See remarks	See remarks	See remarks	NDS[a]	These materials have been used for these components without restriction on temperature, p_{H_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 may not be acceptable.
N08904	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH occurring in production environments are acceptable.
Materials type 3a shall be highly-alloyed austenitic stainless steel with Ni + 2 Mo > 30 (where Mo has a minimum value of 2 %). Materials type 3b shall be highly-alloyed austenitic stainless steel with a $F_{PREN} > 40$. 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.

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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 types	**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
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 will be needed.					

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

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

Materials types	Temperature max. °C (°F)	Partial pressure H_2S, p_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
Annealed alloys of types 4a and 4b	See remarks	See remarks	See remarks	See remarks	Yes	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH occurring in production environments are acceptable.
These wrought or cast solid-solution nickel-based products shall be in the solution-annealed or annealed condition. Wellhead and christmas tree components shall also be in accordance with ISO 10423.						

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Table A.14 — Environmental and materials limits for annealed and cold-worked, solid-solution nickel-based alloys used as downhole tubular components, packers and other subsurface equipment

Materials types	Temperature max. °C (°F)	Partial pressure H_2S, p_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
Cold-worked alloys of types 4c, 4d and 4e	232 (450)	0,2 (30)	See remarks	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
	218 (425)	0,7 (100)	See remarks	See remarks	No	
	204 (400)	1 (150)	See remarks	See remarks	No	
	177 (350)	1,4 (200)	See remarks	See remarks	No	
	132 (270)	See remarks	See remarks	See remarks	Yes	Any combinations of hydrogen sulfide, chloride concentration and *in situ* pH in production environments are acceptable.
Cold-worked alloys of types 4d and 4e	218 (425)	2 (300)	See remarks	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
	149 (300)	See remarks	See remarks	See remarks	Yes	Any combinations of hydrogen sulfide, chloride concentration and *in situ* pH in production environments are acceptable.
Cold-worked alloys of type 4e	232 (450)	7 (1 000)	See remarks	See remarks	Yes	Any combinations of chloride concentration, *in situ* pH occurring in production environments are acceptable.
	204 (400)	See remarks	See remarks	See remarks	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 and shall meet both of the following.

a) The maximum hardness value for alloys in these applications shall be 40 HRC; and

b) 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).

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

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
N10276	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH occurring in production environments are 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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
N04400, N04405	See remarks	See remarks	See remarks	See remarks	NDS[a]	These materials have been used for these components without restriction on temperature, p_{H_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 may 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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
Ferritic stainless steels from materials type described in A.5	See remarks	10 (1,5)	See remarks	≥ 3,5	NDS[a]	Any combinations of temperature and chloride concentration occurring in production environments are 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 the Tables of A.6.2.

Free-machining martensitic stainless steels shall not be used.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
S41000, S42000, J91150, J91151, J91540, S42400	See remarks	10 (1,5)	See remarks	W 3,5	NDS[a]	Any combinations of temperature and chloride concentration occurring in production environments are acceptable
S41425	See remarks	10 (1,5)	See remarks	W 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 (1150°F) minimum, then cooled to ambient temperature, and
   3) tempered at 621°C (1150°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, 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, and
   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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
ISO 11960 L-80 Type 13 Cr, S41426, S42500	See remarks	10 (1,5)	See remarks	W 3,5	NDS[a]	Any combinations of temperature and chloride concentration occurring in production environments are acceptable
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 (1652 °F), then air- or oil-quench; 2) temper at minimum 730 °C (1346 °F), then cool to ambient temperature; and 3) temper at minimum 620 °C (1148 °F), then 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.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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
K90941	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature, p_{H_2S}, chloride concentration and *n situ* pH occurring in production environments are acceptable.
For these applications, UNS K90941 (martensitic 9Cr 1Mo to ASTM A 276 type 9, ASTM A 182/A 182M grade F9, or ASTM A 213/A 213M 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.						

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
AISI 420 (modified)	See remarks	10 (1,5)	See remarks	W 3,5	NDS[a]	Any combinations of temperature and chloride concentration occurring in production environments are acceptable
S41427	See remarks	10 (1,5)	6000	W 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) Temper at 600 °C to 700 °C (1 112 °F to 1 292 °F), then air-cool to ambient temperature.

c) Temper 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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
S41000, S42400, J91150, J91151, J91540	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature, p_{H_2S}, chloride concentration and *in situ* pH occurring in production environments are 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, and
   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, 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, and
   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 shall exhibit a threshold stress W 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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
S41000, S42000, J91150, J91151, J91540, S42400	See remarks	See remarks	See remarks	W 3,5	NDS[a]	Any combinations of temperature, p_{H_2S} and chloride concentration occurring in production environments are 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, and
   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 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; and
   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] 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).

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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 the Table D.7 will be 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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
30 ≤ F_{PREN} ≤ 40, Mo ≥ 1,5 %	232 (450)	10 (1,5)	See remarks	See remarks	NDS[a]	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable
S31803 (HIP)	232 (450)	10 (1,5)	See remarks	See remarks	No	
40 < F_{PREN} ≤ 45	232 (450)	20 (3)	See remarks	See remarks	NDS[a]	
Wrought and cast duplex stainless steels shall — be solution-annealed and liquid-quenched, — have a ferrite content (volume fraction) of between 35 % and 65 %, and — not have undergone ageing heat-treatments. Hot isostatic pressure-produced (HIP) [18] duplex stainless steel UNS S31803 (30 ≤ F_{PREN} ≤ 40, 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.						

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
30 ≤ F_{PREN} ≤ 40, Mo ≥ 1,5 %	See remarks	2 (0,3)	See remarks	See remarks	NDS[a]	Any combinations of temperature, chloride concentration and *in situ* pH occurring in production environments are acceptable.
40 < F_{PREN} ≤ 45	See remarks	20 (3)	120 000	See remarks	NDS[a]	Any combinations of temperature and *in situ* pH occurring in production environments are 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 E 562 and shall be in the range of 30 % to 70 % volume fraction.

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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 Tables A.27, A.28, A.29 and 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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
S66286	65 (150)	100 (15)	See remarks	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are 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						

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
UNS S17400	See remarks	3,4 (0,5)	See remarks	W 4,5	NDS[a]	Any combinations of temperature and chloride concentration occurring in production environments are acceptable.
UNS S45000	See remarks	10 (1,5)	See remarks	W 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); and
      - 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); and
      - 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:
   - solution-anneal;
   - 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.

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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_{H_2S} 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	See remarks	See remarks	See remarks	NDS[a]	These materials have been used for these components without restriction on temperature, p_{H_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 may not be acceptable.
S17400, S15500	See remarks	See remarks	See remarks	See remarks	NDS[a]	
S45000	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature. p_{H_2S}, Cl^-, and *in situ* pH occurring in production environments are acceptable.
Miscellaneous equipment						
S17400	See remarks	See remarks	See remarks	See remarks	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 A 747/A 747M 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); and
      — 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:
   — solution-anneal;
   — 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.

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

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
S15700	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature. p_{H_2S}, Cl^-, and *in situ* pH occurring in production environments are 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.						

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

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
S17400, S15500	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature. p_{H_2S}, Cl^-, and *in situ* pH occurring in production environments are acceptable.
S45000	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature. p_{H_2S}, Cl^-, and *in situ* pH occurring in production environments are 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 ẅ 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.

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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 the Tables of A.9.2.

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

Table A.31, Table A.32 and 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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
N07031, N07048, N07773 and N09777 (wrought) N07718 (cast), N09925 (cast)	232 (450)	200 (30)	See remarks	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
	204 (400)	1 400 (200)	See remarks	See remarks	No	
	149 (300)	2 700 (400)	See remarks	See remarks	No	
N07031, N07048, N07773 and N09777 (wrought)	135 (275)	See remarks	See remarks	See remarks	Yes	Any combinations of hydrogen sulfide, chloride concentration and *in situ* pH in production environments are acceptable.
N09925 (cast)	135 (275)	See remarks	See remarks	See remarks	No	
N07718 (cast)	135 (275)	See remarks	See remarks	See remarks	NDS[a]	
N07924 (wrought)	175 (347)	3 500 (500)	121 300	W 3,5, see also remarks	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.

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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 H_2S, p_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
N07718, N09925	232 (450)	200 (30)	See remarks	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
	204 (400)	1 400 (200)	See remarks	See remarks	No	
	199 (390)	2 300 (330)	See remarks	See remarks	No	
	191 (375)	2 500 (360)	See remarks	See remarks	No	
	149 (300)	2 800 (400)	See remarks	See remarks	No	
	135 (275)	See remarks	See remarks	See remarks	Yes	Any combinations of hydrogen sulfide, chloride concentration and *in situ* pH in production environments are acceptable.

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.

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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_{H_2S} 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	See remarks	No	Any combinations of chloride concentration and *in situ* pH occurring in production environments are acceptable.
	220 (425)	2 000 (300)	See remarks	See remarks	Yes	
	204 (400)	4 100 (600)	See remarks	See remarks	No	
	175 (350)	See remarks	See remarks	See remarks	Yes	Any combinations of hydrogen sulfide, chloride concentration and *in situ* pH in production environments are 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
   - solution-annealed [927 °C (1 700 °F) minimum] and aged [538 °C to 816 °C (1 000 °F to 1 500 °F)], or
   - 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.

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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
N05500	See remarks	3,4 (0,5)	See remarks	W 4,5	NDS[a]	Any combinations of temperature and chloride concentration occurring in production environments are 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.

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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_{H_2S} 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	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature. p_{H_2S}, chloride concentration, and *in situ* pH occurring in production environments are acceptable.
Miscellaneous equipment						
N05500	See remarks	See remarks	See remarks	See remarks	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
   - solution-annealed and aged,
   - solution-annealed,
   - hot-worked, or
   - hot-worked and aged.

b) Wrought UNS N05500 shall have a maximum hardness of 35 HRC and shall be either
   - hot-worked and age-hardened;
   - solution-annealed; or
   - 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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
N07750	See remarks	See remarks	See remarks	See remarks	NDS [a]	This material has been used for these components without restriction on temperature, p_{H_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	See remarks	See remarks	See remarks	NDS [a]	This material has been used for these components without restriction on temperature, p_{H_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 may not be acceptable.

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

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

b) UNS N07090 may 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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
N05500	See remarks	See remarks	See remarks	See remarks	NDS[a]	This material has been used for these components without restriction on temperature, p_{H_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 may 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 the Tables of A.10.2.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
R30003, R30004, R30035, BS HR.3, R30605, R31233	See remarks	See remarks	See remarks	See remarks	Yes	Any combinations of temperature. p_{H_2S}, chloride concentration, and *in situ* pH occurring in production environments are 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 may have a maximum hardness of 51 HRC if it is in the cold-reduced and high-temperature aged heat-treated condition in accordance with one of the following ageing treatments:

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

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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
R30003, R30035	See remarks	See remarks	See remarks	See remarks	NDS[a]	These materials have been used for these components without restriction on temperature, p_{H_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 may not be acceptable.
For this application, these materials shall also comply with the following. a) UNS R30003 shall be in the cold-worked and age-hardened condition and maximum 60 HRC. b) 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.						

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
R30003, R30004, R30260	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature. p_{H_2S}, chloride concentration, and *in situ* pH occurring in production environments are acceptable.
R30159	See remarks	See remarks	See remarks	See remarks	NDS[a]	This material has been used for these components without restriction on temperature, p_{H_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 may 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.

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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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
R50400, R56260, R53400, R56323, R56403, R56404, R58640	See remarks	See remarks	See remarks	See remarks	Yes	Any combinations of temperature. p_{H_2S}, chloride concentration, and *in situ* pH occurring in production environments are acceptable.

These materials shall also comply with the following.

a) UNS 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:

— annealed;

— solution-annealed;

— 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 NACE MR0175/ISO 15156. For example, hydrogen embrittlement of titanium alloys may 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 may 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_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant?	Remarks
R05200	See remarks	See remarks	See remarks	See remarks	NDS[a]	Any combinations of temperature. p_{H_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.

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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, p_{H_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 oilfield 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, p_{H_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 may 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 NACE MR0175/ISO 15156-2 or this part of NACE MR0175/ISO 15156, as applicable.

This may involve the application of heat or stress-relief treatments that could 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 might impact on its corrosion resistance or mechanical properties should be considered.

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A.13.2 Wear-resistant alloys

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

The cracking resistance of these alloys is not specified in NACE MR0175/ISO 15156.

Some materials used for wear-resistant applications can be brittle. Environmental cracking can occur if these materials are subject to tension.

A.13.2.2 Hard-facing materials

If any transformation temperature of the base material is exceeded during the application of a hard-facing, the component shall be heat-treated or thermally stress-relieved according to procedures that have been shown to ensure the base metal complies with NACE MR0175/ISO 15156-2 or this part of NACE MR0175/ISO 15156, as applicable.

The cracking resistance of alloys specifically designed to provide hard-facing is not specified in this part of NACE MR0175/ISO 15156.

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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

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

— 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.

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Table B.1 — Cracking mechanisms to 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 might 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			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			These alloys are not known to suffer from these cracking mechanisms

[a] P indicates primary cracking mechanism.

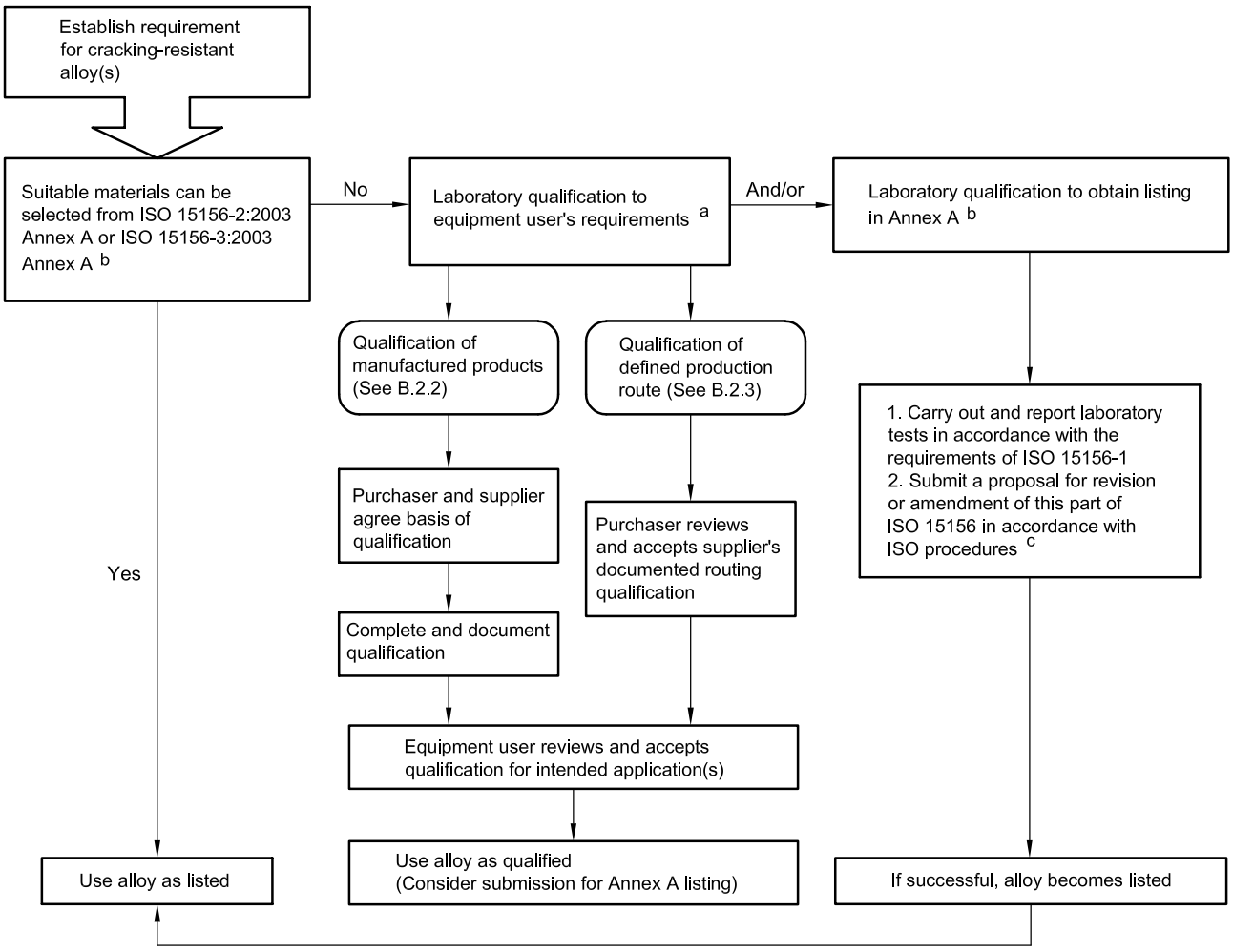
[b] S indicates secondary, possible, cracking mechanism.

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B.2 Uses of laboratory qualifications

B.2.1 General

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



a This part of NACE MR0175/ISO 15156 addresses SSC, SCC and GHSC of CRAs and other alloys, NACE MR0175/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. NACE MR0175/ISO 15156-2:2003, Annex A, addresses SSC of carbon and low alloy steels.

c See final paragraph of “Introduction” for further information regarding document maintenance.

NOTE Flowchart omits qualification by field experience as described in NACE MR0175/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 NACE MR0175/ISO 15156 shall define the qualification requirements for the material in accordance with NACE MR0175/ISO 15156-1 and Annex B of this part of NACE MR0175/ISO 15156.

This definition shall include the application of the following:

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a) general requirements (see NACE MR0175/ISO 15156-1:2001, Clause 5);

b) evaluation and definition of service conditions (see NACE MR0175/ISO 15156-1:2001, Clause 6);

c) material description and documentation (see NACE MR0175/ISO 15156-1:2001, 8.1);

d) requirements for qualification based upon laboratory testing (see NACE MR0175/ISO 15156-1:2001, 8.3);

e) report of the method of qualification (see NACE MR0175/ISO 15156-1:2001, 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.

Re-testing 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 re-tests 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;

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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, which 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 NACE MR0175/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 NACE MR0175/ISO 15156-1.

The product(s) tested shall have been manufactured to a specification that is publicly available and enables manufacture by more than one supplier.

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, in accordance with the ISO/IEC Directives, Part 1, on the suitability of the material for inclusion, by amendment or revision, into this part of NACE MR0175/ISO 15156.

B.3 General requirements for tests

B.3.1 Test method descriptions

The test requirements are based on NACE TM0177-96 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 NACE MR0175/ISO 15156-1:2001, 8.3.2.

In addition, consideration shall be given to:

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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 may 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 TM0198-98, interrupted SSRT in accordance with ISO 7539-7 or RSRT in accordance with the method published as NACE CORROSION/97 Paper 58[13].

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) 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

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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 may not be suitable for materials that can relax by creep when under load.

Lower applied stresses may 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_{H_2S};

— p_{CO_2};

— 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 p_{H_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 may 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.

Annex E, 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 (B.3.5.2), Table E.1 also provides a number of nominated sets of conditions (for temperature, p_{CO_2}, p_{H_2S} and chloride concentration) which 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 Ref. [18] in the Bibliography gives information on the charging of autoclaves.

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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 will be 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 $\pm$ 0,2 pH units.

B.3.5.4 Service simulation at ambient pressure with acetic buffer (Type 3a and 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 $\pm$ 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.

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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 TM0177-96 (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 might suppress SCC of the specimen.

A written test report conforming to the requirements in NACE MR0175/ISO 15156-1:2001, 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 p_{H_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 TM0177-96 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.

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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 TM0177-96 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 may 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 TM0177-96. 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

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b) The test environment shall be NACE TM0177-96 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.

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Annex C
(informative)

Information to be supplied for material purchasing

NACE MR0175/ISO 15156-1 indicates that cooperation and exchange of information may be necessary between the various users of this part of NACE MR0175/ISO 15156, e.g. equipment users, purchasers and manufacturers of equipment, purchasers of materials and manufacturers and suppliers of materials. The following tables may 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 NACE MR0175/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 NACE MR0175/ 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).

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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 NACE MR0175/ ISO 15156-3	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 NACE MR0175/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, 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.

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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 NACE MR0175/ISO 15156 and are based upon reference [19]. 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 referred to. In addition, in most cases, reference is made to the common name used for the alloy.

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/TR 15510 [3] provides assistance for the cross-referencing for some UNS numbers to other standards. ISO 13680 [2] provides information relating 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 percentages (one percent 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.

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

UNS	Name	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	CF-3	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	CF-8	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	CF-3M	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	11 to 16,5
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	14 to 19
J92900	CF-8M	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	201 SS	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	3,5 to 5,5
S20200	202 SS	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	205 SS	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 1,75
S20910	22-13-5	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	14 to 20
S30200	302 SS	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	304 SS	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 10,5
S30403	304L SS	0,03	18,0 to 20,0	8,0 to 12,0	2,00	1,00	0,045	0,030				17 to 19	10 to 13
S30500	305 SS	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	308 SS	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	309 SS	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	310 SS	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	316 SS	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	316L SS	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	316 Ti SS	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
S31700	317 SS	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	16 to 20
S32100	321 SS	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	347 SS	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	13 to 19
S38100	18-18-2	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	17 to 19

[a] Where a range is shown, it indicates min. to max. 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 mass fraction of carbon (%).

[e] Minimum value of Nb shall be ten times the mass fraction of carbon (%).

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

UNS	Name	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	254 SMo	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	29,5 to 31,5
J93254	Cast 254 SMo	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	29,5 to 33,7
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	B66	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	NIC 25	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				29 to 40	26 to 33
S32654	654 SMo	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	CN-7M	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		25 to 32	31,5 to 36,5
N08020 [c]	20 Cb3	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		29 to 40	36 to 44
N08320	20Mod	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	AL6XN	0,030	20,0 to 22,0	23,5 to 25,5	2,00	1,00	0,04	0,04	6,00 to 7,00				20 to 23	45 to 52
N08904	904L	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	25-6Mo	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	1925hMo	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. mass fractions.

[b] Additional elements, expressed as mass fractions, are: Al 0,01 % max., As 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 (%), with a maximum of 1%.

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

UNS	Name	C max.[a] w_C %	Cr w_{Cr} %	Ni w_{Ni} %	Fe max.[a] w_{Fe} %	Mn max.[a] w_{Mn} %	Si max.[a] w_{Si} %	Mo w_{Mo} %	Co max.[a] w_{Co} %	Cu max.[a] w_{Cu} %	P max.[a] w_P %	S max.[a] w_S %	Ti max.[a] w_{Ti} %	Nb + Ta max.[a] w_{Nb+Ta} %	Nb max.[a] w_{Nb} %	V max.[a] w_V %	W max.[a] w_W %	N w_N %	Al max.[a] w_{Al} %
N06002	X	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	G	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	C-22	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	G-30	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	59	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	SM2060Mo	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	Allcorr	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	SM2050	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	SM2550	0,03	23,0 to 26,0	47,0 to 52,0	bal.[b]	1,00	0,03	6,0 to 9,0		1,20	0,03	0,03	0,69				3,0		
N06625	625	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	686	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	G-50	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	52	0,03	23, to 27,	48, to 56,	bal.[b]	1,0	1,0	6, to 8,		0,5 to 1,5	0,03	0,003	0,6 to 1,5						
N06975	G-2	0,03	23,0 to 26,0	47,0 to 52,0	bal.[b]	1,00	1,00	5,0 to 7,0		0,70 to 1,20	0,03	0,03	0,70 to 1,50						
N06985	G-3	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		
N08007	CN-7M	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									

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Table D.3 (*continued*)

UNS	Name	C max.[a] w_C %	Cr w_{Cr} %	Ni w_{Ni} %	Fe max.[a] w_{Fe} %	Mn max.[a] w_{Mn} %	Si max.[a] w_{Si} %	Mo w_{Mo} %	Co max.[a] w_{Co} %	Cu max.[a] w_{Cu} %	P max.[a] w_P %	S max.[a] w_S %	Ti max.[a] w_{Ti} %	Nb + Ta max.[a] w_{Nb+Ta} %	Nb max.[a] w_{Nb} %	V max.[a] w_V %	W max.[a] w_W %	N w_N %	Al max.[a] w_{Al} %
N08020	20Cb3	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	20Mo-4	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	20Mo-6	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	28	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	32	0,01	22	32	bal.[b]	0,4	0,3	4,3			0,015	0,002							
N08042	42	0,03	20, 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	SM2035	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	SM2535	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	825	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	825 cast	0,05	19,5 to 23,5	38,0 to 46,0	22,0	1,00	1,00	2,5 to 3,5		1,5 to 3,0	0,030	0,030			0,60 to 1,20				
N08932	URSB 8	0,020	24,0 to 26,0	24,0 to 26,0	bal.[b]	2,0 max	0,50	4,7 to 5,7		1,0 to 2,0	0,025	0,010						0,17 to 0,25	
N10002	C	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	C-276	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	C-276 cast	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		
CW6MC	625 cast	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. mass fractions.

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

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

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

UNS	Name	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	400	0,3	Bal. [b]	63,0 to 70,0	2,50	2,00	0,50	0,024
N04405	405	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. 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	Name	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	405 SS	0,08	11,5 to 14,5		1,00	1,00			0,040	0,030	Al 0,10 to 0,30
S40900	409 SS	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	430 SS	0,12	16,0 to 18,0		1,00	1,00			0,040	0,030	
S43400	434 SS	0,12	16,0 to 18,0		1,00	1,00	0,75 to 1,25		0,040	0,030	
S43600	436 SS	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	442 SS	0,20	18,0 to 23,0		1,00	1,00			0,040	0,030	
S44400	18-2	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 max. [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	446 SS	0,20	23,0 to 27,0		1,50	1,00		0,25	0,040	0,030	
S44626	26-1 Ti	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 max.
S44627	26-1 Cb	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 max.
S44635	26-4-4	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 max. [b]
S44660	SC-1	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 max. [b]
S44700	29-4	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 max.; Cu 0,15 max.
S44735	29-4C	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	29-4-2	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 max. [b], Cu 0,15 max.

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

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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	410	0,15	11,5 to 13,5			1	0,04	0,03	1		
S41425	S/W 13 Cr	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	13CRS	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
S42000	420	0,15 min[a]	12 to 14			1	0,04	0,03	1		
S42400	F6 NM	0,06	11,5 to 14	3,5 to 4,5	0,3 to 0,7	1	0,03	0,03	0,5 to 1		
S42500	15 Cr	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	CA 15	0,15	11,5 to 14	1	0,5	1,5	0,04	0,04	1		
J91151	CA 15M	0,15	11,5 to 14	1	0,15 to 1	1	0,04	0,04	1		
J91540	CA6 NM	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	9Cr 1Mo	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		1	0,02	0,01	0,25 to 1		Cu 0,25

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

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

UNS	Name	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	44LN	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	DP-3	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	2205	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	U 50	0,04	20,5 to 22,5	5,5 to 8,5	2	1	2,0 to 3,0	0,20 max	1,0 to 2,0	0,030 max	0,03	0,01	27 to 32
S32520	52N+	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	255	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	2507	0,03	24,0 to 26,0	6,0 to 8,0	1,2	0,8	3,0 to 4,0	0,24 to 0,32			0,035	0,02	38 to 44
S32760a[b]	Z100	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	40 to 46
S32803b[c]	2803Mo	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	33 to 41
S32900	329 SS	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	7Mo Plus	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	DP3W	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	AF918	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	CD4MCu	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	Escoloy	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	Z100	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	958	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. mass fractions.

[b] $w_{Cr} + 3{,}3w_{Mo} + 16\ w_N$ shall be 40 minimum,

where

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

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

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

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

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

UNS	Name	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	A286	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	15-5 PH	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	PH 15-7 Mo	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	17-4 PH	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	450	0,05	14,0 to 16,0	5,00 to 7,00	1,00	1,00	0,50 to 1,00	$8 \times C$ min. [b]		1,25 to 1,75		0,030	0,030		

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

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

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

UNS	Name	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	625	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
N07031	31	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	48	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	90	0,13	18,0 to 21,0	Bal.[b]	3,0	1,0			15,0 to 21,0	1,8 to 3,0		0,8 to 2,0					
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	625 plus	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	718	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	725	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	PH3	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	PH7	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	925	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
N05500	K-500	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	X-750	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 mass fraction. Where a range is shown, it indicates min. to max. mass fractions.

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

[c] Additional elements by mass fraction: W = 0,5 % max. and Mg = 0,0050 % max.

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

UNS	Name	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	Elgiloy	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	Havar	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	MP-35N	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	MP-159	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]	Duratherm 2602	0,05	11,7 to 12,3	Bal.[b]	41,0 to 42,0	9,8 to 10,4	0,4 to 1,1	0,2 to 0,60	3,7 to 4,3		0,20 to 0,30	0,1	0,30			
R31233	Ultimet	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	L-605	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. mass fractions.

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

[c] Nb 0,1 % max. mass fraction.

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

UNS	Name	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
R50400	Grade 2			0,10		0,30	0,015		0,03				O 0,25 max.	Bal.[b]
R56260	Ti-6246	6						6			2	4		Bal.[b]
R53400	Grade 12			0,08		0,30	0,015	0,2 to 0,4	0,03	0,6 to 0,9			O 0,25 max.	Bal.[b]
R56323	Grade 28	2,5 to 3,5	2,0 to 3,0	0,08		0,25	0,015		0,03				O 0,15 max., Ru 0,08 to 0,14	Bal.[b]
R56403	Grade 25	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 max., Pd 0,04 to 0,08, Residuals [c]	Bal.[b]
R56404	Grade 29	5,5 to 6,5	3,5 to 4,5	0,08		0,25	0,015		0,03				O 0,13 max., Ru 0,08 to 0,14	Bal.[b]
R58640	Beta-C	3	8		6			4				4		Bal.[b]

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

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

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

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

UNS	Name	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		0,01	0,05	0,01	0,005	0,01	0,03	0,01	0,01	0,015	Bal. [a]

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

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Annex E
(informative)

Nominated sets of test conditions

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

The “Levels” shown in the table were used previously 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	25 °C ± 3 °C (77 °F ± 5 °F)	Test in accordance with B.4	Test in accordance with B.4 and B.8	90 °C ± 5 °C (194 °F ± 9 °F)	150 °C ± 5 °C (302 °F ± 9 °F)	175 °C ± 5 °C (347 °F ± 9 °F)	205 °C ± 5 °C (401 °F ± 9 °F)
p_{CO_2}	Test conditions defined and documented by the user			0,7MPa (100 psi)	1,4 MPa (200 psi)	3,5 MPa (500 psi)	3,5 MPa (500 psi)
p_{H_2S}				0,003 MPa (0,4 psi)	0,7MPa (100 psi)	3,5 MPa (500 psi)	3,5 MPa (500 psi)
Cl^- minimum				91 000 mg/l	91 000 mg/l	121 300 mg/l	151 700 mg/l
pH				See B.3.5.1 and B.3.5.2			
S^0				Optional, see B.7			
Galvanic coupling to steel				Optional, see B.8			
Other				See B.3.5.1			

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