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Petroleum, petrochemical and natural gas industries — Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments

Industries du pétrole, de la pétrochimie et du gaz naturel — Matériaux métalliques résistant à la fissuration sous contrainte induite par les sulfures pour utilisation dans des environnements corrosifs de raffinage du pétrole

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Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

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

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

Introduction

The term “wet H_2S cracking”, as used in the refining industry, covers a range of damage mechanisms that can occur because of the effects of hydrogen charging in wet H_2S refinery or gas plant process environments. One of the types of material damage that can occur as a result of hydrogen charging is sulfide stress cracking (SSC) of hard weldments and microstructures, which is addressed by this International Standard. Other types of material damage include hydrogen blistering, hydrogen-induced cracking (HIC), and stress-oriented hydrogen-induced cracking (SOHIC), which are not addressed by this International Standard.

Historically, many end users, industry organizations (e.g. API), and manufacturers that have specified and supplied equipment and products such as rotating equipment and valves to the refining industry have used NACE MR0175/ISO 15156 to establish materials requirements to prevent SSC. However, it has always been recognized that refining environments are outside the scope of NACE MR0175/ISO 15156, which was developed specifically for the oil and gas production industry. In 2003, the first edition of NACE MR0103 was published as a refinery-specific sour service metallic materials standard. This International Standard is based on the good experience gained with NACE MR0175/ISO 15156, but tailored to refinery environments and applications. Other references for this International Standard are NACE SP0296, NACE Publication 8X194, NACE Publication 8X294, and the refining experience of the task group members who developed NACE MR0103.

The materials, heat treatments, and material property requirements set forth in NACE MR0103 are based on extensive experience in the oil and gas production industry, as documented in NACE MR0175/ISO 15156, and were deemed relevant to the refining industry by the task group.

This International Standard was developed on the basis of NACE MR0103.

Petroleum, petrochemical and natural gas industries — Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments

1 Scope

This International Standard establishes material requirements for resistance to SSC in sour petroleum refining and related processing environments containing H_2S either as a gas or dissolved in an aqueous (liquid water) phase with or without the presence of hydrocarbon. This International Standard does not include and is not intended to include design specifications. Other forms of wet H_2S cracking, environmental cracking, corrosion, and other modes of failure are outside the scope of this International Standard. It is intended to be used by refiners, equipment manufacturers, engineering contractors, and construction contractors.

Specifically, this International Standard is directed at the prevention of SSC of equipment (including pressure vessels, heat exchangers, piping, valve bodies, and pump and compressor cases) and components used in the refining industry. Prevention of SSC in carbon steel categorized under P-No. 1 in Section IX of the ASME Boiler and Pressure Vessel Code (BPVC) is addressed by requiring compliance with NACE SP0472.

This International Standard applies to all components of equipment exposed to sour refinery environments (see Clause 6) where failure by SSC would (1) compromise the integrity of the pressure-containment system, (2) prevent the basic function of the equipment, and/or (3) prevent the equipment from being restored to an operating condition while continuing to contain pressure.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NACE Standard TM0177, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments*[1)]

ANSI/NACE MR0175/ISO 15156, *Petroleum and natural gas industries — Materials for use in H2S-containing environments in oil and gas production*[1)]

ASTM A833, *Standard Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers*

ASTM E384, *Standard Test Method for Knoop and Vickers Hardness of Materials*

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

SAE AMS2430, *Shot Peening, Automatic*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
lower transformation temperature
A_{c1}
temperature at which austenite begins to form during heating

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

3.2
upper transformation temperature
A_{c3}
temperature at which transformation of ferrite to austenite is completed during heating

3.3
alloy steel
iron-based alloy containing carbon (usually less than 2,5 %) and manganese (usually not less than 0,25 %), that contains specified minimum quantities for one or more alloying elements other than manganese, silicon, and copper, and that does not specify a minimum chromium content greater than or equal to 10 %

3.4
austenitic stainless steel
stainless steel whose microstructure, at room temperature, consists predominantly of austenite

3.5
carbon steel
iron-based alloy containing carbon (usually less than 2,0 %) and manganese (usually not less than 0,25 %), with no specified minimum quantity for any alloying element other than manganese, silicon, and copper, and that contains only an incidental amount of any element other than carbon, silicon, manganese, copper, sulfur, and phosphorus

3.6
cladding
metallurgically bonded layer (roll bonded, explosion bonded, or weld overlaid) of a corrosion-resistant alloy material applied to the entire wetted surface of a substrate material that is relatively less corrosion-resistant

Note 1 to entry: See also weld overlay.

3.7
duplex stainless steel
austenitic/ferritic stainless steel
stainless steel whose microstructure at room temperature consists primarily of a mixture of austenite and ferrite

3.8
end user
company or agency that owns and operates the component (e.g. vessel, piping, pump, compressor, etc.)

3.9
ferritic stainless steel
stainless steel whose microstructure, at room temperature, consists predominantly of ferrite

3.10
stainless steel
iron-based alloy containing 10,5 % mass fraction or more chromium, possibly with other elements added to secure special properties

3.11
sulfide stress cracking
SSC
cracking of a metal under the combined action of tensile stress and corrosion in the presence of water and H_2S (a form of hydrogen stress cracking)

3.12
thermal spray coating
high-temperature process by which finely divided metallic or nonmetallic materials are deposited in a molten or semi-molten condition to form a coating on a surface when cooled

3.13
weld overlay, corrosion resistant
deposition of one or more layers of corrosion resistant weld metal to the surface of a base material in an effort to improve the corrosion resistance properties of the surface

Note 1 to entry: See also cladding.

3.14
weld overlay, hard facing
deposition of one or more layers of a weld metal to the surface of a material in an effort to improve the wear resistance properties of the surface

4 Symbols and abbreviated terms

ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	ASME (formerly American Society of Mechanical Engineers)
AWS	American Welding Society
BPVC	boiler and pressure vessel code
HAZ	heat-affected zone
HI	heat input
HIC	hydrogen-induced cracking
NACE	NACE International (formerly National Association of Corrosion Engineers)
ppmw	parts per million by weight, commonly expressed as mg/kg in SI units
PQR	procedure qualification record
PREN	pitting resistance equivalent number
PWHT	postweld heat treatment
SOHIC	stress-oriented hydrogen-induced cracking
SSC	sulfide stress cracking
UNS	unified numbering system (for metals and alloys)
WPQT	welding procedure qualification test

5 Responsibilities

5.1 Responsibilities of the end user

5.1.1 It is the responsibility of the end user (or the end user's agent) to determine the operating conditions and to specify when this International Standard applies.

5.1.2 It is the end user's (or the end user's agent's) responsibility to ensure that a material is satisfactory in the intended environment. The end user (or the end user's agent) may select specific materials for use on the basis of operating conditions that include pressure, temperature, corrosiveness, and fluid properties. A variety of candidate materials may be selected from this International Standard for any given component. Unlisted materials may also be used based on either of the following processes.

a) If a metallurgical review based on scientific and/or empirical knowledge indicates that the SSC resistance will be adequate, these materials may then be proposed for inclusion into the standard using methods in Clause 9.

b) If a risk-based analysis indicates that the occurrence of SSC is acceptable in the subject application.

5.1.3 Other forms of wet H_2S cracking, environmental cracking, corrosion, and other modes of failure, although outside the scope of this International Standard, should be considered in the design and operation of equipment. Severely corrosive and/or hydrogen charging conditions may lead to failures by mechanisms other than SSC and should be mitigated by methods that are outside the scope of this International Standard.

5.2 Responsibility of the manufacturer

The manufacturer is responsible for meeting the metallurgical requirements of this International Standard.

6 Factors contributing to SSC

6.1 General parameters affecting SSC

SSC in refining equipment is affected by complex interactions of parameters including the following:

a) chemical composition, strength (as indicated by hardness), heat treatment, and microstructure of the material exposed to the sour environment;

b) total tensile stress present in the material (applied plus residual);

c) hydrogen flux generated in the material, which is a function of the environment (i.e. presence of an aqueous phase, H_2S concentration, pH, and other environmental parameters such as bisulfide ion concentration and presence of free cyanides);

d) temperature;

e) time.

6.2 Effect of material condition and stress level on susceptibility to SSC

6.2.1 Material susceptibility to SSC is primarily related to material strength (as indicated by hardness), which is affected by chemical composition, heat treatment, and microstructure. Materials with high hardness generally have an increased susceptibility to SSC.

6.2.2 SSC has not generally been a concern for carbon steels typically used for refinery pressure vessels and piping in wet H_2S service because these steels have sufficiently low hardness levels.

6.2.3 Improperly heat-treated metals, weld deposits, and heat-affected zones (HAZ), however, may contain regions of high hardness.

6.2.4 Susceptibility for a given material increases with increased tensile stress.

6.2.5 Residual stresses contribute to the overall tensile stress level. High residual stresses associated with welds increase susceptibility to SSC.

6.2.6 Control of weldment hardness, with or without reduction of residual stresses, is a recognized method for preventing SSC, as outlined in NACE SP0472 for P-No. 1 carbon steels.

6.3 Effect of hydrogen permeation flux on SSC

6.3.1 Susceptibility to SSC is also related to the hydrogen permeation flux in the steel, which is primarily associated with two environmental parameters: pH and total sulfide content of the aqueous phase. In a closed system at equilibrium condition, dissolved hydrogen sulfide (H_2S_{aq}), bisulfide ion (HS^-), and sulfide ion (S^{2-}) (sometimes called "soluble sulfide") exist in an aqueous solution in different pH ranges.

6.3.2 The sulfide species plot exhibited in Figure A.1 shows their relative amounts present in an aqueous solution at 25 C (77°F) as a function of pH. At pH less than 6, H_2S_{aq} is the dominant (>90 % of total) sulfide specie present in the aqueous phase. At pH between 8 and 11, the dominant (>90 % of total) sulfide specie present in the aqueous phase is HS^-. At pH greater than 13, the dominant (>90 % of total) sulfide specie present in the aqueous phase is S^{2-}. At pH 7, the system contains 50 % H_2S_{aq}, 50 % HS^-, and virtually no S^{2-}. At pH 12, the system contains 50 % HS^-, 50 % S^{2-}, and virtually no H_2S_{aq}. The total sulfide content, therefore, refers to the total amount of all three sulfide species present in the aqueous phase (i.e. the sum of H_2S_{aq}, HS^-, and S^{2-}).

6.3.3 Typically, the hydrogen flux in steels has been found to be lowest in near-neutral pH solutions, with increasing flux at both lower and higher pH values. Corrosion at lower pH values is typically caused by H_2S_{aq}, whereas corrosion at higher pH values is typically caused by high concentrations of HS^-.

6.3.4 In many refinery sour water environments, the presence of dissolved ammonia (NH_3) increases the pH, thereby increasing the solubility of H_2S and resulting in a high HS^- concentration. At elevated pH, the presence of free cyanides, which include dissolved hydrogen cyanide (HCN_{aq}) and cyanide ion (CN^-), can further aggravate the degree of atomic hydrogen charging into the steel. Even though SSC susceptibility is known to increase with total sulfide content of the aqueous phase, the presence of as little as 1 ppmw total sulfide in the aqueous phase can cause SSC under conditions that promote aggressive hydrogen charging.

6.3.5 For carbon steel, some environmental conditions known to cause SSC are those containing an aqueous (liquid water) phase and either of the following:

a) >50 ppmw total sulfide content in the aqueous phase;

b) ≥1 ppmw total sulfide content in the aqueous phase and pH < 4;

c) ≥1 ppmw total sulfide content and ≥20 ppmw free cyanide in the aqueous phase, and pH > 7,6;

d) >0,3 kPa absolute (0,05 psia) partial pressure H_2S in the gas phase associated with the aqueous phase of a process.

6.3.6 The high-pH sour environments differentiate refinery sour service from the oil and gas production sour environments covered by NACE MR0175/ISO 15156, because many wet sour streams in oil and gas production also contain carbon dioxide and, hence, exhibit a lower pH. Another major difference is that chloride ion concentrations tend to be significantly lower in refinery sour services than in oil production sour services.

6.4 Effect of elevated temperature exposure on SSC

The hydrogen charging potential increases with increasing temperature provided the aqueous phase is not eliminated by the elevated temperature. Elevated temperature promotes dissociation of H_2S (thereby producing more monatomic hydrogen), and increases the diffusion rates of monatomic hydrogen in metals, thereby promoting hydrogen charging. However, cracking potential is maximized at near-ambient temperature. This distinction is important because metals can become charged during high-temperature exposure and subsequently crack during excursions to lower temperatures (such as during shutdowns).

6.5 Factors affecting time to failure due to SSC

The time to failure decreases as material strength, total tensile stress, and environmental charging potential increase. Exposure time to cause SSC can be very short, if the other SSC factors favour susceptibility. Some susceptible equipment can fail even during short sour water excursions such as those encountered during equipment shutdowns.

6.6 Bases for establishing whether equipment falls within the scope of this International Standard

The end user (or the end user's agent) shall determine whether the parameters necessary to cause SSC exist in the process environment, and whether the equipment falls within the scope of this International Standard. The end user (or the end user's agent) may rely on experience, risk-based analysis, or the above guidance (notably that related to environmental conditions provided in 6.3 and 6.4) to make this determination. When determining whether the equipment falls within the scope of this International Standard, consideration should be given to all plant operating scenarios and the likely impact on the materials of construction, i.e. normal operations, operational upsets, alternate (possible future) operations, and start-up/shutdown conditions (e.g. presulfiding of catalysts).

7 Materials included in this International Standard

7.1 Materials included in this International Standard are resistant to, but not necessarily immune to, SSC. Materials have been included based on their demonstrated resistance to SSC in field applications, in SSC laboratory testing, or both.

7.2 Listed materials do not all exhibit the same level of resistance to SSC. Standard laboratory SSC tests, such as those addressed in NACE Standard TM0177, are accelerated and severe tests. Materials that successfully pass these tests are generally more resistant to cracking in sour service than materials that fail the tests. Many alloys included in this International Standard perform satisfactorily in sour service even though they may crack in laboratory tests.

7.3 Improper design, processing, installation, or handling can cause resistant materials to become susceptible to SSC.

7.4 No effort has been made in this International Standard to rank materials based on their relative resistance to SSC. Selection of the appropriate material for a given application depends on a number of factors, including mechanical properties, corrosion resistance, and relative resistance to SSC, and is beyond the scope of this International Standard.

7.5 There are a number of instances where this International Standard specifically references the ASME BPVC. There are other instances where this International Standard references specific industry standards and/or designations for material grades, conditions, and testing requirements (e.g. ASTM, NACE, API, and UNS numbers). In these cases, the use of alternate "equivalent" standards, grade designations, condition designations, or testing methods shall only be permitted when approved by the end user. It is the responsibility of the agency requesting the substitution to provide to the end user sufficient information, data, etc. in order to prove "equivalency." If it is not clear that an alternate standard, grade designation, and/or condition designation is identical to the standard, grade designation, and/or condition designation specified in this International Standard, the end user is strongly advised to follow the requirements stipulated in Clause 11 to evaluate the acceptability of the alternate material.

8 Hardness requirements

8.1 Hardness is related to tensile strength, a primary factor in SSC susceptibility. Because hardness testing is non-destructive and requires relatively minor component/specimen preparation compared with tensile testing, it is commonly used by manufacturers in production quality control and by users in field inspection. As such, a maximum allowable hardness is specified as a primary requirement for many of the materials in this International Standard.

8.2 Several different hardness scales are used in this International Standard. The most commonly used scales are Rockwell “C” (HRC), Rockwell “B” (HRBS), Brinell (HBW), and Vickers 49 N (5 kgf) or 98 N (10 kgf) (HV 5 or HV 10). Background information on these hardness scales and the logic behind the various references is provided in Annex B.

8.3 Hardness testing and reporting shall be performed in strict compliance with the methods described in the appropriate ASTM or ISO standards. Annex B lists the appropriate standards for the various test methods.

8.4 The standard test parameters (indenters, loads, and major-load dwell time) shall be used for all Rockwell hardness tests. The specimen temperature for Rockwell hardness testing shall be 10 °C to 35 °C (50 °F to 95 °F). No lubricant shall be used. Because Brinell hardness tests are only indicated for steel materials in this International Standard, all Brinell hardness tests shall be performed using 29,4 kN (3 000 kgf) load, a 10 mm indenter, and the standard dwell time of 10 s to 15 s.

8.5 In some cases, maximum allowable hardness values are provided in both HRC (or HRBS) and HBW. In those instances, either scale may be used.

8.6 When hardness requirements are stated in HBW, and testing using stationary Brinell hardness equipment is not viable, testing shall be performed using the comparison hardness test method (commonly, but incorrectly, referred to as portable Brinell hardness testing).

8.7 When applicable, the conversion tables in ASTM E140 or ISO 18265 shall be used for conversion of hardness values obtained by other test methods to HRC, HRBS, or HBW values. However, tables for many materials do not exist in those standards. The tables should be used only for materials that are specifically listed. Conversions may be performed based on empirical data for materials that are not covered when approved by the end user. When converted hardness values are used, they shall be reported in accordance with the requirements specified in ASTM E140 or ISO 18265.

8.8 Sufficient hardness tests shall be made to establish the actual hardness of the material being examined. Individual hardness readings exceeding the specified value shall be considered acceptable if the average of several readings taken within close proximity does not exceed the specified value and no individual reading exceeds the specified value by more than 2 HRC (or by more than 5 % in the case of HBW or HV 10).

8.9 Acceptance criteria for microhardness testing using Knoop or Vickers hardness test methods (see ASTM E384) are outside the scope of this International Standard. See Annex B for more information.

8.10 The use of portable hardness testing methods to verify compliance with the requirements of this International Standard is prohibited unless explicitly approved by the end user. The one exception that does not require end user approval is the use of comparison hardness testing in accordance with ASTM A833 to evaluate weld deposits as specified in NACE SP0472 (see Annex B).

9 Procedure for the addition of new materials or processes

9.1 General balloting requirements

New materials and/or processes may be balloted based on field experience and/or laboratory test data.

9.2 Field experience data requirements

9.2.1 Field experience data shall document the alloy composition(s), condition(s), and hardness level(s), the process fluid parameters that influence SSC, and the exposure history.

9.2.2 In certain alloy families (such as duplex stainless steels), microstructure is also a critical variable, and shall also be documented.

9.3 Laboratory test data requirements

9.3.1 The laboratory testing of materials shall be performed in accordance with NACE Standard TM0177. If actual service conditions are outside these limits, SSC of approved materials may be possible.

9.3.2 The candidate material shall be tested in accordance with the test procedures established in NACE Standard TM0177. The tensile bar, C-ring, bent beam, and double-cantilever beam test specimens described in NACE Standard TM0177 are accepted test specimens. Any of these test specimens may be used.

9.3.3 A minimum of three test specimens from each of three different commercially prepared heats shall be tested in the condition balloted for inclusion. The composition of each heat and the heat treatment(s) used shall be furnished as part of the ballot. The candidate material's composition range and/or UNS number and its heat-treated condition requested for inclusion in this International Standard shall be included with the ballot.

9.3.4 The hardness of each test specimen shall be determined and reported as part of the ballot. The average hardness of each test specimen shall be the hardness of that test specimen. The minimum test specimen hardness obtained for a given heat/condition shall be the hardness of the heat/condition for the purpose of balloting. The maximum hardness requested for inclusion of the candidate material in this International Standard shall be specified in the ballot and shall be supported by the data provided.

9.3.5 In certain alloy families (such as duplex stainless steels), microstructure is also a critical variable, and shall also be documented for each heat/condition.

9.3.6 For each of the tests performed, the testing details shall be reported as part of the ballot item being submitted.

10 New restrictions and deleted materials

10.1 The revision process may be used to impose new restrictions on materials or to delete materials from this International Standard. New restrictions may include such items as imposition of a maximum hardness requirement, reduction of a maximum hardness requirement, elimination of a previously acceptable heat-treatment condition, and elimination of a previously acceptable manufacturing process.

10.2 Affected materials in use at the time of the change that complied with a prior edition of this International Standard and that have not experienced sulfide stress cracking (SSC) in their current application are considered in compliance with this International Standard.

10.3 When affected metallic materials as discussed in 10.2 are eventually removed from their current application, replacement materials shall be compliant with the current edition of this International Standard, except that new equipment manufactured from affected materials, as well as equipment refurbished using new components manufactured from affected materials, may be qualified for use in specific applications in accordance with Clause 11.

11 Qualification of unlisted alloys, conditions, and/or processes for specific applications

11.1 Alloys, conditions, and processes that are not listed in this International Standard may be qualified for use in specific sour applications. Clause 11 provides the minimum requirements for compliance with this International Standard when unlisted alloys, conditions, and/or processes for specific applications are qualified.

11.2 The end user shall be responsible for determining the suitability of an unlisted alloy, condition, and/or process for a specific application based on laboratory test data, field experience, and/or risk-based analysis.

11.3 If laboratory testing is used as an acceptance basis, testing should be performed in accordance with accepted standard test methods such as those documented in NACE Standard TM0177.

11.4 If field experience and/or risk-based analysis is used as an acceptance basis, a number of factors should be considered.

a) The stress level, material form, forming process, heat-treatment condition, microstructure, and mechanical properties (particularly hardness) of the field experience specimen should be well documented.

b) The environmental conditions to which the field experience specimen is exposed should be well documented.

c) The field experience exposure time should be adequate to ensure that the unlisted alloy, condition, and/or process provide resistance to SSC.

11.5 The suitability of the unlisted alloy, condition, and/or process for a specific application should be determined based on an evaluation of the environmental conditions in the intended specific application compared with the environmental conditions in the laboratory tests and/or the field experience.

11.6 The composition, material form, forming processes, heat-treatment condition, and mechanical properties of equipment manufactured using an unlisted alloy, condition, and/or process should be controlled based on the corresponding information for the laboratory test specimens and/or field experience specimens.

11.7 Unlisted alloys, conditions, and/or processes qualified for specific applications based on the requirements in Clause 11 shall not become part of this International Standard unless they are approved through the ISO balloting process.

12 Standard road map

For ease of use, Table 1 provides general information by material/application group, as well as references to specific clauses that cover applicable material and fabrication requirements.

Table 1 — "Road Map" for ISO 17945

Material groups			
Material group or application	**Conditions allowed**	**Applicable material requirement clause(s)**	**Applicable fabrication requirement clause(s)**
Carbon steels	a) Hot-rolled; b) Annealed; c) Normalized; d) Normalized and tempered; e) Normalized, austenitized, quenched, and tempered; f) Austenitized, quenched, and tempered.	13.1	13.1.7, 13.1.9, Clause 15
Alloy steels	a) Annealed; b) Normalized; c) Normalized and tempered; d) Normalized, austenitized, quenched, and tempered; e) Austenitized, quenched, and tempered.	13.1	13.1.8, 13.1.9, Clause 15
Ferritic ductile iron	Annealed	13.2	13.2
Ferritic stainless steels	Annealed	13.3	Clause 15
Specific low-carbon martensitic stainless steels	Quenched and double-tempered	13.4.2	13.4.3, Clause 15
Austenitic stainless steels	Solution-annealed	13.5	13.5, Clause 15
Specific austenitic stainless steels	Solution-annealed or hot-rolled	13.6	13.6, Clause 15
Highly alloyed austenitic stainless steels	Solution-annealed or solution-annealed and cold-worked	13.7	13.7, Clause 15
Duplex stainless steels	Solution-annealed	13.8	13.8, Clause 15
Precipitation-hardenable stainless steels	Solution-annealed and precipitation-hardened	13.9	Clause 15
Solid-solution nickel alloys	Solution-annealed	14.1.1	Clause 15
Precipitation-hardenable nickel alloys	Various	14.1.2	Clause 15
Cobalt-nickel-chromium-molybdenum alloys	Various	14.2	Clause 15
Cobalt-nickel-chromium-tungsten alloys	Not specified	14.3	Clause 15
Titanium alloys	Various	14.4	Clause 15
Aluminium alloys	Not specified	14.5	Clause 15
Copper alloys	Not specified	14.6	Clause 15
Applications			
Fabrication	Various	Clause 15	Clause 15
Bolting	Various	Clause 16	N/A
Platings, coatings	Various	Clause 17	N/A

Table 1 *(continued)*

Material groups			
Material group or application	**Conditions allowed**	**Applicable material requirement clause(s)**	**Applicable fabrication requirement clause(s)**
Special components	Various	Clause 18	Clause 15
Valves	Various	Clause 19	Clause 15
Compressors and pumps	Various	Clause 20	Clause 15

13 Ferrous materials

13.1 Carbon and alloy steels

13.1.1 Requirements for all carbon and alloy steels

Carbon and alloy steels shall require the following:

a) not contain intentional additions of elements such as lead, selenium, or sulfur to improve machinability;

b) meet the criteria of 13.1.6 through 13.1.9;

c) be used in one of the following heat-treatment conditions:

  1) hot-rolled (carbon steels only);

  2) annealed;

  3) normalized;

  4) normalized and tempered;

  5) normalized, austenitized, quenched, and tempered;

  6) austenitized, quenched, and tempered.

NOTE There is no 1 % maximum nickel restriction for carbon steels and alloy steels.

13.1.2 Requirements for carbon steels listed as P-No. 1 Group 1 or 2 in Section IX of the ASME BPVC

13.1.2.1 Carbon steels listed as P-No. 1 Group 1 or 2 materials in Section IX of the ASME BPVC shall meet one of the conditions listed in 13.1.1, c). Base-metal hardness controls are not required.

13.1.2.2 Welding of P-No. 1 carbon steels shall be controlled in accordance with 13.1.7 and 13.1.9.

13.1.2.3 Bends in P-No. 1 piping formed by heating to above the upper transformation temperature, A_{c3}, are allowed. The material shall have met one of the conditions listed in 13.1.1, c) prior to forming. The hardness in the bend area shall not exceed 225 HBW.

13.1.2.4 Weld repairs in P-No. 1 castings shall be performed in accordance with the welding requirements specified in 13.1.7.

13.1.3 Requirements for other carbon steels

Other carbon steels shall have a maximum hardness of 22 HRC (237 HBW).

13.1.4 Requirements for alloy steels listed with P-numbers in Section IX of the ASME BPVC

Alloy steels included under the ASME BPVC Section IX P-numbers listed in Table 2 shall not exceed the indicated maximum hardness levels.

Table 2 — Maximum hardness requirements for P-Numbered alloy steels

Alloy steel	Maximum hardness
P-No. 3	225 HBW
P-No. 4	225 HBW
P-No. 5A	235 HBW
P-No. 5B	235 HBW
P-No. 5C	235 HBW
P-No. 6	235 HBW
P-No. 7	235 HBW
P-No. 10A	225 HBW
P-No. 10B	225 HBW
P-No. 10C	225 HBW
P-No. 10F	225 HBW
P-No. 11	225 HBW

13.1.5 Requirements for other alloy steels

Other alloy steels shall have a maximum hardness of 22 HRC (237 HBW).

13.1.6 Requirements for cold-formed carbon and alloy steels

13.1.6.1 Cold forming of carbon and alloy steels is allowed. The material shall have met one of the conditions listed in 13.1.1 c) prior to cold forming. Cold-formed material 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 %. Hydraulically formed materials shall be thermally stress relieved regardless of the percent outer fibre deformation.

13.1.6.2 Thermal stress relief shall be performed in accordance with the applicable ASME codes, except that the minimum stress-relief temperature shall be 593 °C (1 100 °F). After stress relieving, carbon steels listed as P-No. 1 materials in Section IX of the ASME BPVC shall meet a hardness requirement of 200 HBW maximum. Other carbon and alloy steels shall meet the appropriate hardness requirements in accordance with 13.1.3, 13.1.4, or 13.1.5.

13.1.6.3 Cold-rotary straightened pipe is allowed only when permitted in API specifications. Cold-worked line pipe fittings of ASTM A53 Grade B, ASTM A106 Grade B, API Spec 5L Grade X-42, or lower-strength grades with similar chemical compositions shall contain no more than 15 % cold strain, and the hardness in the strained area shall not exceed 190 HBW.

13.1.6.4 The requirements for cold forming stated above do not apply to pressure testing in accordance with the applicable code.

13.1.7 Welding requirements for carbon steels listed as P-No. 1 in Section IX of the ASME BPVC

13.1.7.1 Welding shall be performed in accordance with the general requirements listed in 15.3.

13.1.7.2 Weldments in carbon steels listed as P-No. 1 materials in Section IX of the ASME BPVC shall be produced using one or more of the methods outlined in NACE SP0472 to prevent excessive weldment hardness.

13.1.8 Welding requirements for alloy steels listed as P-No. 3, 4, or 5A in Section IX of the ASME BPVC

Some industry codes (such as ASME B31.3 and ANSI/NB-23) allow welding of P-No. 3, P-No. 4, and P-No. 5A alloy steels without PWHT in certain circumstances. Non-PWHT procedures of this type may be used provided a hardness survey in accordance with Annex C has been performed on a specimen taken from the welding procedure qualification test (WPQT) coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness limits. No individual hardness reading shall exceed 248 HV 10. Other alloy steel materials shall always receive PWHT when this International Standard applies to ensure low hardness in the weld deposit and HAZ. When PWHT is performed, a hardness survey in accordance with Annex C shall be performed on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the PWHT time and temperature to produce weldments that meet the specified hardness limits. No individual hardness reading shall exceed 248 HV 10.

13.1.9 Corrosion resistant weld overlays, hard facing weld overlays, cladding, and thermal spray coatings on carbon steels and alloy steels

13.1.9.1 Overlays and cladding applied to carbon and alloy steels for use in sour environments shall meet the requirements listed in 15.2 and 15.4 and in 13.1.9.2 to 13.1.9.5.

13.1.9.2 When applied to P-No. 1 carbon steels, partial weld overlays that do not qualify as cladding in accordance with 3.6 shall be applied in such a way that the process-contacted interface between the overlay and the base metal has a HAZ and base metal hardness within the specified limits. Methods used to control the HAZ and base metal hardness, and acceptance criteria, shall be in accordance with NACE SP0472.

13.1.9.3 When applied to alloy steels or to carbon steels not P-Numbered in Section IX of the ASME BPVC, partial weld overlays shall be applied in such a way that the process-contacted interface between the overlay and base metal has a HAZ and base metal hardness within the specified limits. Hardness testing and acceptance criteria shall be in accordance with the limits provided in 13.1.3 through 13.1.5 and/or 13.1.8, as appropriate.

13.1.9.4 When thermal spray coatings are applied to P-No. 1 carbon steel materials in such a manner that any portion of the base metal exceeds the lower transformation temperature (A_{c1}) (e.g. in the case of a spray and fuse coating), the procedures used shall be qualified in accordance with NACE SP0472 requirements to ensure that the HAZ and base metal exhibit hardness within the spcified limits.

13.1.9.5 When thermal spray coatings are applied to alloy steels or to carbon steels not P-Numbered in Section IX of the ASME BPVC, in such a manner that any portion of the base metal exceeds the lower transformaton temperature (A_{c1}) (e.g. in the case of a spray and fuse coating), the procedure used shall be qualified with postweld heat treatment (PWHT) to ensure that the HAZ and base metal exhibit hardness within the specified limits. PWHT, hardness testing, and acceptance criteria shall be in accordance with limits provided in 13.1.3 through 13.1.5 and/or 13.1.8, as appropriate.

13.2 Cast iron and ductile iron

13.2.1 Gray, austenitic, and white cast irons shall not be used as pressure-containing members. These materials may be used in internal components related to API and other appropriate standards, provided their use has been approved by the purchaser.

13.2.2 Ferritic ductile iron in accordance with ASTM A395 is allowed for equipment when API, ANSI, and/or other industry standards approve its use.

13.2.3 Welding is not permitted on gray cast iron or ductile iron components.

13.3 Ferritic stainless steels

13.3.1 Ferritic stainless steels shall be in the annealed condition and shall meet the criteria of Clause 15. The hardness shall not exceed 22 HRC.

13.3.2 Weldments in ferritic stainless steels shall be produced using a weld procedure qualified by performing a hardness survey in accordance with Annex C on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness (248 HV 10 maximum).

13.4 Martensitic stainless steels

13.4.1 Conventional martensitic stainless steels

13.4.1.1 Martensitic stainless steels (UNS S41000, S42000, J91150 [CA15], and J91151 [CA15M]), either cast or wrought, shall be heat treated in accordance with 13.4.1.2 and shall meet the criteria of Clause 15. The hardness shall not exceed 22 HRC. Variations containing alloying elements such as lead, selenium, or sulfur to improve machinability shall not be used. Martensitic stainless steels that are in accordance with this International Standard have provided satisfactory field service in some sour environments. These materials may, however, exhibit threshold stress levels in NACE Standard TM0177 laboratory tests that are lower than the levels for other materials included in this International Standard.

13.4.1.2 Heat-treatment procedure (three-step process) for UNS S41000, S42000, J91150 (CA15), and J91151 (CA15M) martensitic stainless steel is as follows:

a) austenitize and quench or air cool;

b) temper at 621 °C (1 150 °F) minimum; then air cool to ambient temperature;

c) temper at 621 °C (1 150 °F) minimum, but lower than the first tempering temperature; then air cool to ambient temperature.

13.4.2 Low-carbon martensitic stainless steels

13.4.2.1 Low-carbon, 12Cr-4Ni-Mo martensitic stainless steels, either cast UNS J91540 (CA6NM) or wrought UNS S42400, shall be heat treated in accordance with 13.4.2.2. The hardness shall not exceed 23 HRC (255 HBW) (275 HV10). Variations containing alloying elements such as lead, selenium, or sulfur to improve machinability shall not be used.

NOTE The hardness correlation tabulated in ASTM E140 and ISO 18265 does not apply to UNS J91540 (CA6NM) or UNS S42400. When hardness is measured using the Brinell hardness test method, the permissible limit of 255 HBW maximum has been empirically determined to be equivalent to 23 HRC for these alloys.

13.4.2.2 Heat-Treatment Procedure for UNS J91540 (CA6NM) or wrought UNS S42400 (Three Step Process) is as follows:

a) austenitize at 1 010 °C (1 850 °F) minimum and air or oil quench to ambient temperature;

b) temper at 649 °C to 691 °C (1 200 °F to 1 275 °F) and air cool to ambient temperature;

c) temper at 593 °C to 621 °C (1 100 °F to 1 150 °F) and air cool to ambient temperature.

13.4.3 Welding and overlays on martensitic stainless steels

13.4.3.1 Weldments in martensitic stainless steels listed in 13.4.1 shall undergo a PWHT at 621 °C (1 150 °F) minimum. The welding procedure shall be qualified by performing a hardness survey in accordance with Annex C on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness (248 HV 10 maximum).

13.4.3.2 Weldments in low-carbon martensitic stainless steels identified in 13.4.2 shall undergo a double-cycle PWHT after first being cooled to ambient temperature. The double-cycle PWHT shall consist of heating at 671 °C to 691 °C (1 240 °F to 1 275 °F), cooling to ambient temperature, followed by heating at 579 °C to 621 °C (1 075 °F to 1 150 °F). The welding procedure shall be qualified by performing a hardness survey in accordance with Annex C on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness (275 HV 10 maximum).

13.4.3.3 Welding shall only be performed on base materials listed in 13.4.2 that have previously been austenitized, quenched, and double-tempered. Welding between martensitic stainless steels and other materials (including carbon steels, alloy steels, and austenitic stainless steels) is outside the scope of this International Standard.

13.4.3.4 Overlays applied to martensitic stainless steels by thermal processes such as welding, silver brazing, or thermal-spray systems are allowed for use in sour environments. In those cases in which the lower critical temperatures (A_{c1}) are exceeded, the component shall be heat treated or thermally stress relieved in accordance with procedures that have been shown to return the base metal to the specified maximum hardness level. The procedure shall be qualified by performing a hardness survey in accordance with Annex C on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness (248 HV 10 maximum in the case of martensitic stainless steel materials identified in 13.4.1, and 275 HV 10 maximum in the case of low-carbon martensitic stainless steel materials identified in 13.4.2).

13.5 Austenitic stainless steels

13.5.1 Austenitic stainless steels shall meet the chemical composition requirements specified in Table 3, shall not exceed 22 HRC, shall be in the solution-annealed and quenched or solution-annealed and thermally stabilized condition, and shall be free of cold work intended to enhance their mechanical properties. Austenitic stainless steels containing lead or selenium for the purpose of improving machinability are not allowed.

Table 3 — Chemical composition requirements for austenitic stainless steels

Element	Mass percent[a]
C	0,10 max
Cr	16,0 min
Ni	8,0 min
Mn	2,0 max
Si	2,0 max
P	0,045 max
S	0,04 max

[a] The chemical compositions of the cast "austenitic" stainless steels often vary from those of their fully austenitic wrought counterparts to optimize casting characteristics. Many of these alloys are intentionally balanced to contain some ferrite, which renders them partially magnetic.

13.5.2 Unlisted elements, such as molybdenum, nitrogen, titanium, and niobium (columbium), are allowed provided that the chemical composition requirements in Table 3 are met.

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

13.5.4 Welding procedures used for welding and overlaying austenitic stainless steels do not require any hardness surveys or hardness testing to verify hardness in the HAZ.

13.6 Specific austenitic stainless steel grades

13.6.1 Austenitic stainless steel UNS S20910 shall be in the solution-annealed, hot-rolled (hot/cold-worked), or cold-worked condition. The hardness shall not exceed 35 HRC.

13.6.2 Welding procedures used for welding and overlaying UNS S20910 do not require any hardness surveys or hardness testing to verify hardness in the HAZ.

13.7 Highly alloyed austenitic stainless steels

13.7.1 Highly alloyed austenitic stainless steels shall meet the following chemical composition requirements, and shall be in the solution-annealed condition or solution-annealed and cold-worked condition. The hardness shall not exceed 35 HRC. Free-machining highly alloyed austenitic stainless steels are not allowed.

13.7.2 The chemical composition requirements for the highly alloyed austenitic stainless steels are:

a) % Ni + (2 × %Mo) > 30 and Mo > 2 %, or

b) Pitting Resistance Equivalent Number (PREN) > 40,0 %.

Where PREN is determined as shown in Formula (1):

$$\text{PREN} = \%\text{Cr} + 3{,}3\ (\%\text{Mo} + 0{,}5 \times \%\text{W}) + 16 \times \%\text{N} \tag{1}$$

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

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

NOTE For the purposes of this International Standard, PREN is used only to identify a group of alloys from a chemical composition standpoint. Use of PREN to predict relative corrosion resistance is outside the scope of this International Standard.

13.7.5 Welding procedures used for welding and overlaying the highly alloyed austenitic stainless steels do not require any hardness surveys or hardness testing to verify hardness in the HAZ.

13.8 Duplex stainless steels

13.8.1 General requirements for duplex stainless steels

13.8.1.1 Wrought and cast duplex stainless steel products shall be in the solution-annealed and liquid-quenched condition. Tubing shall be rapidly cooled by liquid quenching, or by air or inert gas cooling to below 315 °C (600 °F). The ferrite content shall be 35 vol% to 65 vol%.

13.8.1.2 The hardness of grades with PREN ≤ 40,0 % according to Formula (1) shall not exceed 28 HRC.

13.8.1.3 The hardness of grades with PREN > 40,0 % according to Formula (1) shall not exceed 32 HRC.

13.8.1.4 Brinell hardness measurements obtained on duplex stainless steels cannot be converted to Rockwell C hardness values using existing tables in ASTM E140 or ISO 18265. Use of empirically derived tables for this hardness conversion is subject to the approval of the end user.

13.8.2 Welding requirements for duplex stainless steels

Fabrication and repair welds in all wrought and cast duplex stainless steels shall be produced using a welding procedure qualified by performing the following tests on specimens taken from the WPQT coupon(s).

a) A hardness survey shall be performed in accordance with Annex C. The average hardness shall not exceed 310 HV, and no individual reading shall exceed 320 HV.

b) Metallographic ferrite measurements shall be performed in accordance with ASTM E562. The average ferrite content in the weld deposit and HAZ shall be within the range of 35 % to 65 %, with a relative accuracy of 10 % or lower.

13.9 Precipitation-hardenable stainless steels

13.9.1 Austenitic precipitation-hardenable stainless steel

Austenitic precipitation-hardenable stainless steel with chemical composition in accordance with UNS S66286 shall be in either the solution-annealed and aged or solution-annealed and double-aged condition. The hardness shall not exceed 35 HRC.

13.9.2 Martensitic precipitation-hardenable stainless steels

13.9.2.1 General requirements for 17Cr-4Ni and 15Cr-5Ni grades

UNS S17400 and UNS S15500 wrought martensitic precipitation-hardenable stainless steels shall be in either the H1150D condition (heat treated in accordance with 13.9.2.3) or H1150M condition (heat treated in accordance with 13.9.2.4). The hardness shall not exceed 33 HRC. ASTM A747 CB7Cu-1 and CB7Cu-2 castings shall be in the H1150 DBL condition (heat treated in accordance with 13.9.2.3). The hardness shall not exceed 310 HBW (30 HRC). Precipitation-hardenable martensitic stainless steels that are in accordance with this International Standard have provided satisfactory field service in some sour environments. These materials may, however, exhibit threshold stress levels in NACE Standard TM0177 laboratory tests that are lower than those of other materials included in this International Standard.

13.9.2.2 Restrictions for UNS S17400 and UNS S15500 when used for pressure-retaining bolting

The following restrictions apply to UNS S17400 and UNS S15500 when these materials are used for pressure-retaining bolting.

a) UNS S17400 and UNS S15500 shall not be used for pressure-retaining bolting applications in the double-H1150 condition.

b) When UNS S17400 or UNS S15500 is used for pressure-retaining bolting in the H1150M condition, the hardness shall not exceed 29 HRC.

13.9.2.3 Double-H1150 (H1150D, H1150 DBL) heat-treatment procedure

When heat treating UNS 17400 or UNS 15500 to the H1150 condition, the following heat treatment shall be used.

a) Solution anneal at 1 038 °C ± 14 °C (1 900 °F ± 25 °F) and air cool, or suitable liquid quench, to below 32 °C (90 °F).

b) Harden at 621 °C ± 14 °C (1 150 °F ± 25 °F) for 4 h minimum at temperature and cool in air to below 32 °C (90 °F).

c) Harden at 621 °C ± 14 °C (1 150 °F ± 25 °F) for 4 h minimum at temperature and cool in air.

d) Additional cycles at 621 °C ± 14 °C (1 150 °F ± 25 °F) may be used if required to produce the specified hardness level.

13.9.2.4 H1150M heat-treatment procedure

When heat treating UNS 17400 or UNS 15500 to the H1150M condition, the following heat treatment shall be used.

a) Solution anneal at 1 038 °C ± 14 °C (1 900 °F ± 25 °F) and air cool, or suitable liquid quench, to below 32 °C (90 °F).

b) Harden at 760 °C ± 14 °C (1 400 °F ± 25 °F) for 2 h minimum at temperature and cool in air to below 32 °C (90 °F) before the second precipitation-hardening step.

c) Precipitation harden at 621 °C ± 14 °C (1 150 °F ± 25 °F) for 4 h minimum at temperature and cool in air.

d) Additional cycles at 621 °C ± 14 °C (1 150 °F ± 25 °F) may be used if required to produce the specified hardness level.

13.9.2.5 UNS S45000

Wrought UNS S45000 martensitic precipitation-hardenable stainless steel shall be heat treated in accordance with the following two-step heat–treatment procedure. The hardness shall not exceed 31 HRC.

a) Solution anneal.

b) Precipitation harden at 621 °C (1 150 °F) for a minimum of 4 h.

13.9.3 Welding requirements for precipitation-hardenable stainless steels

Weldments in precipitation-hardenable stainless steels shall be produced using a weld procedure qualified by performing a hardness survey in accordance with Annex C on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness in accordance with Table 4. Welding shall not be performed on UNS S17400 and UNS S15500 bolting.

Table 4 — Maximum hardness requirements for weldments in precipitation-hardenable stainless steels

Alloy(s)	Maximum hardness
UNS S66286	345 HV 10
UNS S17400, UNS S15500	327 HV 10

Table 4 *(continued)*

Alloy(s)	Maximum hardness
UNS J92200 (CB7Cu-1), UNS J92110 (CB7Cu-2)	302 HV 10 (HAZ) 327 HV 10 (weld deposit)
UNS S45000	310 HV 10

14 Nonferrous materials

14.1 Nickel alloys

14.1.1 Solid-solution nickel alloys

14.1.1.1 Wrought or cast solid-solution nickel-chromium-molybdenum alloys with compositions as specified in 14.1.1.2 shall be in the solution-annealed or annealed condition.

14.1.1.2 The chemical composition requirements for the solid-solution nickel-chromium-molybdenum alloys are

a) 19,0 % Cr minimum, 29,5 % Ni + Co minimum, and 2,5 % Mo minimum, or

b) 14,5 % Cr minimum, 52,0 % Ni + Co minimum, and 12,0 % Mo minimum.

14.1.1.3 Wrought UNS N06600 shall not exceed 35 HRC.

14.1.1.4 Wrought UNS N08800 shall not exceed 35 HRC.

14.1.1.5 Only those solid-solution nickel-chromium-molybdenum alloys listed in Table 5 shall be used in the cold-worked condition. The other requirements specified in Table 5 shall also be met.

Table 5 — Cold-worked nickel-chromium-molybdenum alloys and maximum hardness requirements

UNS number	Previous condition	Maximum hardness
N06002	—	35 HRC
N06022	Solution-annealed	40 HRC
N06625	—	35 HRC
N06686	Solution-annealed	40 HRC
N06985	—	39 HRC
N08825	—	35 HRC
N10276	Solution-annealed	35 HRC
N07022	Solution-annealed	43 HRC

14.1.1.6 Wrought UNS N04400 and N04405, and cast ASTM A494 Grades M35-1, M35-2, and M30C shall not exceed 35 HRC.

14.1.1.7 Welding procedures used for welding and overlaying the solid-solution nickel alloys do not require any hardness surveys or hardness testing to verify hardness in the HAZ.

14.1.2 Precipitation-hardenable nickel alloys

14.1.2.1 Only those precipitation-hardenable nickel alloys listed in Table 6 are allowed. The conditions and corresponding maximum hardness requirements listed in Table 6 shall be met.

14.1.2.2 Weldments in precipitation-hardenable nickel alloys shall be produced using a weld procedure qualified by performing a hardness survey in accordance with Annex C on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness in accordance with Table 6.

Table 6 — Precipitation-hardenable nickel alloys, conditions, and maximum hardness requirements

UNS number	Condition(s)	Maximum hardness
N05500	Hot-worked and age-hardened or solution-annealed or solution-annealed and age-hardened	35 HRC (335 HV)
N07022	Solution-annealed, cold worked and aged	47 HRC
N07031	Solution-annealed	35 HRC (335 HV)
	Solution-annealed and aged at 760 °C to 871 °C (1 400 °F to 1 600 °F) for a maximum of 4 h.	40 HRC (382 HV)
N07048	Solution-annealed and aged	40 HRC (382 HV)
N07626	Hot compacted powder, solution-annealed (927 °C [1 700 °F] min) and aged (538 °C to 816 °C [1 000 °F to 1 500 °F]), max tensile strength 1 380 MPa (200 ksi)	40 HRC (382 HV)
N07716	Solution-annealed and aged	43 HRC (416 HV)
N07718	Solution-annealed or hot-worked or hot-worked and aged	35 HRC (335 HV)
	Solution-annealed and aged or cast, solution-annealed, and aged	40 HRC (397 HV)
N07725	Solution-annealed and aged	43 HRC (416 HV)
N07750	Solution-annealed or solution-annealed and aged or hot worked or hot-worked and aged	35 HRC (335 HV)
N07773	Solution-annealed and aged	40 HRC (382 HV)
N07924	Solution-annealed and aged	35 HRC (335 HV)
N09777	Solution-annealed and aged	40 HRC (382 HV)
N09925	Cold-worked or solution-annealed	35 HRC (335 HV)
	Solution-annealed and aged	38 HRC (362 HV)
	Cold-worked and aged or hot-finished and aged	40 HRC (382 HV)
	Cast, solution-annealed, and aged	35 HRC (335 HV)

14.2 Cobalt-Nickel-chromium-molybdenum alloys

14.2.1 UNS R30003, UNS R30004, UNS R30035, and BS 2HR 3 shall not exceed 35 HRC except as otherwise noted below.

14.2.2 Welding requirements for UNS R30003, UNS R30004, UNS R30035, and BS 2HR 3 are outside the scope of this International Standard. Welding requirements shall be in accordance with the agreement between the end user (or the end user's agent) and the manufacturer.

14.2.3 UNS R30035 is allowed in the cold-reduced and high-temperature aged heat-treated condition in accordance with one of the aging treatments listed in Table 7. The hardness shall not exceed 51 HRC.

Table 7 — UNS R30035 heat 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)

14.2.4 Wrought UNS R31233 shall be in the solution-annealed condition. The hardness shall not exceed 33 HRC.

14.2.5 Welding procedures used for welding UNS R31233 do not require any hardness surveys or hardness testing to verify hardness in the HAZ.

14.3 Cobalt-nickel-chromium-tungsten alloys

UNS R30605 shall not exceed 35 HRC.

14.4 Titanium alloys

14.4.1 Specific guidelines shall be followed for successful applications of each titanium alloy specified in this International Standard. 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). Hardness has not been shown to correlate with susceptibility to SSC, but has been included for alloys with high strength to indicate the maximum testing levels at which failure has not occurred.

14.4.2 Only those titanium alloys listed in Table 8 are allowed. The conditions and corresponding maximum hardness requirements listed in Table 8 shall be met.

Table 8 — Titanium alloys, conditions, and maximum hardness requirements

UNS number	Condition(s)	Maximum hardness
R50400	None specified	100 HRBS
R53400	Annealed at 774 °C ± 14 °C (1 425 °F ± 25 °F) for 2 h, air cool	92 HRBS
R56260	Annealed or solution-annealed or solution-annealed and aged	45 HRC
R56323	Annealed	32 HRC
R56403	Annealed	36 HRC
R56404	Annealed	35 HRC
R58640	Annealed	42 HRC

14.4.3 Welding requirements for titanium alloys are outside the scope of this International Standard. Welding requirements shall be in accordance with the agreement between the end user (or the end user's agent) and the manufacturer.

14.5 Aluminium alloys

14.5.1 Aluminium alloys are allowed because they are not susceptible to SSC. However, they can suffer corrosion when exposed outside the pH range of about 4,0 to 8,5 and also pitting corrosion if chloride ions are present.

14.5.2 Welding procedures used for welding aluminium alloys do not require any hardness surveys or hardness testing to verify hardness in the HAZ.

14.6 Copper alloys

14.6.1 Copper alloys are allowed because they are not susceptible to SSC. However, they can suffer corrosion because of the sulfides and also stress corrosion cracking if NH_3 is present, as often noted in sour refinery environments.

14.6.2 Welding procedures used for welding copper alloys do not require any hardness surveys or hardness testing to verify hardness in the HAZ.

15 Fabrication requirements

15.1 General fabrication requirements

Materials and fabrication processes shall meet the requirements of Clause 15.

15.2 Corrosion resistant overlays, hard facing overlays, and cladding

15.2.1 Tungsten-carbide alloys and ceramics are allowed as overlays. Following application of the overlay, the base material shall meet the hardness requirement for that base metal specified in the pertinent material paragraph or subclause within Clause 13 or Clause 14.

15.2.2 Joining of dissimilar materials, such as cemented carbides to alloy steels by silver brazing, is allowed. After brazing, the base material shall meet the hardness requirement for that base metal specified in the pertinent material paragraph or subclause within Clause 13 or Clause 14.

15.2.3 The base materials listed in Clause 13 or Clause 14 are also allowed as weld overlays, provided they meet the provisions of their respective paragraphs after being applied as overlays. Following application of the overlay, the base material shall meet the hardness requirement for that base metal specified in the pertinent material paragraph or subclause within Clause 13 or Clause 14.

15.2.4 Hard facing weld overlays of cobalt-chromium-tungsten, nickel-chromium-boron, and nickel-boron (see SAE AMS4779) alloys are allowed. Following application of the overlay, the base material shall meet the hardness requirement for that base metal specified in the pertinent material paragraph or subclause within Clause 13 or Clause 14.

15.3 Welding

15.3.1 All weldments shall meet the general requirements listed in 15.3. Specific welding requirements are provided for some materials in the pertinent material paragraph or subclause within Clause 13 or Clause 14, in which case those requirements shall also be met. In cases in which the specific welding requirements conflict with the requirements of this subclause, the specific material welding requirements shall override these general requirements.

15.3.2 Welders and welding procedures shall be qualified in accordance with AWS, API, ASME, or other appropriate industry codes.

15.3.3 Dissimilar-metal welds, such as welds produced using filler metals that are nobler than the base metal and/or welds in which the two base metals are different, shall meet the following requirements: The weld metal shall be closely equivalent in chemistry and properties to a base material that is allowed according to this International Standard.

15.3.4 If a Vickers hardness survey is required to be performed during weld procedure qualification for either base metal, or for a base metal that is equivalent to the deposited weld metal, a Vickers hardness survey in accordance with Annex C shall be performed on a specimen taken from the WPQT coupon(s) to demonstrate the ability of the procedure to produce weldments that meet the specified hardness. The hardness criteria for each portion of the weldment shall be as specified in the pertinent material paragraph or subclause in Clause 13 or Clause 14 for that base metal, or, in the case of deposited weld metal, for the base metal that is equivalent to the deposited weld metal.

15.4 Cladding on carbon steels, alloy steels, and martensitic stainless steels

15.4.1 Allowed fabrication methods used for cladding include hot rolling, explosion bonding, weld overlaying, and co-extrusion.

15.4.2 Cladding materials shall be selected from Clause 13 or Clause 14 of this International Standard, and shall meet all requirements for the selected alloy(s) specified in the pertinent paragraph(s) or subclause(s).

15.4.3 A number of factors influence the SSC resistance of clad components, including, but not limited to the following:

a) relative SSC resistance of the cladding material;

b) corrosion resistance of the clad layer in the process environment (which affects the rate of hydrogen production);

c) hydrogen diffusion rate in the clad layer;

d) soundness of the clad layer;

e) relative SSC resistance of the substrate material;

f) fabrication methods used at junctions between neighbouring clad components;

g) fabrication methods used at junctions between clad components and neighbouring nonclad components;

h) galvanic effects (if the substrate material becomes exposed or at junctions with neighbouring nonclad components).

15.4.4 Evaluation of these and other factors is outside the scope of this International Standard. Therefore, the end user shall specify whether or not the substrate material shall meet the requirements of this International Standard.

15.5 Identification stamping

15.5.1 Identification stamping using low-stress (dot, vibratory, and round V) stamps is allowed.

15.5.2 Conventional sharp V stamping is allowed in low-stress areas, such as the outside diameter of flanges. Sharp V stamping is not allowed in high-stress areas unless the item receives a subsequent thermal treatment to reduce the hardness to meet the maximum hardness requirement for the base metal specified in the applicable clauses of this International Standard.

15.6 Threading

15.6.1 Machine-cut threads

Machine-cut threading processes are allowed.

15.6.2 Cold-formed (rolled) threads

After threads have been cold formed, the threaded component shall meet the heat-treatment conditions and hardness requirements specified in either Clause 13 or Clause 14 for the parent alloy from which the threaded component was fabricated.

15.7 Cold-deformation processes

15.7.1 Cold-deformation processes such as burnishing that do not impart cold work exceeding that incidental to normal machining operations (such as turning or boring, rolling, threading, and drilling) are allowed.

15.7.2 Cold deformation by controlled shot peening is permitted when applied to base materials that meet the requirements of this International Standard, and when limited to the use of a maximum shot size of 2,0 mm (0.080 in) and a maximum of 10 C Almen intensity. The process shall be controlled in accordance with SAE AMS2430.

16 Bolting

16.1 General bolting requirements

Materials used for bolting and fasteners that are exposed to sour environments (see Clause 6) shall meet the requirements of Clause 16. The end user (or end user's agent) shall be responsible for specifying whether bolting is exposed or nonexposed in accordance with 16.2 and 16.3.

16.2 Exposed bolting

16.2.1 Bolting that is exposed directly to the sour environment shall meet the requirements of Clause 13 or Clause 14.

16.2.2 External bolting and fasteners used underground, covered with insulation, equipped with flange protectors, or otherwise denied direct atmospheric exposure, and that are used on equipment that contains a sour environment, shall be considered exposed to a sour environment, and shall meet the requirements of Clause 13 or Clause 14.

16.2.3 Users and designers should be aware that it may be necessary to derate the strength of the joint and the pressure rating of the equipment in some cases when using bolting that meets these requirements.

16.2.4 Special restrictions apply to UNS S17400 and UNS S15500 when these alloys are used for pressure-retaining bolting (see 13.9.2.2).

16.2.5 The bolting and nut materials listed in Table 9 were specifically established to meet the requirements of Clause 13 or Clause 14. Other materials meeting the requirements of Clause 13 or Clause 14 are also allowed.

16.2.6 Zinc or cadmium coatings should not be used on bolts, nuts, cap screws, or other fasteners in sour environments. These coatings enhance the generation of hydrogen on the surface and can contribute to hydrogen cracking.

Table 9 — Common bolting materials that meet Clause 13 or Clause 14 requirements

Bolting component	Material specification
Bolt, stud, cap screw	ASTM A193 Grade B7M
	ASTM A193 Grade B8MA, Class 1A
	ASTM A320 Grade L7M
Nut	ASTM A194 Grade 2HM
	ASTM A194 Grade 7M
	ASTM A194 Grade 8MA

16.3 Nonexposed bolting

Nonexposed bolting and fasteners may be furnished to applicable standards such as ASTM A193, ASTM A194, and ASTM A320. To be considered "nonexposed," the bolting shall be used externally on flanges or other parts that are not directly exposed to sour environments, and shall be directly exposed to the atmosphere at all times (see 16.2).

17 Plating, coatings, and diffusion processes

17.1 Metallic coatings (electroplated or electroless), conversion coatings, and plastic coatings or linings are not allowed for preventing SSC of base metals. The use of such coatings for any other purpose (such as wear resistance or corrosion resistance) is outside the scope of this International Standard.

17.2 Nitriding is an allowed surface diffusion treatment when performed at a temperature below the lower critical temperature of the material being treated. Its use as a means of preventing SSC is not allowed.

NOTE Nitriding is not expected to lower resistance to SSC. However, nitriding has been shown to lower corrosion resistance of stainless steels by removing chromium from solution. The designer is cautioned to take this into account when considering nitriding.

18 Special components

18.1 General requirements for special components

Metallic materials for special components including instrumentation, control devices, seals, bearings, and springs shall meet the requirements of Clause 18 if they are directly exposed to sour environments during normal operation of the device. Clause 1 provides guidelines to determine the applicability of the standard to specific uses.

18.2 Bearings

18.2.1 Bearings directly exposed to sour environments shall be made from materials that meet the requirements in Clause 13 or Clause 14, except as noted in 18.2.2. Bearings made from other materials shall be isolated from the sour environment to function properly.

18.2.2 Nickel-chromium-molybdenum-tungsten alloy UNS N10276 is allowed for bearing pins (e.g. core roll pins) in the cold-worked condition. The hardness shall not exceed 45 HRC.

18.3 Springs

18.3.1 Springs directly exposed to the sour environment shall be made from materials that meet the requirements in Clause 13 or Clause 14, except as noted in 18.3.2 to 18.3.4.

18.3.2 Cobalt-nickel-chromium-molybdenum alloy UNS R30003 is allowed for springs in the cold-worked and age-hardened condition. The hardness shall not exceed 60 HRC. UNS R30035 is allowed for springs in the cold-worked and age-hardened condition when aged for a minimum of 4 h at a temperature no lower than 649 °C (1 200 °F). The hardness shall not exceed 55 HRC.

18.3.3 Nickel-chromium alloy UNS N07750 is allowed for springs in the cold-worked and age-hardened condition. The hardness shall not exceed 50 HRC.

18.3.4 UNS N07090 is allowed for springs for compressor valves in the cold-worked and age-hardened condition. The hardness shall not exceed 50 HRC.

18.4 Instrumentation and control devices

18.4.1 General requirements for instrumentation and control devices

18.4.1.1 Instrumentation and control device components directly exposed to sour environments shall be made from materials that meet the requirements in Clause 13 or Clause 14.

18.4.1.2 UNS S31600 austenitic stainless steel, highly alloyed austenitic stainless steel (see 13.7), or nickel alloy (see 14.1) materials are allowed for compression fittings, screen devices, and instrument or control tubing even though these components may not satisfy the requirements stated for those materials in Clause 13 or Clause 14.

18.4.2 Diaphragms, pressure-measuring devices, and pressure seals

18.4.2.1 Diaphragms, pressure-measuring devices, and pressure seals directly exposed to a sour environment shall be made from materials that meet the requirements in Clause 13 or Clause 14, except as noted in 18.4.2.2 to 18.4.2.5.

18.4.2.2 Cobalt-nickel-chromium-molybdenum alloys UNS R30003 and UNS R30004 are allowed for diaphragms, pressure-measuring devices, and pressure seals. The hardness shall not exceed 60 HRC.

18.4.2.3 Cobalt-nickel-chromium-molybdenum-tungsten alloy UNS R30260 is allowed for diaphragms, pressure-measuring devices, and pressure seals. The hardness shall not exceed 52 HRC.

18.4.2.4 Pressure seals shall comply with the material requirements in Clause 13 or Clause 14 or may be manufactured of wrought cobalt-chromium-nickel-molybdenum alloy UNS R30159 with the primary load-bearing or pressure-containing direction parallel to the longitudinal or rolling direction of wrought product. The hardness shall not exceed 53 HRC.

18.4.2.5 Wrought UNS N08904 is allowed for use as instrument tubing in the annealed condition. The hardness shall not exceed 180 HV 10.

18.5 Seal rings and gaskets

18.5.1 Seal rings directly exposed to a sour environment shall be made from materials that meet the requirements in Clause 13 or Clause 14.

18.5.2 Austenitic stainless steel API compression seal rings and gaskets made of wrought or centrifugally cast ASTM A351 Grade CF8 or CF8M chemical compositions are allowed in the as-cast or solution-annealed condition. The hardness shall not exceed 160 HBW (83 HRBS).

18.6 Snap Rings

18.6.1 Snap rings directly exposed to a sour environment shall be made from applicable materials that meet the requirements in Clause 13 or Clause 14, except as noted in 18.6.2.

18.6.2 Precipitation-hardenable stainless steel alloy UNS S15700 originally in the RH950 solution-annealed and aged condition is allowed for snap rings when further heat treated in accordance with the three-step heat treatment procedure below. The hardness shall be 30 to 32 HRC.

a) Temper at 621 °C (1 150 °F) for 4 h, 15 min. Cool to room temperature in still air.

b) Temper at 621 °C (1 150 °F) for 4 h, 15 min. Cool to room temperature in still air.

c) Temper at 566 °C (1 050 °F) for 4 h, 15 min. Cool to room temperature in still air.

18.7 Special process parts

18.7.1 Cobalt-chromium-tungsten and nickel-chromium-boron alloys, whether cast, powder-metallurgy processed, or thermomechanically processed, are allowed.

18.7.2 Tungsten-carbide alloys, whether cast or cemented, are allowed.

19 Valves

19.1 Valves shall meet the requirements of Clause 19 if they are to be exposed to sour environments (see Clause 6). A common failure mode of gate valves exposed to sour environments and not fabricated with hardness-controlled components is a dropped gate, rendering the valve inoperable.

19.2 Valves (new or reconditioned), including internal components, shall be manufactured or remanufactured from materials that meet the requirements in Clause 13 or Clause 14.

20 Compressors and pumps

20.1 Compressor and pump components that are to be exposed to sour environments (see Clause 6) shall be manufactured from materials that meet the requirements in Clause 13 or Clause 14, except as noted in 20.2 to 20.3.

20.2 ASTM A278 Class 35 or 40 gray cast iron and ASTM A395 ductile iron are allowed as compressor cylinders, liners, pistons, and valves. Aluminium alloy ASTM B26 A03550-T7 is allowed for pistons. Aluminium, soft carbon steel, and soft, low-carbon iron are allowed as gaskets in compressors handling sour gas.

20.3 UNS G43200 and a modified version of UNS G43200 that contains 0,28 % to 0,33 % carbon are allowed 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 heat treatment procedure.

a) Austenitize and quench.

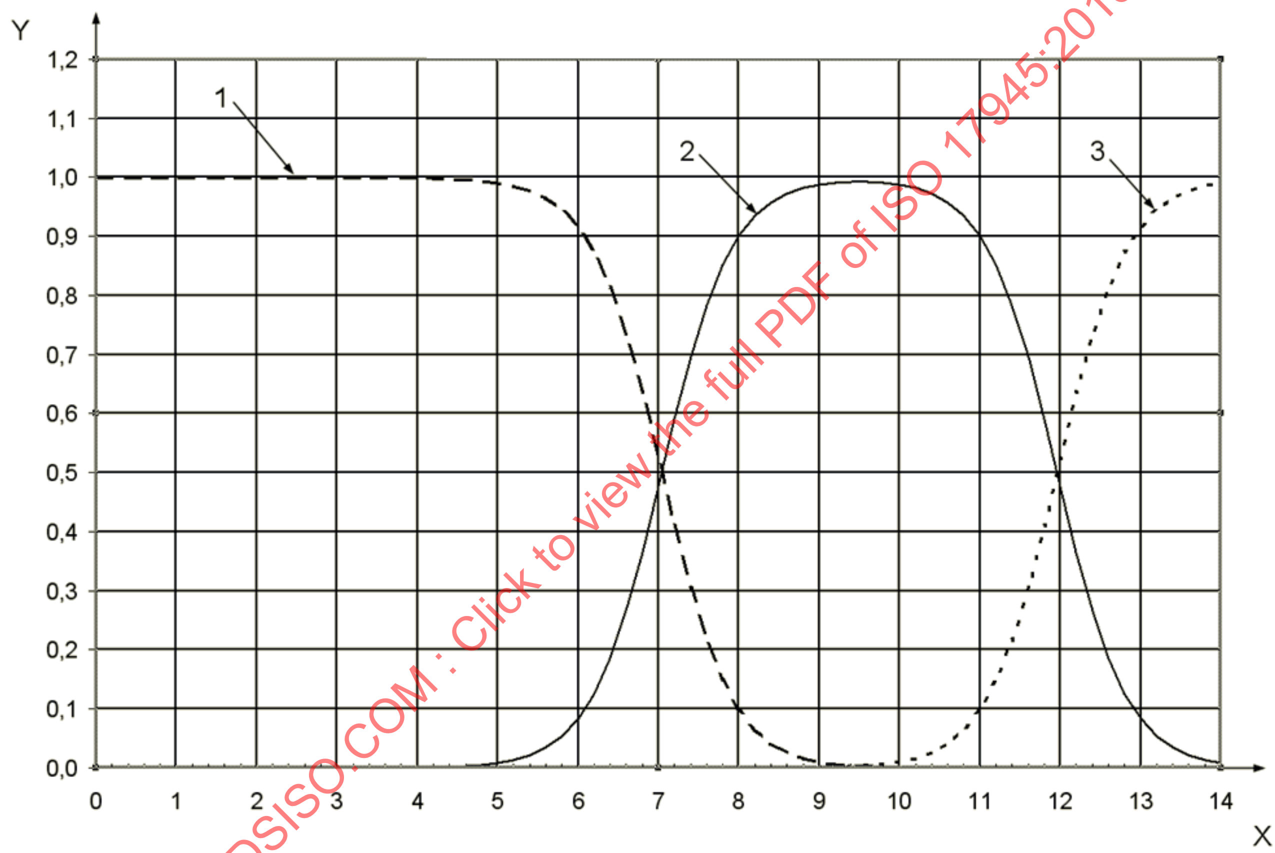
b) Temper at 621 °C (1 150 °F) minimum, but below the lower critical temperature. Cool to ambient temperature before the second temper.

c) Temper at 621 °C (1 150 °F) minimum, but lower than the first tempering temperature. Cool to ambient temperature.

Annex A
(informative)

Sulfide species plot

The plot in Figure A.1 shows sulfide species as a function of pH. This plot was constructed based on the equilibrium constants for H_2S in Section 8-41 of CRC Handbook of Chemistry and Physics, 72nd Edition (see 6.3 for further explanation).



Key

1 H_2S_{aq}

2 HS^-

3 S^{2-}

X pH

Y mole fraction of sulfur species

Figure A.1 — Sulfide species plot for closed system at 25 °C (77 °F)

Annex B
(informative)

Background information on hardness testing and requirements

B.1 Accurate hardness testing requires strict compliance with the hardness test methods described in the appropriate ASTM or ISO standards.

B.2 Rockwell hardness test methods, performed in accordance with ASTM E18 or ISO 6508-1, are relatively quick, direct-reading tests, and as such they are commonly used in manufacturing environments. These hardness test methods use loads ranging from 147 N (15 kgf) to 1 470 N (150 kgf). Because of the relatively small loads that are used, the hardness indentations are small, and the measurements represent the hardness in a very localized volume of material. Therefore, these hardness test methods are very sensitive, and are suited for identifying localized hard spots. Drawbacks to these test methods are the size restrictions on components that can be tested, geometrical limitations that prevent testing in certain locations, and lack of portability.

NOTE Beginning in the 2011 revision of ASTM E18 and the 2012 edition of ASTM A370, use of a hardened steel ball is permitted only for testing thin sheet tin mill products as found in specifications ASTM A623 and A623M using HR15T and HR30T scales with a diamond spot anvil. All other Rockwell "B" hardness testing is now performed with a tungsten carbide ball. The scale designations for Rockwell "B" hardness measurements performed in the past with a steel ball are designated "HRBS". For Rockwell "B" tests performed with a tungsten carbide ball, the scale designation is "HRBW." The hardness values shown in this International Standard are all "HRBS" values, because all testing in the past used the steel ball indenter. HRBS and HRBW test results differ because of the different mechanical properties of the two ball indenters. There are currently no standardized conversion tables available for conversion of HRBS to HRBW.

B.3 The Brinell hardness test method, performed in accordance with ASTM E10 or ISO 6506-1, involves creation of an indentation, optical measurement of the indentation diameter, and calculation of the hardness value. Because of the relatively large test loads used, this test method produces a hardness value that represents an "average" of the material hardness over a relatively large volume of material. The Brinell test method is often used to measure the hardness of castings and forgings. Drawbacks to this test method are the size restrictions on components that can be tested, geometrical limitations that prevent testing in certain locations, and lack of portability. ASTM E10 now requires Brinell hardness testing to be performed with a tungsten carbide ball indenter. The symbol "HBW" denotes Brinell hardness testing performed in this manner.

B.4 Comparison hardness testers (commonly, but incorrectly, referred to as portable Brinell hardness testers) use a hammer blow to simultaneously indent the component being evaluated and a test bar of known hardness. The relative indentation sizes are measured and a calculation is performed to determine the hardness of the component. Comparison hardness testers are commonly used to check field weldments. Comparison hardness testing is performed in accordance with ASTM A833. The hardness values obtained using comparison hardness testers correlate directly to Brinell hardness values obtained using testing parameters discussed in B.3.

B.5 The macro Vickers hardness test method, performed in accordance with ASTM E384 (which has replaced ASTM E92) or ISO 6507-1, is similar to the Brinell hardness test method except it makes use of a diamond pyramid indenter. The advantage of the Vickers hardness test method is that it provides relatively load-independent hardness values when performed with loads ranging from 0,25 N (25 gf) to 1,180 N (120 kgf). It is common practice to use 49 N (5 kgf) or 98 N (10 kgf) Vickers hardness testing for welding procedure qualifications because this produces an accurate assessment of the weldment HAZ hardness. Vickers hardness criteria have been specified for a few selected welding procedure qualifications in this International Standard, based on proven field experience. Further details are available in NACE SP0472.

Vickers hardness is designated as HV, with the test load in kgf indicated by a suffix number (e.g. 248 HV 10 denotes a Vickers hardness of 248 determined using a 98 N /10 kgf load).

B.6 Hardness requirements specified in this International Standard in HBW units are generally lower than the equivalent "acceptable" HRC values (which applies to both conventional Brinell hardness testing and comparison hardness testing) to compensate for nonhomogeneity of some material forms and weld deposits and/or to account for normal variations in field and/or production hardness testing using the comparison hardness tester.

B.7 HRC and HRBS are cited for particular materials or product forms under any of the following conditions:

a) when the raw material specification lists a hardness requirement in HRC or HRBS;

b) when the industry standard testing method for that product form is HRC or HRBS;

c) when the material will be tested at the component level.

B.8 HBW is cited for particular materials or product forms under any of the following conditions:

a) when the raw material specification lists a hardness requirement in HBW;

b) when the industry standard testing method for that product form is HBW;

c) when the hardness requirement pertains to evaluation of weld metal hardness, which is most commonly performed using a portable Brinell hardness tester.

B.9 A standard fixed-location hardness testing machine may not be capable of testing certain samples because of the sample size, weight, location, accessibility, or other requirements. In these circumstances, the use of a portable hardness tester may be the only option available. However, not all portable hardness testers meet the requirements of ISO or ASTM standard hardness test methods. The following is a list of portable hardness test standards used for ferrous materials.

a) ASTM A833, *Comparison Hardness*

b) ASTM A956, *Leeb Hardness Testing*

c) ASTM A1038, *Portable Hardness Testing by the Ultrasonic Contact Impedance Method*

d) ASTM E110, *Indentation Hardness of Metallic Materials by Portable Hardness Testers*

e) DIN 50156-1, *Leeb Hardness Testing*

B.10 Portable hardness testers that do not meet any of the above standards are deemed to be non-standard testing equipment and are outside the scope of this International Standard.

B.11 There are two major types of portable hardness testers, described as follows.

a) Portable hardness testers that follow the same test principles as those defined for a standard fixed-location hardness tester using the same test method, e.g. Brinell, Rockwell, and Vickers test methods that are included in ASTM E110.

b) Portable hardness testers that measure hardness by a means or procedure that is different than those defined for a standard fixed-location hardness tester, e.g. Brinell, Rockwell, and Vickers test methods that are included in ASTM A833, ASTM A956, ASTM A1038, and DIN 50156.

B.12 The most common sources of error when using portable hardness testers are the alignment of the indenter to the test surface and the timing of the test forces. The user is cautioned to do everything possible to keep the centerline of the indenter perpendicular to the test surface and to strictly follow the standard test method procedures.

B.13 Portable hardness testers are subject to damage when they are moved from one test site to another. Therefore, the user should be aware of the test method verification requirements when the portable hardness tester is new, or when adjustments, modifications, and repairs are made that could affect the application of the test forces or depth measuring system.

B.14 It is also important to follow the standard test method requirements for daily verifications before each use and oriented in the position that it will be used to ensure that they are working properly. It is recommended that the daily verification be repeated occasionally during testing and after testing is completed.

B.15 Precision is the closeness of agreement between test results obtained under prescribed conditions. Bias is a systematic error that contributes to the difference between the mean of a large number of test results and an accepted reference value. Portable hardness testers, in comparison to fixed-location hardness testers, inherently introduce larger precision variances and bias errors that influence the test results.

B.16 The user should understand that not all portable hardness testing standards include precision and bias rules that may be used to establish differences in test results that would be expected between portable and fixed-location instruments.

B.17 Precision rules, bias rules, and results differ not only between standard fixed location and portable hardness test methods, but also between standard portable hardness test methods. Consequently, the user is cautioned that all portable hardness testers should not be considered as equals and that the appropriate hardness testing standard(s) should be thoroughly reviewed and considered before approving its application to meet the hardness requirements in this International Standard for the equipment's intended service conditions.

B.18 For example, a) and b) below show ASTM E110 values of R_{PB} (the typical amount of variation that can be expected between test results obtained for the same material by different operators using a different hardness tester on different days) at two different hardness levels.

EXAMPLE 1 Test material hardness: 201 HBW R_{PB} = 14 HBW

EXAMPLE 2 Test material hardness: 543 HBW R_{PB} = 39 HBW

NOTE ASTM A833 is a practice and not a test method. Consequently, it does not contain precision and bias rules and likewise it is not capable of establishing precision variances and bias errors that may influence the test results.

B.19 To be in compliance with the standard portable hardness test listed herein, the hardness number should be reported accordingly. Examples are as follows.

EXAMPLE 1 197 HBC/200 where 197 is the hardness determined and 200 is the Brinell hardness of the comparative test bar; the identification of the manufacturer's equipment and the diameters of the impressions in the test piece and comparative test bar is also reported when using a portable comparative hardness tester and procedures that meet the requirements of ASTM A833.

EXAMPLE 2 187 HB (HLG) = Brinell hardness number of 187 that was converted from the Leeb hardness number when using a portable Leeb hardness tester and procedures that meet the requirements of ASTM A956 or DIN 50156–1.

EXAMPLE 3 250 HV (UCI) 10 = UCI hardness number of 250 under a force of 10 kgf when using a portable Vickers hardness tester and procedures that meet the requirements of ASTM A1038.

EXAMPLE 4 22 HRC/*P* = Rockwell hardness number of 22 on Rockwell C scale when using a portable Rockwell hardness tester and procedures that meet the requirements of ASTM E110.

B.20 Conversion of hardness values from one hardness scale to another can introduce errors. ASTM E140 and ISO 18265 include warnings regarding the limitations and risks associated with conversion of hardness values, including indications that conversions are not always precise for all metallic materials and may even be of questionable precision, bias, and uncertainty. These limitations and risks apply to hardness conversions involving the various standard fixed-location hardness test methods as well as the various portable hardness test methods.

B.21 Some fixed-location and portable hardness testers perform internal conversions between hardness scales using the tables in ASTM E140 or ISO 18265. There may also be some instances where hardness scale conversions are handled outside of the ASTM E140 or ISO 18265 tables based on proprietary data or algorithms, especially in some portable instruments where no standardized conversion tables exist. In either case, conversions may be an additional source inaccuracy and uncertainty.

B.22 Both ASTM E140 and ISO 18265 have specific rules for reporting converted hardness numbers using their tables. Examples are as follows.

a) ASTM E140: When reporting converted hardness numbers, the measured hardness and test scale are indicated in parentheses as in the following example:

EXAMPLE 1 353 HBW (38 HRC)

b) ISO 18265: Conversion results are reported in a manner that clearly indicates which method was used to determine the original hardness value. In addition, the relevant annex to this International Standard or the table used is given.

EXAMPLE 2

Conversion ISO 18265 - 50,5 HRC - B.2 - HV

Standard number: Conversion ISO 18265

Converted hardness value: 50,5 HRC

Table used for comparison: B.2

Original hardness test method used: HV

EXAMPLE 3 If it is agreed that the uncertainty of the converted value is to be given, this is included in the result as follows: Conversion ISO 18265 - (62,0 ±1,0) HRC - C.2 - HV

Standard number: Conversion ISO 18265

Converted hardness value, with uncertainty: (62,0 ± 1,0) HRC

Table used for comparison: C.2

Original hardness test method used: HV

B.23 Microhardness evaluation, performed in accordance with ASTM E384 using either the Vickers or Knoop hardness test method, may be necessary for some components that are too small to be tested by conventional (macro) hardness test methods. Microhardness testing uses loads of 9,8 N (1 kgf) or less. Microhardness testing is more sensitive than macrohardness testing methods because of the very small indentation size. Because of this sensitivity, microscopic constituents such as second phases can cause individual hardness readings that are much higher than the bulk hardness. Thus, it is more difficult to establish general acceptance criteria based on microhardness testing. Individualized microhardness test procedures and associated acceptance criteria may need to be developed for each material/component combination being evaluated.

Annex C
(normative)

Welding procedure qualification hardness survey layouts

C.1 Hardness surveys shall be performed on a specimen taken from the WPQT coupon(s) using the Vickers hardness test method with a load of 98 N (10 kgf) or 49 N (5 kgf) in accordance with ASTM E384. The standard load is 98 N (10 kgf). Note that for low heat input welds, such as mechanized welds, a 49 N (5 kgf) load may be necessary to measure the hardness in the HAZ.

C.2 The minimum distance from the centre of any hardness indentation to any surface, or between the centers of any two hardness indentations, shall be 1 mm (0.04 in), or the distance required by ISO 6507-1, whichever is greater.

C.3 The hardness surveys shall be performed in accordance with the appropriate layout(s). Figures C.1 through C.3 show the required hardness test lines for butt welds.

C.4 When it is deemed necessary to qualify a special welding procedure to repair flaws in existing welds, a hardness survey shall be performed in accordance with Figure C.4. The need for a such a special procedure shall be based upon agreement between the end user (or the end user's agent) and the manufacturer, and will usually be considered necessary when there are significant differences in parameters (such as welding process, filler metal, preheat/interpass temperature, heat input, and/or PWHT condition) between the original welding procedure and the proposed repair procedure.

C.5 Details for placement of hardness indentations in butt welds, fillet welds, and weld overlays are shown in Figures C.5 through C.7.

C.6 For qualification of procedures utilizing temper bead techniques, the hardness surveys shall be performed as defined in paragraph QW-290.5 (c) and Figure QW-462.12 in Section IX of the ASME B&PV Code, except the Vickers testing may be performed using a 49 N (5 kgf) load, and instrumented indentation testing shall not be allowed.

C.7 Hardness surveys performed in accordance with the layouts in NACE MR0175/ISO 15156 are allowed if the testing was performed prior to the following dates:

a) Carbon steels: 2009-01-01;

b) All other materials requiring hardness surveys: 2011-01-01.

C.8 Hardness surveys performed in accordance with the layouts in NACE MR0103 or NACE SP0472 are allowed if the testing was performed prior to 2015-01-01 (or the release date of this International Standard).

C.9 Microhardness testing using Knoop or Vickers tests with ≤4,9 N (500 gf) loads may be considered; however, the effects of surface preparation, etching, mounting procedures, appropriate criteria, and other details shall be reviewed and approved by the end user (or the end user's agent) before being used. Guidance on these hardness test techniques is given in ASTM E384.

C.10 Individual HAZ hardness readings exceeding the value permitted by this International Standard shall be considered acceptable if the average of three hardness readings taken in the equivalent HAZ profile location adjacent to the hard HAZ reading (by repolishing the existing specimen taken from that WPQT coupon or taking additional specimens from that WPQT coupon) does not exceed the values permitted by this International Standard and no individual hardness reading is greater than 5 % above the specified value.

C.11 The hardness test results shall be appended to the PQR. The results shall include a sketch of the hardness test locations and corresponding results.

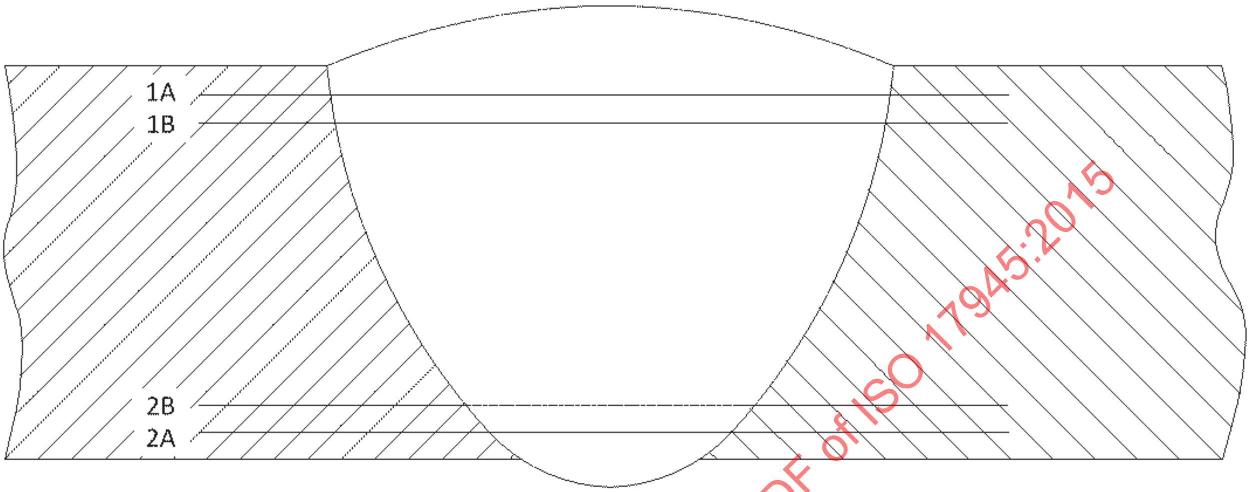


Figure C.1 — Rows of indentations in butt welds from one side

Coupon Thickness, T (base metal thickness or weld deposit thickness, whichever is smaller)	**Survey Lines/Types Required** Example: 1A is survey line 1, using line type A. See Figure C.5 for butt weld survey line types.	
	Process contacts the cap side (top)	**Process contacts the root side (bottom)**
7,5 mm and over	Lines 1A, 1B, 2A, and 2B	
6 mm ≤ T < 7,5 mm	Lines 1A, 1B, and 2A	Lines 1A, 2A, and 2B
4,5 mm ≤ T < 6 mm	Lines 1A and 2A	
2 mm ≤ T < 4,5 mm	Line 1A	Line 2A
T < 2 mm	Line 1A (reduced test force may be required)	Line 2A (reduced test force may be required)