Standard
Material Requirements

Metals for Sulfide Stress Cracking and Stress Corrosion Cracking Resistance in Sour Oilfield Environments

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Foreword

This NACE standard materials requirement is one step in a series of committee studies, reports, symposia, and standards that have been sponsored by former Group Committee T-1 (Corrosion Control in Petroleum Production) relating to the general problems of sulfide stress cracking (SSC) and stress corrosion cracking (SCC) of metals. Much of this work has been directed toward the oil- and gas-production industry. This standard is a materials requirement for metals used in oil and gas service exposed to sour gas, to be used by oil and gas companies, manufacturers, engineers, and purchasing agents. Many of the guidelines and specific requirements in this standard are based on field experience with the materials listed, as used in specific components, and may be applicable to other components and equipment in the oil-production industry or to other industries, as determined by the user. Users of this standard must be cautious in extrapolating the content of this standard for use beyond its scope.

The materials, heat treatments, and metal-property requirements given in this standard represent the best judgment of Task Group 081 (formerly T-1F-1) and its administrative Specific Technology Group (STG) 32 on Oil and Gas Production—Metallurgy (formerly Unit Committee T-1F on Metallurgy of Oilfield Equipment).

This NACE standard updates and supersedes all previous editions of MR0175. The original 1975 edition of the standard superseded NACE Publication 1F166 (1973 Revision) titled "Sulfide Cracking-Resistant Metallic Materials for Valves for Production and Pipeline Service," and NACE Publication 1B163 titled "Recommendation of Materials for Sour Service" (which included Tentative Specifications 150 on valves, 51 on severe weight loss, 60 on tubular goods, and 50 on nominal weight loss).

This standard will be revised as necessary to reflect changes in technology. (See Sections 13, 14, and 15.)

Whenever possible, the recommended materials are defined by reference to accepted generic descriptors (such as UNS[(1)] numbers) and/or accepted standards, such as AISI,[(2)] API,[(3)] ASTM,[(4)] or DIN[(5)] standards.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state something considered good and is recommended but is not mandatory. *May* is used to state something considered optional.

(1) Metals and Alloys in the Unified Numbering System (latest revision), a joint publication of ASTM International (ASTM) and the Society of Automotive Engineers Inc. (SAE), 400 Commonwealth Drive, Warrendale, PA 15096.
(2) American Iron and Steel Institute (AISI), 1101 17th St. NW, Suite 1300, Washington, DC 20036.
(3) American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005.
(4) ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.
(5) Deutsches Institut für Normung (DIN), Burggrafenstrasse 6, D-10787 Berlin, Germany.

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Contents

Section 1: General

1.1 Scope

This standard presents metallic material requirements to provide resistance to sulfide stress cracking (SSC) and/or stress corrosion cracking (SCC) for petroleum production, drilling, gathering and flow line equipment, and field processing facilities to be used in hydrogen sulfide (H_2S)-bearing hydrocarbon service.

This standard is applicable to the materials and/or equipment specified by the materials standards institutions listed in Table 1 (or by equivalent standards or specifications of other agencies).

This standard does not include and is not intended to include design specifications.

Other forms of corrosion and other modes of failure, although outside the scope of this standard, should also be considered in design and operation of equipment. Severely corrosive conditions may lead to failures by mechanisms other than SSC and/or SCC and should be mitigated by corrosion inhibition or materials selection, which are outside the scope of this standard. For example, some lower-strength steels used for pipelines and vessels may be subjected to failure by hydrogen-induced cracking (blistering and stepwise cracking) as a result of hydrogen damage associated with general corrosion in the presence of H_2S.[1,2]

TABLE 1
Sources of Material Standards

1.	Aerospace Material Specifications (AMS): Society of Automotive Engineers Inc. (SAE), 400 Commonwealth Drive, Warrendale, PA 15096.
2.	American Iron and Steel Institute (AISI), 1101 17th St. NW, Suite 1300, Washington, DC 20036.
3.	American National Standards Institute (ANSI), 11 West 42nd St., New York, NY 10036.
4.	American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005.
5.	ASME International (ASME), Three Park Ave., New York, NY 10016-5990.
6.	ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.
7.	American Welding Society (AWS), P.O. Box 251040, Miami, FL 33126.
8.	British Standards Institution (BSI), British Standards House, 389 Chiswick High Rd., London W4 4AL, United Kingdom.
9.	CSA International, 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3.
10.	Deutsches Institut für Normung (DIN), Burggrafenstrasse 6, D-10787, Berlin, Germany.

1.2 Procurement

It is the responsibility of the user to determine the operating conditions and to specify when this standard applies.[6] A variety of candidate materials may be selected from this standard for any given component. The manufacturer is responsible for meeting metallurgical requirements. It is the user's responsibility to ensure that a material will be satisfactory in the intended environment. The user may select specific materials for use on the basis of operating conditions that include pressure, temperature, corrosiveness, fluid properties, etc. For example, when bolting components are selected, the pressure rating of flanges could be affected. The following could be specified at the user's option: (1) materials from this standard used by the manufacturer, and (2) materials from this standard proposed by the manufacturer and approved by the user. It is always the responsibility of the equipment user to convey the environmental conditions to the equipment supplier, particularly if the equipment will be used in sour service.

1.3 Applicability

This standard applies to all components of equipment exposed to sour environments, where failure by SSC or SCC would (1) prevent the equipment from being restored to an operating condition while continuing to contain pressure, (2) compromise the integrity of the pressure-containment system, and/or (3) prevent the basic function of the equipment from occurring. Materials selection for items such as atmospheric and low-pressure systems, water-handling facilities, sucker rods, and subsurface pumps are covered in greater detail in other NACE International and API documents and are outside the scope of this standard.

1.4 MR0175 Application

Sulfide stress cracking (SSC) is affected by the following factors:

(1) metallurgical condition and strength, which are affected by chemical composition, heat treatment, cold work, and microstructure;

[6] See Section 2 for the definition of *user*.

(2) hydrogen ion concentration (activity) (pH) of the water phase;

(3) H_2S partial pressure, which is a function of the H_2S concentration and total absolute pressure;

(4) total tensile stress (applied plus residual);

(5) temperature;

(6) exposure duration;

(7) galvanic effects;

(8) chloride or other halide ion concentration;

(9) oxidants; and

(10) non-production fluids (including those used for acid stimulation and for packer fluids).

Stress corrosion cracking (SCC) in sour service is affected by the following factors:

(1) metallurgical condition and strength, which are affected by chemical composition, cold work, heat treatment, and microstructure;

(2) hydrogen ion concentration (activity) (pH) of the water phase;

(3) H_2S partial pressure, which is a function of the H_2S concentration and total absolute pressure;

(4) total tensile stress (applied plus residual);

(5) temperature;

(6) exposure duration;

(7) galvanic effects;

(8) chloride or other halide ion concentration;

(9) oxidants; and

(10) non-production fluids (including those used for acid stimulation and for packer fluids).

The user shall determine whether or not the environmental conditions are such that MR0175 applies. Please see Appendix A for sample calculations.

1.4.1 MR0175 *shall* apply to conditions containing water as a liquid and H_2S exceeding the limits defined in Paragraph 1.4.1.1. Highly susceptible materials may fail in less severe environments.

1.4.1.1 All gas, gas condensate, and sour crude oil (except as noted in Paragraph 1.4.2)

When the partial pressure of H_2S in a wet (water as a liquid) gas phase of a gas, gas condensate, or crude oil system is equal to or exceeds 0.0003 MPa abs (0.05 psia).

1.4.2 MR0175 need not apply (the user shall determine) when the following conditions exist:

1.4.2.1 Low-pressure gas

When the total pressure is less than 0.45 MPa abs (65 psia).

1.4.2.2 Low-pressure oil and gas multiphase systems

When the total pressure is less than 1.83 MPa abs (265 psia), the maximum gas:oil ratio is 142 SCM:bbl (5,000 SCF:bbl), the H_2S content is less than 15 mol%, and the H_2S partial pressure is less than 0.07 MPa abs (10 psia).

1.4.2.3 Salt water wells and salt water handling facilities. These are covered by NACE Standard RP0475.[3]

1.4.2.4 Refineries and chemical plants.

1.4.2.5 Parts loaded in compression.

1.5 Control of SSC and/or SCC

1.5.1 SSC and/or SCC may be controlled by any or all of the following measures:

(1) using the materials and processes described in this standard;

(2) controlling the environment;

(3) isolating the components from the sour environment; or

(4) using appropriate anodic or cathodic polarization.

Metals susceptible to SSC and/or SCC have been used successfully by controlling drilling or workover fluid properties, during drilling and workover operations, respectively.

1.6 Materials Included in MR0175

1.6.1 Metallic materials have been included in this standard as acceptable materials based on their resistance to SSC and/or SCC either in actual field applications, in SSC and SCC laboratory tests, or both. Many alloys included in the first edition of MR0175 had proved to be satisfactory in sour service even though they might have cracked in standard SSC and/or SCC laboratory tests, such as those addressed in NACE Standard TM0177.[4]

1.6.2 Materials included in this standard are resistant to, but not necessarily immune to, SSC and/or SCC in stated conditions. Improper design, manufacturing, installation, selection, or handling can cause resistant materials to become susceptible to SSC and/or SCC.

1.7 Hardness Requirements

1.7.1 Because hardness testing is nondestructive, it is used by manufacturers as a quality control method and by users as a field inspection method. Accurate hardness testing requires strict compliance with the methods described in appropriate ASTM standards.

1.7.2 Hardness tests sufficient to establish the actual hardness of the material or component being examined shall be made. Individual hardness readings exceeding the value permitted by this standard are considered acceptable if the average of several readings taken within close proximity does not exceed the value permitted by this standard and no individual reading is greater than 2 Rockwell C hardness (HRC) units above the acceptable value. The number and location of test areas are outside the scope of this standard.

1.7.3 The HRC scale is referred to throughout this standard. Rockwell C hardness values measured in accordance with ASTM E 18[5] shall be the primary basis for acceptance. Brinell hardness (HBW), Vickers (HV) 5-kg or 10-kg, or other hardness testing methods may be used. When applicable, conversion of hardness values obtained by these other test methods to HRC values shall be made in accordance with ASTM E 140.[6] [(7)] Empirical conversion data are acceptable when approved by the purchaser. Acceptance criteria using microhardness testing, as defined by ASTM E 384,[7] are considered outside the scope of this standard.

1.8 How to Use MR0175 (a Road Map)

1.8.1 See Figure 1. A user of materials in sour service must first determine whether MR0175 is applicable for the intended application. Section 1 of MR0175 may be used for guidance. Refer to Section 2 for definitions of terms used in MR0175.

1.8.2 If the user chooses to use MR0175 for materials selection in sour service, the process involves determining whether the desired materials are within the scope of the standard, the metallurgical requirements for the materials, and the environmental restrictions, if any, for the material.

1.8.3 The following process should be used for finding acceptable materials and their requirements in MR0175:

1.8.3.1 For carbon steels, low-alloy steels, and cast irons, first review Section 3. This section contains the most general requirements for widespread applications of these alloys.

1.8.3.1.1 If questions about these alloys are not adequately answered in Section 3 or if the alloy in question is not within the scope of Section 3, review requirements for specific types of equipment in Sections 6, 8, 9, 10, 11, and 12.

1.8.3.1.2 For specific requirements during fabrication, including welding, review Section 5.

1.8.3.1.3 For plating and coatings applications of these alloys, see Section 7.

1.8.3.2 The process is the same for selecting corrosion-resistant alloys (CRAs) except that the general requirements are first found in Section 4. Section 4 contains specific alloys and groups of alloys (categories); these are discussed in Paragraph 1.8.3.3.

1.8.3.2.1 See Appendix C for previously submitted ballot data. This appendix gives information on data submitted for ballot for acceptance into MR0175.

1.8.3.3 Individual Alloys Versus Alloy Categories

Section 4 lists CRAs as individual alloys or in alloy categories. Alloy (CRA) categories permit a broad-based description of similar alloys. A CRA category in Section 4 defines a group of alloys in terms of broad-based but essential chemical compositions, manufacturing processes, and finished conditions. The entire chemical composition range of an alloy shall meet all the requirements of the given CRA category in order to be included within the category.

1.8.3.3.1 All applicable environmental restrictions are defined for all of the alloys in the category. These environmental restrict-tions may include the maximum acceptable partial pressures of H_2S, minimum acceptable water pH, maximum acceptable chlorides in the water, temperature, and whether the presence of elemental sulfur is acceptable.

[(7)] The hardness correlation tabulated in ASTM E 140 does not apply to martensitic stainless steels and precipitation-hardened stainless steels. When hardness is measured by Brinell testing, the permissible limit for UNS J91540 (CA6NM) and UNS S42000 is 255 HBW maximum, which has been empirically determined to be equivalent to 23 HRC for these alloys. For materials not listed in ASTM E 140, empirical data are acceptable in determining hardness conversion.

When environmental restrictions are listed in tables, interpolation between H_2S partial pressures, temperatures, etc., is permitted.

1.8.3.3.2 Some categories may include alloy-specific requirements. These are metallurgical requirements typically restricting chemistry and hardness.

1.8.3.3.3 Examples of CRA individual alloy and CRA category use:

Individual CRA Alloy Example: UNS J93254 (CK3MCuN) is listed in Paragraph 4.3.2 as an *individual alloy*. All requirements for this alloy are located solely in Paragraph 4.3.2.

CRA Category Example: The ferritic stainless steels in Paragraph 4.7.1 are listed as an alloy *category*. Any ferritic stainless steel may be used within the environmental restrictions of this paragraph. Individual alloys do not have to be listed.

CRA Category with Specific Alloy Requirements Example: The martensitic stainless steels are more loosely grouped in Paragraph 4.8 as a *category with alloy-specific requirements*. Environmental restricttions are the same for all of the martensitic stainless steels, but there are metallurgical requirements for each of the alloys within the category.

1.8.4 If the material in question is outside the scope of MR0175, the following options may be used:

1.8.4.1 See Sections 13, 14, and 15 for proposals for balloting changes and additions to all sections of MR0175. See Appendix B for sample test data tables and the definition of available Test Levels I through VII.

1.8.4.2 See Section 16 for guidance through a process for choosing materials for application-specific cases without proposing to add new materials to MR0175.

1.8.5 Four appendixes are included in this standard.

1.8.5.1 Appendix A provides sample calculations of the partial pressure of H_2S.

1.8.5.2 Appendix B provides sample test data tables.

1.8.5.3 Appendix C provides ballot submittal data in tabular form.

1.8.5.4 Appendix D provides lists of acceptable materials for various applications.

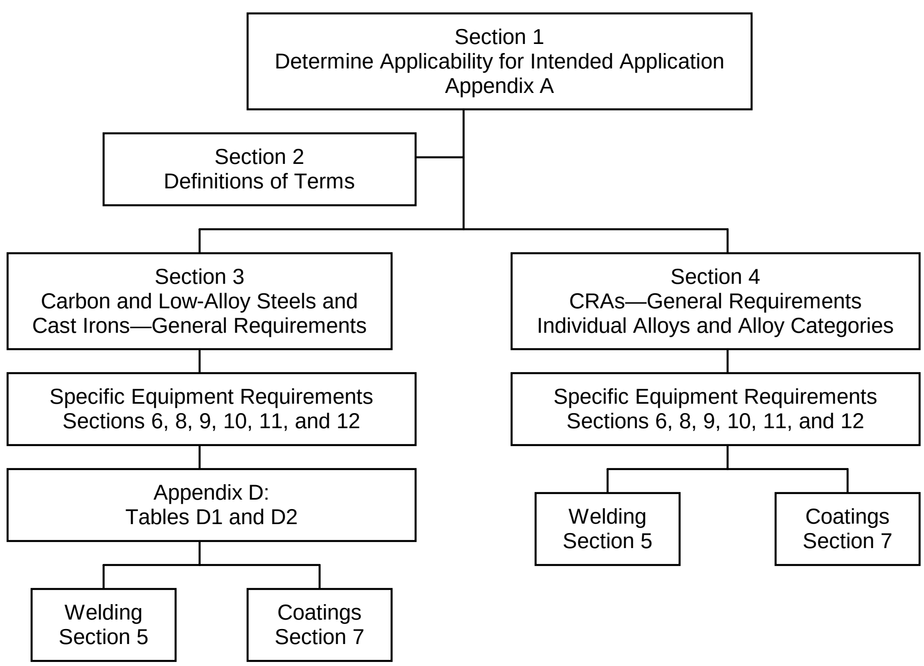

FIGURE 1
Road Map for MR0175

1.9 Materials are added to MR0175 either as an individual alloy or as alloy categories. Ballot items shall conform to the standard's method. If a ballot proposes an addition of an individual alloy or modification to the requirements for that alloy, the ballot must address only that individual alloy. Conversely, if a ballot proposes an addition or modification of requirements for alloys in a category, the ballot must address the category of alloys.

1.10 The Effect of Changing Requirements in MR0175 on Existing Equipment

When new restrictions are placed on materials in this standard or when materials are deleted from this standard, materials in use at the time of the change that complied with this standard prior to the standard revision and that have not experienced SSC and SCC failures in their local environment are in compliance with this standard. However, when these materials are removed from their local environment, the replacement materials must be listed in this standard at the time of replacement in order to be in compliance with this standard.

1.10.1 Successful use of materials outside the limitations of MR0175 may be perpetuated by qualification in accordance with Section 16.

1.10.2 The user may replace materials in kind for existing wells or for new wells within a given field if the design basis for the equipment has not changed. The user shall verify that the environmental conditions of the field have not changed to dictate the need for new materials substitutions, and the replacement materials are the same.

Section 2: Definitions

Age Hardening: Hardening (strengthening) by aging, usually after rapid cooling or cold working.

Aging: A change in metallurgical properties that generally occurs slowly at room temperature (natural aging) and more rapidly at higher temperature (artificial aging).

Annealing: Heating a metal to a suitable temperature, holding at that temperature for a suitable period of time, and then cooling at a suitable rate, for such purposes as reducing hardness, improving machinability, or obtaining desired properties.

Austenite: The face-centered cubic crystalline phase of ferrous or nonferrous alloys.

Austenitic Steel: A steel whose microstructure at room temperature consists predominantly of austenite.

Austenitizing: Forming austenite by heating a ferrous metal to a temperature in the transformation range (partial austenitizing) or above the transformation range (complete austenitizing).

Blowout Preventers: Mechanical devices capable of containing pressure, used for control of well fluids and drilling fluids during drilling operations.

Brazing: Joining metals by flowing a thin layer (of capillary thickness) of a lower-melting-point nonferrous filler metal in the space between them.

Brinell Hardness: A hardness value obtained by use of a 10-mm diameter hardened steel (or carbide) ball and normally a load of 3,000 kg, in accordance with ASTM E 10.[8]

Burnishing: Smoothing surfaces with frictional contact between the material and some other hard pieces of material, such as hardened steel balls.

Carbon Steel: An alloy of carbon and iron containing up to 2% carbon and up to 1.65% manganese and residual quantities of other elements, except those intentionally added in specific quantities for deoxidation (usually silicon and/or aluminum). Carbon steels used in the petroleum industry usually contain less than 0.8% carbon.

Case Hardening: Hardening a ferrous alloy so that the outer portion, or case, is made substantially harder than the inner portion, or core. Typical processes are carburizing, cyaniding, carbonitriding, nitriding, induction hardening, and flame hardening.

Cast Component (Casting): A piece of metal that is formed at or near its finished shape by the solidification of molten metal in a mold.

Cast Iron: An iron-carbon alloy containing approximately 2 to 4% carbon. Cast irons may be classified as:

(1) gray cast iron—cast iron that gives a gray fracture as a result of the presence of flake graphite;

(2) white cast iron—cast iron that gives a white fracture as a result of the presence of cementite (Fe_3C);

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

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

(5) austenitic cast iron—cast iron with a sufficient amount of nickel added to produce an austenitic microstructure.

Cemented Tungsten Carbide: Pressed and sintered monolithic tungsten carbide alloys consisting of tungsten carbide with alloy binders of primarily cobalt or nickel.

Cold Deforming: See *Cold Working*.

Cold Forming: See *Cold Working*.

Cold Reducing: See *Cold Working*.

Cold Working: Deforming metal plastically under conditions of temperature and strain rate that induce strain hardening, usually, but not necessarily, conducted at room temperature.

CRA Alloy Categories: Alloy categories that permit a broad-based description of similar alloys. A CRA category in Section 4 defines a group of alloys in terms of broad-based but essential chemical compositions, manufacturing processes, and finished conditions.

Design Basis: The pressure rating and design factor/safety factor in accordance with the applicable industry code and/or manufacturer's standard.

Double Tempering: A heat treatment in which normalized or quench-hardened steel is given two complete tempering cycles (cooling to a suitable temperature after each cycle) with the second tempering cycle performed at a temperature at or below the first tempering temperature. The object is to temper any martensite that may have formed during the first tempering cycle.

Duplex Stainless Steel: A stainless steel whose microstructure at room temperature consists primarily of a mixture of austenite and ferrite.

Elastic Limit: The maximum stress to which a material may be subjected without retention of any permanent deformation after the stress is removed.

Ferrite: The body-centered cubic crystalline phase of iron-based alloys.

Ferritic Steel: A steel whose microstructure at room temperature consists predominantly of ferrite.

Ferrous Metal: A metal in which the major constituent is iron.

Free-Machining Steel: Steel to which elements such as sulfur, selenium, or lead have been added intentionally to improve machinability.

Hardness: Resistance of metal to plastic deformation, usually by indention.

Heat Treatment: Heating and cooling a solid metal or alloy in such a way as to obtain desired properties. Heating for the sole purpose of hot working is not considered heat treatment.

Heat-Affected Zone: That portion of the base metal that is not melted during brazing, cutting, or welding, but whose microstructure and properties are altered by the heat of these processes.

Hot Isostatic Pressing: (1) A process for heating and forming a compact in which the powder is contained in a sealed flexible sheet metal or glass enclosure and the so-contained powder is subjected to equal pressure from all directions at a temperature high enough to permit plastic deformation and sintering to take place. (2) A process that subjects a component (casting, powder forging, etc.) to both elevated temperature and isostatic gas pressure in an autoclave. The most widely used pressurizing gas is argon.[8]

Hot Rolling: Hot working a metal through dies or rolls to obtain a desired shape. Hot rolling does not include hot forging.

Hot Working: Deforming metal plastically at such a temperature and strain rate that recrystallization takes place simultaneously with the deformation, thus avoiding any strain hardening.

Low-Alloy Steel: Steel with a total alloying element content of less than about 5%, but more than specified for carbon steel.

Lower Critical Temperature: The temperature of a ferrous metal at which austenite begins to form during heating or at which the transformation of austenite is completed during cooling.

Manufacturer: The firms or persons involved in some or all phases of manufacturing or assembly of components. For example, the firm used to upset tubing is considered a manufacturer.

Martensite: A hard supersaturated solid solution of carbon in iron characterized by an acicular (needle-like) microstructure.

Martensitic Steel: A steel in which a microstructure of martensite can be attained by quenching at a cooling rate fast enough to avoid the formation of other microstructures.

[8] From ASM Materials Engineering Dictionary, ed. J.R. Davis. Reprinted with permission from ASM International (ASM), 9639 Kinsman Rd., Materials Park, OH 44073-0002.

Microstructure: The structure of a metal as revealed by microscopic examination of a suitably prepared specimen.

Nitriding: A case-hardening process whereby nitrogen is introduced into the surface of metallic materials (most commonly ferrous alloys). Typical processes include, but are not limited to, liquid nitriding, gas nitriding, and ion or plasma nitriding.

Nonferrous Metal: A metal in which the major constituent is an element other than iron.

Normalizing: Heating a ferrous alloy to a suitable temperature above the transformation range (austenitizing), holding at temperature for a suitable time, and then cooling in still air to a temperature substantially below the transformation range.

Partial Pressure: Ideally, in a mixture of gases, each component exerts the pressure it would exert if present alone at the same temperature in the total volume occupied by the mixture. The partial pressure of each component is equal to the total absolute pressure multiplied by its mole fraction in the mixture. For an ideal gas, the mole fraction is equal to the volume fraction of the component.

Plastic Deformation: Permanent deformation caused by stressing beyond the elastic limit.

Postweld Heat Treatment: Heating and cooling a weldment in such a way as to obtain desired properties.

Precipitation Hardening: Hardening caused by the precipitation of a constituent from a supersaturated solid solution.

PREN: A number calculated from heat analyses of intentionally added alloying elements as shown in Equation (1). The PREN is used in this standard as a means to group similar-composition alloys and does not indicate comparable corrosion-resistance properties in sour service.

$$PREN = Cr\,\% + 3.3\,(Mo\,\% + 0.5\,W\,\%) + 16\,N\,\% \qquad (1)$$

Pressure-Containing Parts: Those parts whose failure to function as intended would result in a release of retained fluid to the atmosphere. Examples are valve bodies, bonnets, and stems.

Quench and Temper: Quench hardening followed by tempering.

Recrystallization Temperature: The minimum temperature at which a new strain-free structure is produced in cold-worked metal within a specified time.

Residual Stress: Stress present in a component free of external forces or thermal gradients.

Rockwell C Hardness: A hardness value obtained by use of a cone-shaped diamond indentor and a load of 150 kg, in accordance with ASTM E 18.

Shot Peening: Inducing compressive stresses in the surface layer of a material by bombarding it with a selected medium (usually steel shot) under controlled conditions.

Slush Pump: Pump normally used to circulate drilling fluids through the drill stem into the annulus of the well-bore hole and to the surface for the purpose of removing cuttings and maintaining a hydrostatic head.

Solid Solution: A single crystalline phase containing two or more elements.

Solution Heat Treatment (Solution Anneal): Heating a metal to a suitable temperature and holding at that temperature long enough for one or more constituents to enter into solid solution, then cooling rapidly enough to retain the constituents in solution.

Sour Environment: In general, environments containing water and H_2S are considered sour. Those sour environments for which MR0175 applies are defined herein.

Stainless Steel: Steel containing 10.5% or more chromium. Other elements may be added to secure special properties.

Standard Cubic Foot of Gas: The quantity of a gas occupying one cubic foot at a pressure of one atmosphere (0.10133 MPa abs [14.696 psia]) and a temperature of 16°C (60°F).

Standard Cubic Meter of Gas: The quantity of a gas occupying one cubic meter at a pressure of one atmosphere (0.10133 MPa abs [14.696 psia]) and a temperature of 16°C (60°F).

Stress Corrosion Cracking: Cracking of a material produced by the combined action of corrosion and tensile stress (residual or applied). For the purposes of MR0175, cracking of metal involving tensile stress (residual or applied) and anodic processes of corrosion in the presence of chlorides and water affected by H_2S, oxidants, and elevated temperature.

Stress Cracking: For the purpose of MR0175, *stress cracking* is a general term intended to include *stress corrosion cracking* and *sulfide stress cracking* as a result of exposure to produced fluids or gases.

Stress Relieving (Thermal): Heating a metal to a suitable temperature, holding at that temperature long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses.

Sulfide Stress Cracking: 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). For the purpose of MR0175, brittle failure promoted by cathodic processes under the action of tensile stress in the presence of water and H_2S.

Tempering: Reheating hardened steel or hardened cast iron to some temperature below the lower critical temperature for the purpose of decreasing the hardness and increasing the toughness. The process is also sometimes applied to normalized steel.

Tensile Strength: In tensile testing, the ratio of maximum load to original cross-sectional area (see ASTM A 370[9]). Also called "ultimate strength."

Tensile Stress: The net tensile component of all combined stresses—axial or longitudinal, circumferential or "hoop," and residual.

Transformation Ranges: Those ranges of temperature for steels within which austenite forms during heating and transforms during cooling. The two ranges are distinct, sometimes overlapping, but never coinciding.

Tubular Component: A cylindrical component having one or more longitudinal holes.

User: Someone who is responsible for operating the equipment that is installed and operated in the field.

Welding: Joining two or more pieces of metal by applying heat and/or pressure, with or without filler metal, to produce a union through localized fusion of the substrates and solidification across the interface.

Weldment: That portion of a component on which welding has been performed. A weldment includes the weld metal, the heat-affected zone, and the base metal.

Weld Metal: That portion of a weldment that has been molten during welding.

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

Yield Strength: The stress at which a material exhibits a specified deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain by either the offset method (usually at a strain of 0.2%) or the total-extension-under-load method (usually at a strain of 0.5%). (See ASTM A 370.)

Section 3: Carbon and Low-Alloy Steels and Cast Irons

3.1 General

3.1.1 Carbon and low-alloy steels and cast irons shall meet the requirements of this section if they are to be exposed to sour environments. See Section 5 of MR0175 for additional requirements during welding and fabrication. See Sections 6 through 12 for equipment-specific requirements.

3.1.2 The susceptibility to SSC of these metals can be strongly affected by heat treatment, cold work, or both. The following paragraphs describe heat treatments for specific materials that have been found to provide acceptable resistance to SSC.

3.2 Carbon and Low-Alloy Steels

3.2.1 All carbon and low-alloy steels are acceptable at 22 HRC maximum hardness provided they (1) contain less than 1% nickel, (2) meet the criteria of Paragraphs 3.2.2, 3.2.3, and Section 5, and (3) are used in one of the following heat-treatment conditions:

(a) hot-rolled (carbon steels only);

(b) annealed;

(c) normalized;

(d) normalized and tempered;

(e) normalized, austenitized, quenched, and tempered; or

(f) austenitized, quenched, and tempered.

3.2.1.1 Forgings produced in accordance with the requirements of ASTM A 105/A 105M[10] are acceptable, provided the hardness does not exceed 187 HBW maximum.

3.2.2 The metal must be thermally stress relieved following any cold deforming by rolling, cold forging, or another manufacturing process that results in a permanent outer fiber deformation greater than 5%. Thermal stress relief shall be performed in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1,[11] except that the minimum stress-relief temperature shall be 593°C (1,100°F). The component shall have a hardness after stress relief of 22 HRC maximum.

3.2.2.1 This requirement does not apply to pipe grades listed in Table D2 in Appendix D or cold work imparted by pressure testing according to the applicable code. Cold-rotary straightened pipe is acceptable only when permitted in API specifications. Cold-worked line pipe fittings of ASTM A 53/A 53M[12] grade B, ASTM A 106[13] grade B, API Spec 5L[14] grade X-42, or lower-strength grades with similar chemical compositions are acceptable with cold strain equivalent to

15% or less, provided the hardness in the strained area does not exceed 190 HBW.

3.2.3 Free-Machining Steels

3.2.3.1 Free-machining steels are not acceptable.

3.3 Cast Irons

3.3.1 Gray, austenitic, and white cast irons are not acceptable for use as a pressure-containing member. These materials may be used in nonpressure-containing parts in internal components related to API and other appropriate standards, provided their use has been approved by the purchaser.

3.3.2 Ferritic ductile iron ASTM A 395/A 395M[15] is acceptable for equipment when API, ANSI, and/or other industry standards approve its use.

Section 4: Corrosion-Resistant Alloys (CRAs)—All Other Alloys Not Defined as Carbon and Low-Alloy Steels and Cast Irons in Section 3

4.1 General

4.1.1 Corrosion-resistant alloys (CRAs) shall meet the requirements of this section. See Section 5 of MR0175 for additional requirements during welding and fabrication. See Sections 6 and 8 through 12 for equipment-specific requirements. These equipment-specific sections may permit the use of alloys not included in this section on CRAs. Also, the equipment-specific sections may allow for the use of higher-strength grades of alloys within specified environmental limits. It is always the responsibility of the equipment user to convey the environmental conditions to the equipment supplier, particularly if the equipment will be used in sour service.

4.1.2 CRAs are presented here as individual alloys and categories of alloys with essential chemical compositions, manufacturing processes, and finished conditions. The categories of these CRAs may have environmental restrictions with respect to the partial pressures of H_2S, in situ pH, chlorides, temperature, and the presence of elemental sulfur. See Paragraph 1.8 for a further discussion.

4.1.3 MR0175 provides material requirements and acceptable environments for SSC/SCC resistance for these alloys, whether listed within categories or as individual alloys. MR0175 is not intended to be a listing of all acceptable CRAs within the limits mentioned in the text unless they are individually identified. The limits are set to minimize the possibility of SSC and/or SCC in sour environments. The acceptable environments specified do not take into account the effects of oxygen on SCC and SSC; more conservative acceptable environments may be required if oxygen is present. General corrosion, pitting corrosion, and other types of corrosion, or cracking mechanisms are outside the scope of this standard.

4.1.3.1 Interpolation between H_2S partial pressures and temperatures and data points listed to establish the acceptable environments in each CRA category is permitted.

4.2 Austenitic Stainless Steels (Category with Alloy-Specific Requirements)

Austenitic stainless steels, substantially free of martensite, with chemical compositions as specified in Paragraph 4.2.1, at a hardness of 22 HRC maximum in the solution-annealed and quenched, or annealed and thermally stabilized, condition, are acceptable for the environments defined in Paragraph 4.2.2, provided they are free of cold work intended to enhance their mechanical properties. Free-machining austenitic stainless steel products (containing alloying elements such as lead, selenium, or sulfur to improve machinability) are not acceptable. Austenitic stainless steel products are acceptable for sour environments within the following composition ranges and physical requirements.

4.2.1 Austenitic stainless steels shall contain at least these elements in the ranges specified: C 0.08% max., Cr 16% min., Ni 8% min., P 0.045% max., S 0.04% max., Mn 2.0 % max., and Si 2.0% max. Other alloying elements are permitted.

4.2.1.1 A higher carbon content for UNS S30900 and S31000 is acceptable up to the limits of their respective specifications.

4.2.2 The maximum acceptable H_2S partial pressure shall be 100 kPa abs (15 psia) at a maximum temperature of 60°C (140°F), with no restrictions on chlorides, and no elemental sulfur. If the chloride content is less than 50 mg/L, the H_2S partial pressure shall be less than 350 kPa abs (50 psia).

4.3 Austenitic Stainless Steels—Individual Alloys

4.3.1 UNS S20910 (Individual Alloy)

Austenitic stainless steel UNS S20910 is acceptable in elemental sulfur-free environments when the maximum H_2S partial pressure is 100 kPa abs (15 psia) to 66°C (150°F) in the annealed or hot-rolled (hot/cold-worked) condition at 35 HRC maximum hardness.

4.4 Highly Alloyed Austenitic Stainless Steels with Ni% + 2 Mo% >30 and 2% Mo Minimum (Category)

Highly alloyed austenitic stainless steels in this category are those with Ni% + 2 Mo% >30 and 2% Mo minimum. All highly alloyed austenitic stainless steel alloys are acceptable for use in the solution-annealed condition. Free-machining highly alloyed austenitic stainless steels are not acceptable. Environmental restrictions for these alloys are as follows:

4.4.1 These alloys are acceptable for use with a maximum H_2S partial pressure of 100 kPa abs (15 psia) at a maximum temperature of 60°C (140°F) with no restrictions on chlorides and no elemental sulfur. If the chloride content is less than 50 mg/L, the H_2S partial pressure shall be less than 350 kPa abs (50 psia).

4.5 Highly Alloyed Austenitic Stainless Steels with PREN >40 (Category)

Highly alloyed austenitic stainless steels in this category are those having a PREN >40. All highly alloyed austenitic stainless steel alloys are acceptable for use in the solution-annealed condition. Free-machining highly alloyed austenitic stainless steels are not acceptable. Environmental restrictions for these alloys are as follows:

4.5.1 At a maximum temperature of 121°C (250°F), the maximum H_2S partial pressure shall be 700 kPa abs (100 psia), maximum 5,000 mg/L chloride, and no elemental (free) sulfur shall be present.

4.5.2 At a maximum temperature of 149°C (300°F), the maximum H_2S partial pressure shall be 310 kPa abs (45 psia), maximum 5,000 mg/L chloride, and no elemental (free) sulfur shall be present.

4.5.3 At a maximum temperature of 171°C (340°F), the maximum H_2S partial pressure shall be 100 kPa abs (15 psia), maximum 5,000 mg/L chloride, and no elemental (free) sulfur shall be present.

4.6 Highly Alloyed Austenitic Stainless Steels (Individual Alloy)

4.6.1 UNS N08926 (individual alloy) is acceptable in the solution-annealed condition at a maximum temperature of 121°C (250°F), with a maximum H_2S partial pressure of 0.7 MPa abs (100 psia), maximum 60,700 mg/L chloride, a maximum CO_2 partial pressure of 1.4 MPa abs (200 psia), and no elemental (free) sulfur.

4.6.2 UNS J93254 (Individual Alloy)

Cast UNS J93254 (CK3MCuN) in accordance with ASTM A 351/A 351M,[16] A 743/A 743M,[17] or A 744/A 744M[18] is acceptable in the cast, solution heat-treated condition at a hardness level of 100 Rockwell B hardness (HRB) maximum in the absence of elemental sulfur.

4.7.2 UNS J95370 is acceptable in the cast, solution-heat-treated, and water-quenched condition to 94 HRB maximum in the absence of elemental sulfur.

4.7 Ferritic Stainless Steels (Category)

4.7.1 Ferritic stainless steels are acceptable for use within the acceptable environments of 10 kPa abs (1.5 psia) H_2S partial pressure and a pH ≥3.5 provided they are in the annealed condition at up to 22 HRC and meet the criteria of Section 5.

4.8 Martensitic Stainless Steels (Category with Alloy-Specific Requirements)

Cast or wrought martensitic stainless steels are acceptable for use in accordance with Paragraphs 4.8.1, 4.8.2, and 4.8.3. Martensitic stainless steels that are in accordance with this 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 for other materials included in this standard. Free-machining martensitic stainless steel products are not acceptable.

The acceptable environments shall be 10 kPa abs (1.5 psia) H_2S partial pressure and a pH ≥3.5.

4.8.1 Martensitic stainless steels UNS S41000, S42000, J91150 (CA15), and J91151 (CA15M), either cast or wrought, are acceptable at 22 HRC maximum hardness provided they meet the criteria of Section 5 as applicable.

4.8.1.1 Heat-treatment procedure (three-step process) for UNS S41000, J91150, and J91151 shall be as follows:

(1) Austenitize and quench or air cool.

(2) Temper at 621°C (1,150°F) minimum; then cool to ambient temperature.

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

4.8.1.2 UNS S42000 shall be in the quenched and tempered condition.

4.8.2 Low-Carbon Martensitic Stainless Steels[(7)]

Low-carbon, 12Cr-4Ni-Mo martensitic stainless steels, either cast UNS J91540 (CA6NM) or wrought S42400, are acceptable to 23 HRC maximum provided they are heat treated in accordance with Paragraph 4.8.2.1.

4.8.2.1 Heat-treatment procedure (three-step process) for low-carbon martensitic stainless steels shall be as follows:

(1) Austenitize at 1,010°C (1,850°F) minimum and air or oil quench to ambient temperature.

(2) Temper at 649 to 691°C (1,200 to 1,275°F) and air cool to ambient temperature.

(3) Temper at 593 to 621°C (1,100 to 1,150°F) and air cool to ambient temperature.

4.8.3 UNS S41425 (individual alloy). Wrought low-carbon martensitic stainless steel UNS S41425 is acceptable in the austenitized, quenched, and tempered condition to 28 HRC maximum hardness in the absence of elemental sulfur.

4.9 Duplex Stainless Steels with 30≤PREN≤40 (Category)[9]

4.9.1 Duplex stainless steels are acceptable under the following chemical compositions and heat-treatment condition and for the specific environment set forth for that individual alloy. Duplex stainless steel products in the solution-annealed and liquid-quenched condition are acceptable. Aging heat treatments are prohibited. The ferrite content shall be 35 to 65 vol%.

4.9.2 For requirements for cold-worked duplex stainless steels, refer to Paragraph 10.4.

4.9.3 Wrought and cast duplex stainless steel products in the solution-annealed and quenched condition with 30≤PREN≤40 (>1.5% Mo) are acceptable for use to a maximum temperature of 232°C (450°F) and a maximum H_2S partial pressure of 10 kPa abs (1.5 psia).

4.9.4 Hot isostatic pressure-produced duplex stainless steel UNS S31803 is acceptable to 25 HRC maximum if solution annealed and water quenched.

4.10 Duplex Stainless Steels with PREN >40 (Category)[9]

4.10.1 Duplex stainless steels are acceptable under the following chemical compositions and heat-treat condition and for the specific environment set forth for that individual alloy. Duplex stainless steel products in the solution-annealed and liquid-quenched condition are acceptable. Aging heat treatments are prohibited. The ferrite content shall be 35 to 65 vol%.

4.10.2 For requirements for cold-worked duplex stainless steels, refer to Paragraph 10.4.

4.10.3 Wrought and cast duplex stainless steel products in the solution-annealed and quenched condition with a PREN of 40<PREN≤45 are acceptable for use to a maximum temperature of 232°C (450°F) and a maximum H_2S partial pressure of 20 kPa abs (3 psia).

4.11 Solid-Solution Nickel-Based Alloys (Category)

Wrought or cast solid-solution nickel-based products shall be in the solution-annealed condition.

4.11.1 The chemical composition of these alloys shall be:

19.0% Cr	minimum,
29.5% Ni + Co	minimum, and
2.5% Mo	minimum.

or

14.5% Cr	minimum,
52% Ni + Co	minimum, and
12% Mo	minimum.

4.11.2 There are no environmental limits with respect to partial pressures of H_2S or elemental sulfur.

4.12 Cobalt-Nickel-Chromium-Molybdenum Alloys (Category with Alloy-Specific Requirements)

There are no environmental limits with respect to partial pressures of H_2S or elemental sulfur.

4.12.1 Alloys UNS R30003, R30004, R30035, and British Standard, Aerospace Series HR3 are acceptable at 35 HRC maximum except when otherwise noted.

4.12.2 In addition, UNS R30035 is acceptable at 51 HRC maximum in the cold-reduced and high-temperature aged condition in accordance with one of the following aging heat treatments:

Minimum Time (hours)	**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)

4.12.3 Wrought UNS R31233 is acceptable in the solution-annealed condition to 22 HRC maximum.

4.13 Cobalt-Nickel-Chromium-Tungsten Alloys (Category with Alloy-Specific Requirements)

There are no environmental limits with respect to partial pressures of H_2S or elemental sulfur.

[9] Normally the duplex stainless steels contain a maximum of about 2% manganese.

4.13.1 UNS R30605 is acceptable to 35 HRC maximum.

4.14 Titanium Alloys (Category with Alloy-Specific Requirements)

There are no environmental limits with respect to partial pressures of H_2S or elemental sulfur.

Specific guidelines must be followed for successful applications of each titanium alloy specified in this 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). Some titanium alloys may be susceptible to crevice corrosion and/or SSC in chloride environments. Although hardness has not been shown to correlate with susceptibility to SSC/SCC, hardness limits for alloys with high strength have been included to indicate the maximum testing levels and heat-treatment conditions (when applicable) at which failure has not occurred.

4.14.1 UNS R53400 is acceptable in the annealed condition. Heat treatment shall be annealing at 774° ±14°C (1,425° ±25°F) for 2 hours followed by air cool. The maximum hardness shall be 92 HRB.

4.14.2 UNS R58640 is acceptable to 42 HRC maximum.

4.14.3 UNS R50400 is acceptable to 100 HRB maximum.

4.14.4 UNS R56260 is acceptable to 45 HRC maximum in each of the three following conditions: (1) annealed; (2) solution-annealed; and (3) solution-annealed and aged.

4.14.5 Wrought UNS R56403 is acceptable to 36 HRC maximum in the annealed condition.

4.14.6 UNS R56404 is acceptable to 35 HRC maximum in the annealed condition.

4.14.7 UNS R56323 is acceptable to 32 HRC maximum in the annealed condition.

4.15 Precipitation-Hardenable Nickel-Based Alloys I (Category with Alloy-Specific Requirements)

Precipitation-hardenable nickel-based alloys listed in Paragraphs 4.15.1 through 4.15.7 are acceptable within the environments shown in Table 2, unless exceptions are noted within these paragraphs.

Table 2: Acceptable Environments for Precipitation-Hardenable Nickel-Based Alloys, Paragraphs 4.15.1 Through 4.15.7

Temperature	H_2S Partial Pressure	Elemental Sulfur
232°C (450°F) maximum	0.2 MPa abs (30 psia) maximum	no
204°C (400°F) maximum	1.4 MPa abs (200 psia) maximum	no
149°C (300°F) maximum	2.7 MPa abs (400 psia) maximum	no
135°C (275°F) maximum	no limit	yes(A)

(A) See Paragraphs 4.15.1 through 4.15.7 for more restrictions.

4.15.1 Cast UNS N09925 is acceptable, in the absence of elemental sulfur, in the solution-annealed and aged condition to 35 HRC maximum.

4.15.2 Cast UNS N07718 is acceptable, in the solution-annealed and aged condition, to 40 HRC maximum.

4.15.3 Wrought UNS N07031 is acceptable in each of the two following conditions: (1) solution-annealed condition to 35 HRC maximum, and (2) solution-annealed and aged at 760 to 871°C (1,400 to 1,600°F) for a maximum of 4 hours to 40 HRC maximum.

4.15.4 Wrought UNS N07773 is acceptable in the solution-annealed and aged condition to 40 HRC maximum.

4.15.5 Wrought UNS N09777 is acceptable in the solution-annealed and aged condition to 40 HRC maximum.

4.15.6 Wrought UNS N07048 is acceptable to 40 HRC maximum in the solution-annealed and aged condition.

4.15.7 Wrought UNS N07924 is acceptable in the solution-annealed and aged condition at a maximum hardness of 35 HRC for use in environments with no elemental sulfur up to 175°C (347°F), in accordance with Table B1, Level VI.

4.16 Precipitation-Hardenable Nickel-Based Alloys II (Category with Alloy-Specific Requirements)

Precipitation-hardenable nickel-based alloys listed in Paragraphs 4.16.1 and 4.16.2 are acceptable within the acceptable environments shown in Table 3:

Table 3: Acceptable Environments for Precipitation-Hardenable Nickel-Based Alloys, Paragraphs 4.16.1 and 4.16.2

Temperature	H_2S Partial Pressure	Elemental Sulfur
232°C (450°F) maximum	0.2 MPa abs (30 psia) maximum	no
204°C (400°F) maximum	1.4 MPa abs (200 psia) maximum	no
199°C (390°F) maximum	2.3 MPa abs (330 psia) maximum	no
191°C (375°F) maximum	2.5 MPa abs (360 psia) maximum	no
149°C (300°F) maximum	2.8 MPa abs (400 psia) maximum	no
135°C (275°F) maximum	no limit	yes

4.16.1 Wrought UNS N09925 is acceptable in each of the five following conditions: (1) cold-worked to 35 HRC maximum; (2) solution-annealed to 35 HRC maximum; (3) solution-annealed and aged to 38 HRC maximum; (4) cold-worked and aged to 40 HRC maximum; and (5) hot-finished and aged to 40 HRC maximum.

4.16.2 Wrought UNS N07718 is acceptable in each of the four following conditions: (1) solution-annealed to 35 HRC maximum; (2) hot-worked to 35 HRC maximum; (3) hot-worked and aged to 35 HRC maximum; and (4) solution-annealed and aged to 40 HRC maximum.

4.17 Precipitation-Hardenable Nickel-Based Alloys III (Category with Alloy-Specific Requirements)

Precipitation-hardenable nickel-based alloys listed in Paragraphs 4.17.1 and 4.17.2 are acceptable within the acceptable environments shown in Table 4:

Table 4: Acceptable Environments for Precipitation-Hardenable Nickel-Based Alloys, Paragraphs 4.17.1, 4.17.2, and 4.17.3

Temperature	H_2S Partial Pressure	Elemental Sulfur
232°C (450°F) maximum	1.0 MPa abs (150 psia) maximum	no
220°C (425°F) maximum	2.1 MPa abs (300 psia)	yes
204°C (400°F) maximum	4.1 MPa abs (600 psia) maximum	no
177°C (350°F) maximum	no limit	yes

4.17.1 Wrought UNS N07716 is acceptable to 43 HRC maximum in the solution-annealed and aged condition.

4.17.2 Wrought UNS N07725 is acceptable to 43 HRC maximum in the solution-annealed and aged condition.

4.17.3 UNS N07626, totally dense hot compacted by a powder metallurgy process, is acceptable in the solution-annealed (927°C [1,700°F] minimum) plus aged (538 to 816°C [1,000 to 1,500°F]) condition or the direct-aged (538 to 816°C [1,000 to 1,500°F]) condition to a maximum hardness of 40 HRC and a maximum tensile strength of 1,380 MPa (200 ksi).

4.18 Austenitic Precipitation-Hardenable Stainless Steel (Individual Alloy)

4.18.1 Austenitic precipitation-hardenable stainless steel with chemical composition in accordance with UNS S66286 (individual alloy) is acceptable at 35 HRC maximum hardness provided it is in either the solution-annealed and aged or solution-annealed and double-aged condition. The alloy is acceptable up to a maximum H_2S partial pressure of 0.1 MPa abs (15 psia) at 65°C (150°F) maximum, with no elemental sulfur.

4.19 Aluminum-Based Alloys (Category)

Environmental limits have not been established.

4.20 Copper Alloys (Category)[10]

Environmental limits have not been established.

4.21 Commercially Pure Tantalum (Individual Alloy). UNS R05200 is acceptable in the annealed and gas tungsten arc-welded and annealed conditions to 55 HRB maximum.

[10] Copper-based alloys may undergo accelerated mass-loss corrosion in sour oilfield environments, particularly if oxygen is present.

Section 5: Fabrication

5.1 General. Materials and fabrication processes shall meet the requirements of this section if the material is to be exposed to sour environments.

5.2 Overlays

5.2.1 Overlays applied to carbon and low-alloy steel or to martensitic stainless steels by thermal processes such as welding, silver brazing, or spray metallizing systems are acceptable for use in sour environments, provided the substrate does not exceed the lower critical temperature during application. In those cases in which the lower critical temperature is exceeded, the component must be heat treated or thermally stress relieved in accordance with procedures that have been shown to return the base metal to the base metal hardness as specified in this standard.

5.2.2 Tungsten-carbide alloys and ceramics are satisfactory, subject to the conditions of Paragraph 5.2.1.

5.2.3 Joining of dissimilar materials, such as cemented carbides to alloy steels by silver brazing, is acceptable. The base metal after brazing shall meet the requirements of Paragraph 5.2.1.

5.2.4 The materials listed in Section 4 are acceptable as weld overlays, provided they meet the provisions of Paragraph 5.2.1.

5.2.5 Overlays of nickel-based and cobalt-based alloys are acceptable for hardfacing applications, subject to the conditions of Paragraph 5.2.1.

5.3 Welding[(11)]

5.3.1 Welding procedures shall be used to produce weldments that comply with the hardness requirements specified for the base metal in Sections 3 and 4. Welding procedures and welders shall be qualified according to AWS, API, ASME, or other appropriate industry codes.

5.3.1.1 Tubular goods listed in Table D2 in Appendix D with specified minimum yield strength of 360 MPa (52 ksi) or less and pressure vessel steels classified as P-No. 1, Category 1 or 2, in of the ASME Boiler and Pressure Vessel Code, Section IX,[19] meet the requirements of Paragraph 5.3.1 in the as-welded condition. Welding procedure qualifications, in accordance with AWS, API, ASME, or other appropriate specifications, shall be performed for any welding procedure that is used.

5.3.1.2 Welding procedures for carbon steels and low-alloy steels may control welding variables to achieve a hardness of 22 HRC maximum in the weldment. The controls generally involve restricted base and filler metal chemical composition and welding parameters. The procedure qualification shall verify that the 22 HRC maximum hardness requirement is achieved in the weld deposit, HAZ, and base metal in the as-welded condition. The resulting welding procedure specification shall document the required controls to assure that the 22 HRC maximum hardness requirement will be achieved in production weldments.[(11)]

5.3.1.3 Carbon steel and low-alloy steel weldments produced without restrictions on base and filler metal chemical compositions and welding parameters in accordance with Paragraph 5.3.1.2 shall be post-weld heat treated at a minimum temperature of 621°C (1,150°F) to produce a hardness of 22 HRC maximum.

5.3.1.4 Welding rods, electrodes, fluxes, filler metals, and carbon and low-alloy steel welding consumables with more than 1% nickel shall not be used for welding carbon and low-alloy steels as indicated in Paragraph 3.2.1

5.3.2 Martensitic Stainless Steel Welding

This paragraph addresses martensitic stainless steel welding in which the base metal is welded with a nominally matching consumable.

5.3.2.1 Weldments in martensitic stainless steels defined in Paragraph 4.8.1 shall undergo a postweld heat treatment (PWHT) at 621°C (1,150°F) minimum and shall produce HAZ and weld metal hardness that meets the base metal hardness requirements as specified in this standard.

5.3.2.2 Weldments in low-carbon martensitic stainless steels defined in Paragraph 4.8.2 shall undergo a single- or multiple-cycle PWHT after first being cooled to 38°C 100°F).

(1) The single-cycle PWHT shall be 579 to 621°C (1,075 to 1,150°F).

(2) The multiple-cycle PWHT shall be 671 to 691°C (1,240 to 1,275°F), with cooling to 38°C (100°F) or less prior to heating to 579 to 621°C (1,075 to 1,150°F).

(11) Vickers (HV 5- or 10-kg) hardness measurements on welds are permitted but not required.

5.3.3 Austenitic Stainless Steel, Duplex Stainless Steel, and Nickel-Based Alloy Welding

This paragraph's requirements for welding pertain to austenitic and duplex stainless steels and nickel-based alloys that are solid-solution strengthened in the solution-annealed condition and are welded to like base metals. These weldments can be classified into two types: (1) those using matching filler material or (2) those using filler material with greater PREN (higher alloy content) than the base metal.

Welding of austenitic and duplex stainless steels and nickel-based alloys shall be performed in accordance with the requirements of Paragraph 5.3.1. The hardness of the HAZ after welding shall not exceed the maximum hardness allowed for the base metal, and the hardness of the weld metal shall not exceed the maximum hardness limit of the respective alloy used for the welding consumable.

5.3.3.1 Welding Austenitic Stainless Steels

5.3.3.1.1 When austenitic stainless steel "L" grade consumables are specified, they shall have 0.03% carbon maximum.

5.3.3.2 Welding Duplex Stainless Steels

5.3.3.2.1 The weld procedure qualification record (PQR) shall assure that all regions of the weldment contain 30 to 70 vol% ferrite.

5.3.3.3 Welding Solution-Annealed Nickel-Based Alloys

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

5.3.4 Precipitation-Hardenable Stainless Steel and Nickel-Based Alloy Welding

This paragraph's requirements for welding pertain to precipitation-hardenable stainless steels and nickel-based alloys that are permitted in Section 4.

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

5.4 Identification Stamping

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

5.4.2 Conventional sharp V stamping is acceptable in low-stress areas, such as the outside diameter of flanges. Sharp V stamping is not permitted in high-stress areas unless the metal is subsequently stress relieved at 593°C (1,100°F) minimum.(12)

5.5 Threading

5.5.1 Machine-Cut Threads

5.5.1.1 Machine-cut threading processes are acceptable.

5.5.2 Cold-Formed (Rolled) Threads

5.5.2.1 After threads have been cold formed, the threaded component shall meet the heat-treat conditions and hardness requirements given in either Section 3 or 4 for the parent alloy from which the threaded component was fabricated.

5.6 Cold-Deformation Processes

5.6.1 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 acceptable.

5.6.2 Cold deformation by controlled shot peening is permitted when applied to base materials that meet the requirements of this standard and when limited to the use of a maximum shot size of 2.0 mm (0.080 in.) and a maximum of 10C Almen intensity. The process shall be controlled in accordance with AMS-S-13165.[20]

Section 6: Bolting

6.1 General. Materials shall meet the requirements of this section if they are to be exposed to sour environments.

6.2 Exposed Bolting

6.2.1 Bolting that will be exposed directly to the sour environment or that will be buried, insulated, equipped with flange protectors, or otherwise denied direct atmospheric exposure must be as described in Paragraphs 6.2.1.1, 6.2.1.2, or 6.2.1.3. It may be necessary to derate the pressure rating in some cases when using low-strength bolts. For API Spec 6A[21] flanges using exposed bolting, see API Spec 6A.

(12) The user should be aware that this stress relief may not be appropriate for certain alloys.

6.2.1.1 Acceptable nuts and bolting materials shall meet the requirements of Section 3 or Section 4 as applicable to the base material.

6.2.1.2 Bolting materials that meet the specifications of ASTM A 193/A 193M[22] grade B7M, 550-MPa (80,000-psi) minimum yield strength, and 22 HRC; grades B8A Class 1A and B8MA Class 1A, 200-MPa (30,000-psi) minimum yield strength, and 90 HRB maximum; ASTM A 320/A320M[23] grade L7M 550-MPa (80,000-psi) minimum yield strength, and 22 HRC maximum; and grades B8A Class 1A and B8MA Class 1A, 200-MPa (30,000-psi) minimum yield strength, and 90 HRB maximum are acceptable.

6.2.1.3 Nuts shall meet the specifications of ASTM A 194/A 194M[24] grade 2HM (22 HRC maximum); grade 7M (22 HRC maximum); grades 8A and 8MA (90 HRB maximum); or Paragraph 6.2.1.1.

6.3 Nonexposed Bolting

6.3.1 Bolting that is not directly exposed to sour environments and is not to be buried, insulated, equipped with flange protectors, or otherwise denied direct atmospheric exposure may be furnished to applicable standards such as ASTM A 193/A 193M grade B7.

Section 7: Platings and Coatings

7.1 General. Materials shall meet the requirements of this section if they are to be exposed to sour environments.

7.1.1 Metallic coatings (electroplated or electroless), conversion coatings, and plastic coatings or linings are not acceptable for preventing SSC/SCC of base metals. The use of such coatings for other purposes is outside the scope of this standard. Coatings are used by the industry as barriers against corrosion and against various forms of wet H_2S cracking, but these applications are outside the scope of this standard.

7.2 Nitriding

7.2.1 Nitriding with a maximum case depth of 0.15 mm (0.0060 in.) is an acceptable surface treatment when conducted at a temperature below the lower critical temperature of the alloy system being treated. Its use as a means of preventing SSC/SCC is not acceptable.

Section 8: Special Components

8.1 General. Materials for special components including instrumentation, control devices, seals, bearings, and springs shall meet the requirements of this section if they are directly exposed to sour environments during normal operation of the device. Paragraph 1.4 provides guidelines to determine the applicability of the standard to specific uses. The materials in the paragraphs in Section 8 do not have environmental limits unless so stated in the paragraph.

8.2 Bearings

8.2.1 Bearings directly exposed to sour environments shall be made from materials in Sections 3 and 4.

8.2.2 Nickel-chromium-molybdenum-tungsten alloy UNS N10276 bearing pins, e.g., core roll pins, are acceptable in the cold-worked condition to 45 HRC maximum.

8.2.3 Bearings made from other materials must be isolated from the sour environment to function properly, except as noted in Paragraph 8.2.2.

8.3 Springs

8.3.1 Springs directly exposed to the sour environment shall be made from materials described in Sections 3 and 4, except as noted in Paragraphs 8.3.2, 8.3.3, and 8.3.4.

8.3.2 Cobalt-nickel-chromium-molybdenum alloy UNS R30003 may be used for springs in the cold-worked and age-hardened condition to 60 HRC maximum. UNS R30035 may be used for springs in the cold-worked and age-hardened condition to 55 HRC maximum when aged for a minimum of 4 hours at a temperature no lower than 649°C (1,200°F).

8.3.3 Nickel-chromium alloy UNS N07750 springs are acceptable in the cold-worked and age-hardened condition to 50 HRC maximum.

8.3.4 UNS N07090 may be used for springs for compressor valves in the cold-worked and age-hardened condition to 50 HRC maximum.

8.4 Instrumentation and Control Devices

8.4.1 Instrumentation and control device components directly exposed to sour environments shall be made from materials in Sections 3 and 4.

8.4.1.1 Paragraphs 4.2, 4.5, and 4.11 are not intended to preclude the use of UNS S31600 austenitic stainless steel, highly alloyed austenitic stainless steel, or nickel-based alloy compression fittings, screen devices, and instrument or control tubing even though these components will not satisfy the requirements stated in those paragraphs.

8.4.2 Diaphragms, Pressure-Measuring Devices, and Pressure Seals

8.4.2.1 Diaphragms, pressure-measuring devices, and pressure seals directly exposed to a sour environment shall be made from materials in Sections 3 and 4, except as noted in Paragraphs 8.4.2.2, 8.4.2.3, and 8.4.2.4.

8.4.2.2 Cobalt-nickel-chromium-molybdenum alloys UNS R30003 and R30004 for diaphragms, pressure-measuring devices, and pressure seals are acceptable to 60 HRC maximum.

8.4.2.3 Cobalt-nickel-chromium-molybdenum-tungsten alloy UNS R30260 diaphragms, pressure-measuring devices, and pressure seals are acceptable to 52 HRC maximum.

8.4.2.4 Pressure seals shall comply with the requirements of Sections 3 and 4 or may be manufactured of wrought cobalt-chromium-nickel-molybdenum alloy UNS R30159 to 53 HRC maximum with the primary load-bearing or pressure-containing direction parallel to the longitudinal or rolling direction of wrought product.

8.4.3 Wrought UNS N08904 is acceptable for use as instrument tubing in the annealed condition of 180 HV10 maximum.

8.5 Seal Rings and Gaskets

8.5.1 Seal rings directly exposed to a sour environment shall be made from materials in Sections 3 and 4.

8.5.2 Austenitic stainless steel API compression seal rings and gaskets made of wrought or centrifugally cast ASTM A 351/A 351M grade CF8 or CF8M chemical compositions are acceptable in the as-cast or solution-annealed condition to 160 HBW (83 HRB) maximum.

8.6 Snap Rings

8.6.1 Snap rings directly exposed to a sour environment shall be made from applicable materials in Sections 3 and 4, except as noted in Paragraph 8.6.2.

8.6.2 Precipitation-hardenable stainless steel alloy UNS S15700 snap rings originally in the RH950 solution-annealed and aged condition are acceptable when further heat treated to a hardness of 30 to 32 HRC as follows:

8.6.2.1 Heat-treatment procedure (three-step process) shall be:

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

(2) Temper at 621°C (1,150°F) for 4 hours, 15 minutes. Cool to room temperature in still air.

(3) Temper at 566°C (1,050°F) for 4 hours, 15 minutes. Cool to room temperature in still air.

8.7 Bearing Pins

8.7.1 Bearing pins, e.g., core roll pins, made from UNS N10276 in the cold-worked condition with a maximum hardness of 45 HRC, may be used.

8.8 Special Process Parts[13]

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

8.8.2 Tungsten-carbide alloys, whether cast or cemented, are acceptable

Section 9: Wellheads, Christmas Trees, Valves, Chokes, and Level Controllers

9.1 General. Materials shall meet the requirements of this section if they are to be exposed to sour environments.

9.2 Wellheads and Christmas Trees

9.2.1 Components directly exposed to sour environments shall be manufactured in accordance with the requirements of Sections 3 through 8. Wellhead components that are not directly exposed to the sour environment or that are exposed to the controlled drilling environment (see Paragraph 12.2.2) are outside the scope of this standard.

9.2.2 Components made from UNS S41000, S42000, S42400, J91150 (CA15), J91151 (CA15M), and J91540 (CA6NM) are acceptable for use in sour environments when the pH is ≥3.5. The alloys shall be

[13] Some of the materials used for wear-resistant applications can be brittle. Environmental cracking may occur if these materials are subject to tension.

processed in accordance with Paragraph 4.8.1 or 4.8.2. Acceptable components shall not include casing hangers, tubing hangers, and valve stems.

9.2.3 Components made from nickel-based alloys in accordance with Paragraph 4.11.1 or 4.15, and in accordance with API Spec 6A, are acceptable.

9.2.4 Components (with the exception of bodies and bonnets) made from precipitation-hardenable stainless steels in accordance with Paragraphs 9.2.4.1 and 9.2.4.2 are acceptable within the environmental limits listed for each alloy.

9.2.4.1 Martensitic Precipitation-Hardenable Stainless Steel

UNS S17400, a wrought precipitation-hardenable stainless steel with a 33 HRC maximum hardness limit, is acceptable to 3.4 kPa abs (0.50 psia) H_2S at a pH of 4.5 or higher. The alloy shall be in one of the following heat-treatment conditions listed.

9.2.4.1.1 Double-Age-Hardening Heat Treatment at 621°C (1,150°F)

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

(2) First precipitation-hardening cycle at 621 ±14°C (1,150 ±25°F) for 4 hours minimum at temperature and air cool or liquid quench to below 32°C (90°F).

(3) Second precipitation-hardening cycle at 621 ±14°C (1,150 ±25°F) for 4 hours minimum at temperature and air cool or liquid quench to below 32°C (90°F).

9.2.4.1.2 Modified Double-Age-Hardening Heat Treatment

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

(2) First precipitation-hardening cycle at 760 ±14°C (1,400 ±25°F) for 2 hours minimum at temperature and air cool or liquid quench to below 32°C (90°F).

(3) Second precipitation-hardening cycle at 621 ±14°C (1,150 ±25°F) for 4 hours minimum at temperature and air cool or liquid quench to below 32°C (90°F).

9.2.4.2 Molybdenum-Modified Martensitic Precipitation-Hardenable Stainless Steel

UNS S45000, a wrought molybdenum-modified martensitic precipitation-hardenable stainless steel with a 31 HRC maximum hardness limit (equal to 306 HBW for this alloy), is acceptable to 10 kPa abs (1.5 psia) H_2S at a pH of 3.5 or higher. The heat-treatment procedure for this alloy shall be as follows:

(1) Solution anneal.

(2) Precipitation harden at 621 ±8°C (1,150 ±15°F) for 4 hours minimum at temperature.

9.2.5 Components (with the exception of bodies and bonnets) made from wrought UNS N05500 with a 35 HRC maximum hardness are acceptable to 3.4 kPa abs (0.5 psia) H_2S maximum in each of the following conditions at a pH of 4.5 or higher: (1) hot-worked and age-hardened; (2) solution-annealed; and (3) solution-annealed and age-hardened.

9.3 Valves and Chokes

Valves and chokes shall be manufactured from materials in accordance with Sections 3 through 9.

9.4 Shafts, Stems, and Pins

Shafts, stems, and pins shall be manufactured from materials in accordance with Sections 3, 4, and 9, and as noted in Paragraph 9.4.1.

9.4.1 Austenitic stainless steel UNS S20910 is acceptable for valve shafts, stems, and pins at a maximum hardness level of 35 HRC in the cold-worked condition, provided this cold working is preceded by a solution-anneal heat treatment.

9.5 Internal Components for Valves, Pressure Regulators, and Level Controllers

9.5.1 Cast CB7Cu-1 and CB7Cu-2 in the H1150 DBL condition in accordance with ASTM A 747/A 747M[25] are acceptable for nonpressure-containing components at 310 HBW maximum (30 HRC maximum). Precipitation-hardenable martensitic stainless steels that are in accordance with this 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 for other materials included in this standard.

9.5.2 Wrought UNS S17400 and S15500 martensitic precipitation-hardenable stainless steels are acceptable for nonpressure-containing components to 33 HRC maximum hardness provided they have been heat treated in accordance with Paragraph 9.2.4.1.1 or 9.2.4.1.2. Precipitation-hardenable martensitic stainless steels that are in accordance with this 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 for other materials included in this standard.

9.5.3 Wrought UNS S45000 martensitic precipitation-hardenable stainless steel is acceptable for nonpressure-containing components at 31 HRC maximum hardness (equivalent to 306 HBW for this alloy), provided it has been heat treated as follows:

9.5.3.1 Two-Step Heat-Treatment Procedure

(1) Solution anneal.

(2) Precipitation harden at 621 ±8°C (1,150 ±15°F) for a minimum of 4 hours.

9.5.4 Wrought UNS N05500 is acceptable for nonpressure-containing components to 35 HRC maximum in each of the three following conditions: (1) hot-worked and age-hardened; (2) solution-annealed; and (3) solution-annealed and age-hardened.

9.5.5 Wrought UNS N07750 is acceptable for nonpressure-containing components in accordance with the hardness limit and heat-treatment conditions to 35 HRC maximum in each of the four following conditions: (1) solution-annealed and aged; (2) solution-annealed; (3) hot-worked; and (4) hot-worked and aged.

9.5.6 Components (with the exception of bodies and bonnets) made from wrought UNS N05500 in accordance with the hardness limit and heat-treatment conditions in Paragraph 9.2.5 have been used in service tool applications at the surface for temporary service in well environments. A valid use limit has not been established for these alloys for these applications.

9.5.7 UNS S17400 in accordance with the hardness limits and heat treatments in Paragraph 9.2.4.1 has been used in service tool applications at the surface when stressed at less than 60% of its minimum specified yield strength under working conditions. Environmental limits for this alloy for these applications have not been established.

Section 10: Downhole Casing, Downhole Tubing, and Downhole Equipment

Casing or tubing directly exposed to sour environments shall meet the requirements of Table D2 in Appendix D. Casing that will not be exposed to sour fluids or that will be exposed only to the controlled drilling fluid environment (see Paragraph 12.2.2) is outside the scope of this standard. Qualified materials shall be standardized by recognized national codes and standardization bodies.

10.1 Carbon and Low-Alloy Steel Tubular Components

10.1.1 Tubular components made of CrMo low-alloy steels (AISI 41XX and its modifications) are acceptable at a 26 HRC maximum hardness, provided they are in the quenched and tempered condition.

10.1.2 Tubular components made of CrMo low-alloy steels (AISI 41XX and its modifications) are acceptable in the quenched and tempered condition at 30 HRC maximum hardness and in specified minimum yield strength (SMYS) grades of 690, 720, and 760 MPa (100, 105, and 110 ksi). The maximum yield strength for each grade shall be 100 MPa (15 ksi) higher than SMYS. SSC/SCC resistance shall be measured using NACE Standard TM0177 Test Method A, and the minimum threshold stress shall be 85% of SMYS. For the high-strength, low-alloy steels there are no correlative data between NACE test methods and field results, and no data that can technically support a finite restriction exist. At the time these alloys were added to MR0175, the primary application for these steels was for protective casing in wells with less than 7 kPa abs (1 psia) H_2S partial pressure.

10.1.3 Careful attention to chemical composition and heat treatment is required to ensure SSC/SCC resistance of these alloys at greater than 22 HRC. Accordingly, when using these alloys above 22 HRC, it is common practice for the user to conduct SSC/SCC tests (in accordance with Paragraph 1.6) to determine that the material is equivalent in SSC/SCC performance to similar materials that have given satisfactory service in sour environments.

10.1.4 If tubular components are cold straightened at or below 510°C (950°F), they shall be stress relieved at a minimum of 482°C (900°F). If tubular components are cold formed (pin nosed and/or box expanded) and the resultant permanent outer fiber deformation is greater than 5%, the cold-formed regions shall be thermally stress relieved at a minimum temperature of 593°C (1,100°F). Cold forming the connections of high-strength tubular components with hardnesses above 22 HRC shall require thermal stress relieving at a minimum temperature of 593°C (1,100°F).

10.2 Highly Alloyed Austenitic Stainless Steel Tubular Components

Highly alloyed austenitic stainless steels shall contain at least these elements and meet the PREN or Ni + 2 Mo requirements of the subsequent paragraphs: C—0.08% maximum, Cr—16% minimum, Ni—8% minimum, P—0.03% maximum, S—0.030% maximum, Mn—2% maximum, and Si—0.5% maximum. Other alloying elements are permitted.

10.2.1 Ni% + 2 Mo% >30 and 2% Mo Minimum

Highly alloyed austenitic stainless steels in this category are those with Ni% + 2 Mo% >30 and 2% Mo minimum. All highly alloyed austenitic stainless steels are acceptable for use in the solution-annealed and cold-worked condition to 35 HRC maximum. Free-machining alloys are not acceptable. Environmental restrictions are as follows:

10.2.1.1 Ni% + 2 Mo% >30 and 2% Mo minimum alloys are acceptable for use with a maximum H_2S partial pressure of 100 kPa (15 psia) at a maximum temperature of 60°C (140°F) with no elemental sulfur and no restrictions on chlorides. If the chloride content is less than 50 mg/L, the H_2S partial pressure shall be less than 350 kPa (50 psia).

10.2.2 PREN >40

Highly alloyed austenitic stainless steels in this category are those having PREN >40. All highly alloyed austenitic stainless steels are acceptable for use in the solution-annealed and cold-worked condition to 35 HRC maximum. Free-machining alloys are not acceptable. Environmental restrictions are as follows:

10.2.2.1 At a maximum temperature of 121°C (250°F), the maximum H_2S partial pressure shall be 700 kPa abs (100 psia), maximum 5,000 mg/L chloride, and no elemental (free) sulfur shall be present.

10.2.2.2 At a maximum temperature of 149°C (300°F), the maximum H_2S partial pressure shall be 310 kPa abs (45 psia), maximum 5,000 mg/L chloride, and no elemental (free) sulfur shall be present.

10.2.2.3 At a maximum temperature of 171°C (340°F), the maximum H_2S partial pressure shall be 100 kPa abs (15 psia), maximum 5,000 mg/L chloride, and no elemental (free) sulfur shall be present.

10.2.3 UNS N08926 (Individual Alloy)

UNS N08926 is acceptable in the solution-annealed and cold-worked condition to 35 HRC maximum at a maximum temperature of 121°C (250°F) with a maximum H_2S partial pressure of 700 kPa abs (100 psia), maximum 60,700 mg/L chloride, a maximum CO_2 partial pressure of 1.4 MPa abs (200 psia), and no elemental (free) sulfur.

10.3 Martensitic Stainless Steel Tubular Components

10.3.1 API Spec 5CT/5CTM[26] grade L-80 type 13Cr tubular components are acceptable up to a maximum H_2S partial pressure of 10 kPa abs (1.5 psia) in production environments with a produced water pH ≥3.5.

10.3.2 UNS S41426 tubular components are acceptable when quenched and tempered to 27 HRC maximum and yield strength 724 MPa (105 ksi) maximum, and applied up to a maximum H_2S partial pressure of 10 kPa abs (1.5 psia) in production environments with a produced water pH ≥3.5.

10.3.3 15% Cr Tubular Components

UNS S42500 (15Cr) is acceptable to a maximum H_2S partial pressure of 10 kPa abs (1.5 psia) in production environments with a produced water pH ≥3.5 as tubing and casing in the quenched and double-tempered condition (Paragraph 10.3.3.1) at a maximum hardness of 22 HRC as grade 80 only. The tubing and casing is limited to applications in which the H_2S partial pressure is less than 10 kPa abs (1.5 psia) and the pH of any produced aqueous phase is greater than 3.5. The quench and temper heat-treatment procedure shall conform to the following limitations:

10.3.3.1	Austenitize	900°C (1,652°F) or greater
	Quench	Air or oil quench
	1st Temper	730°C (1,346°F) minimum, then cool to ambient
	2nd Temper	620°C (1,148°F) minimum, then cool to ambient

10.4 Duplex Stainless Steel Tubular Components

Duplex stainless steel tubular components in the solution-annealed, quenched, and cold-worked condition (ferrite content shall be 35 to 65 vol %) are acceptable in the following conditions:

10.4.1 Duplex stainless steels with 30≤PREN≤40 are acceptable with a maximum hardness of 36 HRC for environments containing 2 kPa abs (0.3 psia) H_2S partial pressure or less.

10.4.2 Duplex stainless steels with 40<PREN<45 are acceptable with a maximum hardness of 36 HRC for environments containing 20 kPa abs (3 psia) H_2S partial pressure and 120,000 mg/L chloride or less.

10.5 Nickel-Based Tubular Components

Nickel-based components used for downhole casing, tubing, and the related equipment (hangers and downhole component bodies; components that are internal to the downhole component bodies) are subject to the requirements of Section 4 for general-usage alloys or this portion of the standard if the user chooses. The alloys fall into two divisions:

(1) Solution-annealed and cold-worked alloys

(2) Solution-annealed and precipitation-hardenable alloys

10.5.1 Tubular Components

Solution-annealed and cold-worked alloys are acceptable to 40 HRC maximum. The alloys are assigned to performance categories according to possible environmental parameters. The aim is to match strength and environmental requirements of the tubular components with those of the tubulars. The higher-numbered categories can be used in lower-numbered categories.

10.5.1.1 Group 1 — 1,030-MPa (150-ksi) maximum yield strength

Chemical Composition: The chemical composition of these alloys shall be:

19.5% Cr	minimum,
29.5% Ni + Co	minimum, and
2.5% Mo	minimum.

The acceptable environment shall be one of the following shown in Table 5:

Table 5: Acceptable Environments for Tubular Components, Group 1

Temperature	H_2S partial pressure	Sulfur
232°C (450°F) maximum	0.2 MPa abs (30 psia) maximum	no
218°C (425°F) maximum	0.7 MPa abs (100 psia) maximum	no
204°C (400°F) maximum	1.0 MPa abs (150 psia) maximum	no
177°C (350°F) maximum	1.4 MPa abs (200 psia) maximum	no
132°C (270°F) maximum	no limit	yes

10.5.1.2 Group 2 — 1,030-MPa (150-ksi) maximum yield strength

Chemical Composition: The chemical composition of these alloys shall be:

19% Cr	minimum,
45% Ni + Co	minimum, and
6% Mo + W	minimum.

The acceptable environment shall be one of the following shown in Table 6:

Table 6: Acceptable Environments for Tubular Components, Group 2

Temperature	H_2S partial pressure	Sulfur
218°C (425°F) maximum	2.0 MPa abs (300 psia) maximum	no
149°C (300°F) maximum	no limit	yes

10.5.1.3 Group 3 — 1,240-MPa (180-ksi) maximum yield strength

Chemical Composition: The chemical composition of these alloys shall be:

14.5% Cr	minimum,
52% Ni + Co	minimum, and
12% Mo	minimum.

The acceptable environment shall be one of the following shown in Table 7:

Table 7: Acceptable Environments for Tubular Components, Group 3

Temperature	H_2S partial pressure	Sulfur
232°C (450°F) maximum	7.0 MPa abs (1,000 psia) maximum	yes
204°C (400°F) maximum	no limit	yes

10.6 Artificial Lift Equipment

10.6.1 Sucker-Rod Pumps and Sucker Rods

10.6.1.1 Sucker-rod pumps and sucker rods for sour service are outside the scope of this standard and are covered by other NACE International and API standards. (Refer to NACE Standard MR0176.[27])

10.6.2 Gas Lift Equipment

10.6.2.1 Surface and subsurface equipment shall comply with the requirements of Sections 3 through 8. Casing and tubing shall comply with the requirements of Section 10.

10.6.2.2 Austenitic stainless steels and highly alloyed stainless steels and nickel-copper alloys (UNS N05500, UNS N04400, and UNS N04405) are used for gas lift service. A valid use limit has not been established for these alloys for this application.

10.6.3 Other Artificial Lift Equipment

10.6.3.1 Other artificial lift equipment is outside the scope of this standard.

10.7 Packers and Other Subsurface Equipment

10.7.1 Materials listed in Table D1 in Appendix D and covered in Sections 3, 4, 8, and 10 are acceptable for packers and other subsurface equipment, regardless of shape, when used within the specified condition, hardness, and environmental limitations.

10.7.1.1 Martensitic precipitation-hardenable stainless steels are acceptable for packers and other subsurface equipment at the maximum hardnesses, in the heat-treated condition, and within the environmental limits as listed in Paragraphs 9.2.4.1 and 9.2.4.2.

10.7.1.2 Type 420M (chemical composition in accordance with API Spec 5CT/5CTM grade L-80 type 13Cr) is acceptable for packers and other subsurface equipment when quenched and tempered to 22 HRC maximum and applied up to a maximum H_2S partial pressure of 10 kPa abs (1.5 psia) in production environments with a produced water pH ≥3.5.

10.7.1.3 Components manufactured from wrought, low-carbon martensitic stainless steel UNS S41427 bar in the austenitized, quenched, and double-tempered condition to 29 HRC maximum are acceptable up to a maximum H_2S partial pressure of 10 kPa abs (1.5 psia) in production environments with a produced water pH ≥3.5 and NaCl ≤1.0%, provided they are heat treated in accordance with Paragraph 10.7.1.3.1.

10.7.1.3.1 Heat-Treatment Procedure (Three-Step Process):

(1) Austenitize 900 to 980°C (1,652 to 1,796°F) and air cool or oil quench to ambient temperature.

(2) Temper at 600 to 700°C (1,112 to 1,292°F) and air cool to ambient temperature.

(3) Temper at 540 to 620°C (1,004 to 1,148°F) and air cool to ambient temperature.

10.7.2 Austenitic stainless steels (such as UNS S31600 and UNS N08020) and nickel-iron-molybdenum alloys (such as UNS N08825) are successfully used in downhole screens, control line tubing, hardware (e.g., set screws, etc.), injection tubing, and injection equipment in more severe environments than those shown in MR0175. Environmental limits for these alloys for these applications have not been established.

10.7.3 Wrought nickel-copper alloys (UNS N05500 in accordance with the hardness limit and heat treatment conditions in Paragraph 9.2.5, UNS N04400, and UNS N04405) have been used in downhole running, setting, and service tool applications for temporary service. Environmental limits for these alloys for these applications have not been established.

10.7.4 UNS S17400 in accordance with the hardness limits and heat treatments in Paragraph 9.2.4.1 has been used for temporary drilling and subsurface well-servicing equipment that is stressed at less than 60% of its minimum specified yield strength under working conditions. Environmental limits for this alloy for these applications have not been established.

10.8 Slips

10.8.1 Slips are outside the scope of this standard.

Section 11: Wells, Flow Lines, Gathering Lines, Facilities, and Field Processing Plants

11.1 General. Materials used for production facilities and field processing installations shall meet the requirements of this section if they are to be exposed to sour environments and shall be fabricated in compliance with Section 5.

11.2 Flow Lines and Gathering Lines

Materials and fabrication procedures shall comply with the requirements of Sections 3 through 8.

11.3 Production Facilities

11.3.1 Oil and Gas Processing and Injection Facilities

11.3.1.1 Materials and fabrication procedures shall comply with the requirements of Sections 3 through 8.

11.3.1.2 If the chloride content in aqueous solutions is known or controlled to be low (typically less than 50 mg/L chloride) in operations after separation, the use limits for austenitic stainless steels (Paragraph 4.2), highly alloyed austenitic stainless steels (Paragraph 4.5), duplex stainless steels (Paragraphs 4.9 and 4.10), and nickel-based alloys (Paragraph 4.11) are less constrained than those reported in this standard. A valid use limit has not been established for these alloys for this application.

11.3.2 Cryogenic Gas Processing Plants

11.3.2.1 The use of alloy steels containing more than 1% nickel may be desirable in low-temperature service to provide resistance to brittle fracture. Because of the absence of water in this service, these alloys are acceptable, provided that adequate precautions (such as protecting the equipment by using inhibited methanol) are taken during startup and shutdown. Typical steels included in the class are ASTM A 333/A 333M[28] grades 3, 4, 7, 8, and 9; A 334/A 334M[29]; A 203/A 203M[30]; A 420/A 420M[31] grades WPL-3, WPL-6, and WPL-8; A 350/A 350M[32] grade LF 3; A 353/A 353M[33]; and A 689.[34]

11.3.3 Water Injection and Water Disposal

11.3.3.1 Materials selection for water-handling facilities is outside the scope of this standard. Refer to NACE Standard RP0475.

11.4 Compressors and Pumps

11.4.1 Materials exposed to the sour environment shall comply with the requirements of Sections 3 through 8, except as noted in Paragraphs 11.4.2 and 11.4.3.

11.4.2 Gray cast iron (ASTM A 278/A 278M[35] Class 35 or 40) and ductile iron (ASTM A 395/A 395M) are acceptable as compressor cylinders, liners, pistons, and valves. Aluminum alloy 355, temper T-7 (ASTM B 26/B 26M[36]), is acceptable for pistons. Aluminum, soft carbon steel, and soft, low-carbon iron are acceptable as gaskets in compressors handling sour gas.

11.4.3 UNS G43200 and a modified version of G43200 that contains 0.28 to 0.33% carbon are acceptable for compressor impellers at a maximum yield strength of 620 MPa (90 ksi) provided they have been heat treated in accordance with the following three-step process:

(1) Austenitize and quench.

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

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

11.4.4 Cast or wrought martensitic stainless steel alloys UNS S41000, S42400, J91150 (CA15), J91151 (CA15M), J91540 (CA6NM), are acceptable for use in compressors in sour environments at a maximum hardness stated in Paragraph 4.8 and when heat treated in accordance with Paragraphs 4.8.1.1 and 4.8.2.1.

11.4.4.1 Using these alloys for impellers at a higher strength level shall require that they exhibit a threshold stress of 95% of actual yield strength in an anticipated service environment of equivalent pH, H_2S partial pressure, and chloride content.

11.4.5 Wrought UNS S17400 and S15500 martensitic precipitation-hardenable stainless steels are acceptable for use in compressors in sour environments at 33 HRC maximum hardness and when heat treated in accordance with Paragraph 9.2.4.1.1 or 9.2.4.1.2.

11.4.5.1 Using these alloys for impellers at a >33 HRC hardness level shall require that they exhibit a threshold stress of 95% of actual yield strength in an anticipated service environment of equivalent pH, H_2S partial pressure, and chloride content.

11.4.6 Wrought UNS S45000 martensitic precipitation-hardenable stainless steel is acceptable for use in compressors in sour environments at 31 HRC maximum hardness (equivalent to 306 HBW for this alloy) and when heat treated in accordance with Paragraph 9.5.3.1

11.4.7 Austenitic stainless steels meeting the requirements of Paragraph 4.2 are acceptable for use in compressors in sour environments.

11.5 Pipe Fittings

11.5.1 Carbon steels meeting the requirements of ASTM A 105/A 105M or A 234/A 234M[37] grades WPB and WPC are acceptable in the hot-worked condition to the following maximum hardnesses: A 105/A 105M (187 HBW); A 234/A 234M WPB and WPC (197 HBW).

Section 12: Drilling and Well-Servicing Equipment

12.1 General. Metallic materials used for drilling and well-servicing equipment shall meet the requirements of this section if they are to be exposed to sour environments and shall be fabricated in compliance with Section 5, except as otherwise indicated herein.

12.2 Control of Drilling and Well-Servicing Environments

12.2.1 The service stresses involved in drilling and well-servicing operations often require the use of materials and components having hardness (strength) greater than that permitted for carbon and low-alloy steels in Section 3. When such materials and components are required for drilling formations or are operating in sour environments, the primary means for avoiding SSC/SCC is control of the drilling or well-servicing environment. As service stresses and material hardnesses increase, drilling fluid control becomes increasingly important.

12.2.2 The drilling environment is controlled by maintenance of drilling fluid hydrostatic head and fluid density to minimize formation fluid in-flow and by the use of one or more of the following: (1) maintenance of pH 10 or higher to neutralize H_2S in the drilled formation; (2) use of chemical sulfide scavengers; and (3) use of a drilling fluid in which oil is the continuous phase.

12.2.3 When aluminum drill pipe is used, the drilling fluid pH should not exceed 10.5 to avoid accelerated mass-loss corrosion.

12.3 Drilling Equipment

12.3.1 Drill Stem

12.3.1.1 Drill pipe, tool joints, drill collars, and other tubular components.

12.3.1.1.1 Steel tubular components meeting API specifications listed in Table D2 in Appendix D are acceptable if the drilling environment is controlled (see Paragraph 12.2). For optimum SSC/SCC resistance, steel components having specified minimum yield strengths greater than 660 MPa (95 ksi) should be heat treated by quenching and tempering.

12.3.1.2 Welding of Tool Joints to Drill Pipe

12.3.1.2.1 The weld and HAZ shall be heat treated by austenitizing, cooling to a temperature below the transformation range, and tempering at a minimum tempering temperature of 593°C (1,100°F).

12.3.1.3 Hardsurfacing

12.3.1.3.1 Hardsurfacing deposits on tubular drilling components may be applied only to regions of increased cross-section where service stresses are reduced. These deposits do not require heat treatment after being applied.

12.3.2 Drill Bits

12.3.2.1 Drill bits are outside the scope of this standard.

12.3.3 Other Drilling Components

12.3.3.1 Other drilling components (slush pumps, swivels, kelly cocks, etc.) shall be manufactured from materials in compliance with Sections 3 through 8. Parts of these components that are isolated from the sour drilling fluid or that are exposed only to the controlled drilling fluid environment (see Paragraph 12.2.2) are outside the scope of this standard.

12.4 Blowout Preventer (BOP)

12.4.1 Blowout preventer body and parts (excluding ram and ram shear blades) shall meet the requirements of Sections 3 through 8.

12.4.2 Blowout Preventer Shear Blades

12.4.2.1 High-strength and high-hardness steels are required for ram shear blades to shear drill pipe during drilling emergency conditions. However, these materials are highly susceptible to SSC/SCC.

12.4.3 Rams

12.4.3.1 Low-alloy steels processed in accordance with Sections 3 through 8 are acceptable for rams. Low-alloy steels in the chromium-molybdenum class (and its modifications) are acceptable as rams at 26 HRC maximum in the quenched and tempered condition. Careful attention to chemical composition and heat treatment is required to ensure SSC resistance of these alloys at hardness levels greater than 22 HRC. SSC tests shall be conducted to establish that the material is equivalent in SSC performance to materials that have given satisfactory service in sour environments.

12.5 Choke Manifolds and Choke and Kill Lines

12.5.1 Choke manifolds and choke and kill lines shall comply with the requirements of Sections 3 through 8.

12.6 Drill Stem Testing

12.6.1 Drill stem testing is not ordinarily conducted in a controlled drilling environment. Materials for drill stem testing shall comply with the requirements of Sections 3 through 10 and Paragraph 12.2.1.

12.6.2 Materials shown in Table D2 in Appendix D can also be used with operational procedures that take into consideration the factors enumerated in Paragraph 1.4, which may involve use of inhibitors, limited entry, limited time, limited pressure, and metallurgical or design factors. Such operational procedures are outside the scope of this standard (see API RP 7G[38]).

12.7 Formation-Testing Tools

12.7.1 Materials for formation-testing tools shall comply with the requirements of Sections 3 through 10 and Paragraph 12.2.1.

12.8 Floating Drilling Operations

12.8.1 Blowout Preventers (BOP)

12.8.1.1 Blowout preventers shall comply with the requirements of Paragraph 12.4.

12.8.2 Drilling Riser Systems

12.8.2.1 If the flow of sour formation fluids is handled by diverting the flow at the sea floor BOP through the choke and kill lines, the drilling riser pipe, riser connections, ball or flex joints, and telescoping joints need not comply with this standard. If, however, the riser system is to be exposed to sour environments, materials used shall meet the requirements of Sections 3 through 8 and Table D1.

12.8.3 Choke and Kill Lines

12.8.3.1 Materials for the choke and kill lines and manifolds shall comply with the requirements of Sections 3 through 8.

12.9 Well-Servicing Equipment

12.9.1 Fluid Sampling Containers

12.9.1.1 Containers pressurized with the production environment shall meet the requirements of this standard.

12.9.2 Downhole Service Tools

12.9.2.1 Downhole servicing tools are not covered by this standard. The user shall ensure that the material is satisfactory for the limited time in the intended service environment.

12.9.3 Work String

12.9.3.1 Work strings used during well servicing when sour fluids are to be encountered shall comply with the requirements of Paragraph 10.1 or 12.3 as applicable. Work strings that are to be exposed to controlled drilling fluid environments only are outside the scope of this standard.

12.9.4 Blowout Preventers

12.9.4.1 Blowout preventers shall comply with the requirements of Paragraph 12.4.

12.9.5 Choke and Kill Lines

12.9.5.1 Choke and kill lines and manifolds shall comply with the requirements of Sections 3 through 9.

12.9.6 Production Test Facilities

12.9.6.1 Production test facilities shall comply with the requirements of Sections 3 through 8.

12.9.7 Wire Line Lubricator Assembly

12.9.7.1 Wire line lubricator and auxiliary equipment shall comply with the requirements of Sections 3 through 8 and Table D1 in Appendix D.

Section 13: Adding New Materials to Section 3: Carbon and Low-Alloy Steels and Cast Irons

13.1 Balloting criteria: Carbon and low-alloy steels and cast irons with a hardness greater than 22 HRC that are not otherwise covered by this standard must meet the following minimum balloting criteria for balloting prior to inclusion in this standard. These balloting criteria are necessary but may not be sufficient conditions for inclusion in all cases.

13.1.1 Additions are accomplished using laboratory or field tests performed and successful balloting in accordance with the requirements of this standard.

13.1.2 Requests for revision of this standard shall be made in writing to NACE Headquarters as described in the *NACE Technical Committee Publications Manual*.[39] These requests shall state the specific changes proposed, supported by appropriate documentation, including a complete description of the materials or processes and laboratory or field test data or service performance, or other technical justification. The requested change shall be reviewed and balloted as described in the *NACE Technical Committee Publications Manual*.

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

13.1.4 A minimum of three test specimens from each of three different commercially prepared heats must be tested in the (heat-treated) condition balloted for MR0175 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 MR0175 must be included with the ballot.

13.1.5 The Rockwell hardness of each test specimen must 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 that heat/condition for the purpose of balloting. The maximum hardness requested for inclusion of the candidate material in MR0175 must be specified in the ballot and shall be supported by the data provided.

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

13.1.7 See Appendix B for sample test data tables and the definition of available Test Levels I through VII. Test Levels are defined in terms of temperature, minimum CO_2 content, minimum H_2S content, minimum NaCl content, water pH, and other variables. Appendix C provides previously submitted ballot data that may be useful as a reference

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Section 14: Adding New Materials to MR0175 Section 4: Corrosion-Resistant Alloys (CRAs)—All Other Alloys Not Defined as Carbon and Low-Alloy Steels and Cast Irons in Section 3

14.1 New individual materials (alloys) and/or new processes that are associated with individual alloy(s) shall be balloted according to a Test Level in paragraphs or sections that deal with individual alloys. Each Test Level corresponds to a level of environmental severity, which is listed in Appendix B, Table B1; the balloter is free to increase the severity at which the tests are conducted subject to the minimum environmental constraints of the balloted Test Level. Ballots on new materials and/or processes that are based only on laboratory data shall contain results of tests conducted on test specimens from at least three heats of material.

14.1.1 Additions are accomplished using laboratory or field tests performed and successful balloting in accordance with the requirements of this standard.

14.1.2 Requests for revision of this standard shall be made in writing to NACE Headquarters as described in the *NACE Technical Committee Publications Manual*. These requests shall state the specific changes proposed, supported by appropriate documentation, including a complete description of the materials or processes and laboratory or field test data or service performance, or other technical justification. The requested change shall be reviewed and balloted as described in the *NACE Technical Committee Publications Manual*.

14.1.3 See Sections 13 and 15 and other paragraphs within Section 14 for additional requirements.

14.1.4 See Appendix B for sample test data tables and the definition of available Test Levels I through VII. Test Levels are defined in terms of temperature, minimum CO_2 content, minimum H_2S content, minimum NaCl content, water pH, and other variables. Appendix C provides previously submitted ballot data that may be useful as a reference.

14.2 Austenitic and duplex stainless steels, nickel-based alloys, and titanium alloys may be susceptible to cracking at elevated temperatures. Test data for these alloys at Test Level II or III qualify them for use only at ambient temperature. For use at elevated temperature, data at Test Level IV, V, VI, or VII should be submitted. When a Test Level higher than III is being balloted, the ballot item submitter shall also include test results at room temperature in accordance with the requirements of Test Level III. Cracking of some duplex stainless steels has been inhibited by galvanic coupling with steel; therefore, evaluation of duplex stainless steel at room temperature using Test Level II may be considered.

14.3 Laboratory data produced in accordance with the requirements of NACE Standards TM0177 and TM0198[40] provide two accepted bases for required laboratory test information. Other test methods may be employed. These test environments are not intended to represent actual service conditions. The test results with testing details shall be available to the public. The data that are presented in Appendix B, Table B2 are not meant as guidelines on application or a limit in service environments in which materials may be used; for example, for tension testing, the threshold stress at which cracking occurs or the maximum stress at which failure/cracking does not occur shall be listed with the material and the conditions under which it has been tested. It is the user's responsibility to ensure that a material will be satisfactory in the intended service environment. NACE Headquarters shall make data submitted to NACE for these ballot items available for public review. Appendix C contains ballot submittal data for some materials accepted in recent years.

14.3.1 Changing the environmental use limits (of temperature, chlorides, pH, partial pressure of H_2S, or the presence of elemental sulfur) for an individual alloy may be accomplished only if the alloy is listed individually.

14.4 Adding alloy categories or changing the environmental use limits (of temperature, chlorides, pH, partial pressure of H_2S, or the presence of elemental sulfur) for an alloy category may be accomplished only by balloting data that support changing these conditions for the *entire* alloy category. Therefore, changing the environmental use conditions (of temperature, chlorides, pH, partial pressure of H_2S, or the presence of elemental sulfur) for an individual alloy contained in an alloy category may be accomplished only by balloting data that support changing these conditions for the *entire* alloy category containing the individual alloy.

Section 15: Proposing Changes and Making Additions for MR0175 Sections 5 Through 11: Fabrication, Welding, and Specific Equipment

Changes or additions to these sections require a ballot procedure described in Sections 13 and/or 14 depending on the material in question. Alternatively, the user may also choose to follow the procedure given in Section 16 for application-specific cases.

Section 16: Materials for Application-Specific Cases Without Proposing Adding New Materials to MR0175

Materials that are not specifically listed in MR1075 may comply with the standard for application-specific cases. This section provides the minimum requirements for compliance with this standard for application-specific cases when using:

(1) alloys in the specific categories outside MR0175,

(2) alloys included in MR0175 but used outside the acceptable environments of MR0175, or

(3) alloys not listed in MR0175 and not included in a specific category.

16.1 General Requirements

For specific applications (for example, wells or fields), alloy usage shall be supported by documented laboratory testing and/or field experience. Supporting documentation shall be submitted to NACE International Headquarters, which will make these data available to the public. NACE International will neither review nor approve this documentation. It is the user's responsibility to evaluate and determine the applicability of the documented data for the intended application.

New alloy categories and acceptable environments shall not become part of MR0175 until they are approved by ballot. MR0175 places limits on (1) manufacturing processes and (2) environments. Alloy use outside the requirements of this standard is the responsibility of the user.

Broadening alloy use applies only to each alloy composition and material condition for which documentation has been obtained. (Alloy composition refers to a UNS number or other identification of a particular chemical composition range.) The equipment user shall determine the applicability for products with different manufacturing processing methods (e.g., wrought versus cast, size and form, hot/cold work, etc.).

16.2 Testing Requirements

Tests shall be conducted on specimens taken from products having a size and form similar to the intended application. The chemical composition shall be specified and shall be tested within the compositional range of that alloy. The user shall specify the maximum strength and hardness for the product specification based on the laboratory data. For environmental testing, the following shall be recorded for the test specimen(s):

- test specimen size, test specimen type, and test specimen location within the part.
- the part form and complete processing history. This shall include wrought vs. cast, size and form, hot/cold work, and any heat treatments.

16.2.1 Expanding the Acceptable Environments
It is the user's responsibility to ensure that the testing cited is relevant to intended applications. Choice of appropriate temperatures and environment for evaluating susceptibility to both SCC and SSC is required. NACE Standard TM0177 and EFC[(14)] Publication #17[41] provide guidelines for laboratory testing. Typically, an expanded environmental limit may be an increase in the H_2S partial pressure limit and may be linked to either low chloride or pH limits, or to a temperature limitation.

16.2.2 Test Protocols

Test methods and acceptance criteria in EFC Publication #16[42] for low-alloy steels are suggested as a basis for qualifying alloys in this section in appropriate SCC/SSC test environments. It is the equipment user's responsibility to accept the test procedures and acceptance criteria.

16.2.3 Field Experience

Expanded applications based on field experience shall be limited to both the alloy composition and the deployment of manufactured components under similar environmental and stress conditions as those cited in the successful field experience.

Field-based documentation for expanded alloy use requires exposure of a component for sufficient time to demonstrate its resistance to SCC/SSC. Sufficient information on factors that affect SCC/SSC (e.g., stress levels, fluid and gas composition, operating conditions, galvanic coupling, etc.) shall be documented.

References

1. E.M. Moore, J.J. Warga, "Factors Influencing the Hydrogen Cracking Sensitivity of Pipeline Steels," CORROSION/76, paper no. 144 (Houston, TX: NACE International, 1976).

2. NACE Standard TM0284 (latest revision), "Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking" (Houston, TX: NACE).

3. NACE Standard RP0475 (latest revision), "Selection of Metallic Materials to Be Used in All Phases of Water Handling for Injection into Oil-Bearing Formations" (Houston, TX: NACE).

4. NACE Standard TM0177 (latest revision), "Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments" (Houston, TX: NACE).

5. ASTM E 18 (latest revision), "Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials" (West Conshohocken, PA: ASTM).

6. ASTM E 140 (latest revision), "Standard Hardness Conversion Tables for Metals — Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, Knoop Hardness, and Scleroscope Hardness" (West Conshohocken, PA: ASTM).

7. ASTM E 384 (latest revision), "Standard Test Method for Microindentation Hardness of Materials" (West Conshohocken, PA: ASTM).

8. ASTM E 10 (latest revision), "Standard Test Method for Brinell Hardness of Metallic Materials" (West Conshohocken, PA: ASTM).

9. ASTM A 370 (latest revision), "Standard Test Methods and Definitions for Mechanical Testing of Steel Products" (West Conshohocken, PA: ASTM).

10. ASTM A 105/A 105M (latest revision), "Standard Specification for Carbon Steel Forgings for Piping Applications" (West Conshohocken, PA: ASTM).

11. ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 (latest revision), "Rules for Construction of Pressure Vessels" (New York, NY: ASME).

12. ASTM A 53/A 53M (latest revision), "Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless" (West Conshohocken, PA: ASTM).

13. ASTM A 106 (latest revision), "Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service" (West Conshohocken, PA: ASTM).

14. API Spec 5L (latest revision), "Line Pipe" (Washington, DC: API); ISO[(15)] 3183-1 (latest revision), "Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 1: Pipes of requirement class A" (Geneve, Switzerland: ISO); ISO 3183-2 (latest revision), "Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions — Part 2: Pipes of requirements class B" (Geneve, Switzerland: ISO).

[(14)] European Federation of Corrosion (Society of Chemical Industry), Institute of Metals, 1 Carlton House Terrace, London, SW1Y 5DB, United Kingdom.
[(15)] International Organization for Standardization (ISO), 1 rue de Varembe, Case Postale 56, CH-1121 Geneve 20, Switzerland.

15. ASTM A 395/A 395M (latest revision), "Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures" (West Conshohocken, PA: ASTM).

16. ASTM A 351/A 351M (latest revision), "Standard Specification for Castings, Austenitic, Austenitic-Ferritic (Duplex), for Pressure-Containing Parts" (West Conshohocken, PA: ASTM).

17. ASTM A 743/A 743M (latest revision), "Standard Specification for Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application" (West Conshohocken, PA: ASTM).

18. ASTM A 744/A 744M (latest revision), "Standard Specification for Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service" (West Conshohocken, PA: ASTM).

19. ASME Boiler and Pressure Vessel Code, Section IX (latest revision), "Welding and Brazing Qualifications" (New York, NY: ASME).

20. SAE AMS-S-13165 (latest revision), "Shot Peening of Metal Parts" (Warrendale, PA: SAE).

21. API Spec 6A (latest revision), "Wellhead and Christmas Tree Equipment" (Washington, DC: API).

22. ASTM A 193/A 193M (latest revision), "Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service" (West Conshohocken, PA: ASTM).

23. ASTM A 320/A 320M (latest revision), "Standard Specification for Alloy/Steel Bolting Materials for Low-Temperature Service" (West Conshohocken, PA: ASTM).

24. ASTM A 194/A 194M (latest revision), "Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both" (West Conshohocken, PA: ASTM).

25. ASTM A 747/A 747M (latest revision), "Standard Specification for Steel Castings, Stainless, Precipitation Hardening" (West Conshohocken, PA: ASTM).

26. API Spec 5CT (latest revision), "Casing and Tubing (U.S. Customary Units)" and API Spec 5CTM (latest revision), "Casing and Tubing (Metric Units)" (Washington, DC: API).

27. NACE Standard MR0176 (latest revision), "Metallic Materials for Sucker-Rod Pumps for Corrosive Oilfield Environments" (Houston, TX: NACE).

28. ASTM A 333/A 333M (latest revision), "Standard Specification for Seamless and Welded Steel Pipe for Low-Temperature Service" (West Conshohocken, PA: ASTM).

29. ASTM A 334/A 334M (latest revision), "Standard Specification for Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service" (West Conshohocken, PA: ASTM).

30. ASTM A 203/A 203M (latest revision), "Standard Specification for Pressure Vessel Plates, Alloy Steel, Nickel" (West Conshohocken, PA: ASTM).

31. ASTM A 420/A 420M (latest revision), "Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service" (West Conshohocken, PA: ASTM).

32. ASTM A 350/A 350M (latest revision), "Standard Specification for Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components" (West Conshohocken, PA: ASTM).

33. ASTM A 353/A 353M (latest revision), "Standard Specification for Pressure Vessel Plates, Alloy Steel, 9 Percent Nickel, Double-Normalized and Tempered" (West Conshohocken, PA: ASTM)

34. ASTM A 689 (latest revision), "Standard Specification for Carbon and Alloy Steel Bars for Springs" (West Conshohocken, PA: ASTM).

35. ASTM A 278/A 278M (latest revision), "Standard Specification for Gray Iron Castings for Pressure-Containing Parts for Temperatures up to 650°F" (West Conshohocken, PA: ASTM).

36. ASTM B 26/B 26M (latest revision), "Standard Specification for Aluminum-Alloy Sand Castings" (West Conshohocken, PA: ASTM).

37. ASTM A 234/A 234M (latest revision), "Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service" (West Conshohocken, PA: ASTM).

38. API RP 7G (latest revision), "Drill Stem Design and Operating Limits" (Washington, DC: API); ISO 10407 (latest revision), "Petroleum and natural gas industries — Drilling and production equipment — Drill stem design and operating limits" (Geneve, Switzerland: ISO).

39. NACE Technical Committee Publications Manual (latest revision) (Houston, TX: NACE).

40. NACE Standard TM0198 (latest revision), "Slow Strain Rate Test Method for Screening Corrosion-Resistant Alloys (CRAs) for Stress Corrosion Cracking in Sour Oilfield Service" (Houston, TX: NACE).

41. European Federation of Corrosion (EFC) Publication #17, 2nd ed., "Corrosion Resistant Alloys for Oil and Gas Production: Guidance on General Requirements and Test Methods for H_2S Service" (London, UK: EFC, 2002).

42. EFC Publication #16, 2nd ed., "Guidelines on Materials Requirements for Carbon and Low Alloy Steel for H_2S Environments in Oil and Gas Production" (London, UK: EFC, 2002).

43. ASTM A 494/A 494M (latest revision), "Standard Specification for Castings, Nickel and Nickel Alloy" (West Conshohocken, PA: ASTM).

44. ASTM A 536 (latest revision), "Standard Specification for Ductile Iron Castings" (West Conshohocken, PA: ASTM).

45. ASTM A 571/A 571M (latest revision), "Standard Specification for Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service" (West Conshohocken, PA: ASTM).

46. ASTM A 220/A 220M (latest revision), "Standard Specification for Pearlitic Malleable Iron" (West Conshohocken, PA: ASTM).

47. ASTM A 602 (latest revision), "Standard Specification for Automotive Malleable Iron Castings" (West Conshohocken, PA: ASTM).

48. ASTM A 48/A 48M (latest revision), "Standard Specification for Gray Iron Castings" (West Conshohocken, PA: ASTM).

49. ASTM A 276 (latest revision), "Standard Specification for Stainless Steel Bars and Shapes" (West Conshohocken, PA: ASTM).

50. ASTM A 182/A 182M (latest revision), "Standard Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service" (West Conshohocken, PA: ASTM).

51. ASTM A 213/A 213M (latest revision), "Standard Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes" (West Conshohocken, PA: ASTM).

52. ASTM A 524 (latest revision), Standard Specification for Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures" (West Conshohocken, PA: ASTM).

53. ASTM A 381 (latest revision), "Standard Specification for Metal-Arc-Welded Steel Pipe for Use with High-Pressure Transmission Systems" (West Conshohocken, PA: ASTM).

54. API Spec 5D (latest revision), "Drill Pipe" (Washington, DC: API).

Appendix A
Sample Calculations of the Partial Pressure of H_2S

Figure A-1 provides a graphical representation of the partial pressure relationship described in Paragraph 1.4 as it applies to sour gas systems.

Figure A-2 provides a graphical representation of the partial pressure relationship described in Paragraph 1.4 as it applies to sour multiphase systems.

Partial pressure may be calculated by multiplying the system total absolute pressure times the mole fraction of H_2S. For example, in a 69 MPa abs (10,000 psia) system in which the H_2S is 10 mol% in the gas, the H_2S partial pressure is:

$$\frac{10}{100} \, x \, 69 = 6.9 \text{ MPa abs}$$

$$\left(\frac{10}{100} \, x \, 10{,}000 = 1{,}000 \text{ psia} \right)$$

For downhole liquid crude oil systems operating above the bubble point pressure, for which no equilibrium gas composition is available, the partial pressure of H_2S may be determined by using the mole fraction of H_2S in the gas phase at the bubble point pressure. For example, for an oil with a 34.5 MPa abs (5,000 psia) bubble point pressure which has 10 mol% H_2S in the gas phase at the bubble point, the H_2S partial pressure would be:

$$34.5 \, x \, \frac{10}{100} = 3.45 \text{ MPa abs}$$

$$\left(5{,}000 \, x \, \frac{10}{100} = 500 \text{ psia} \right)$$

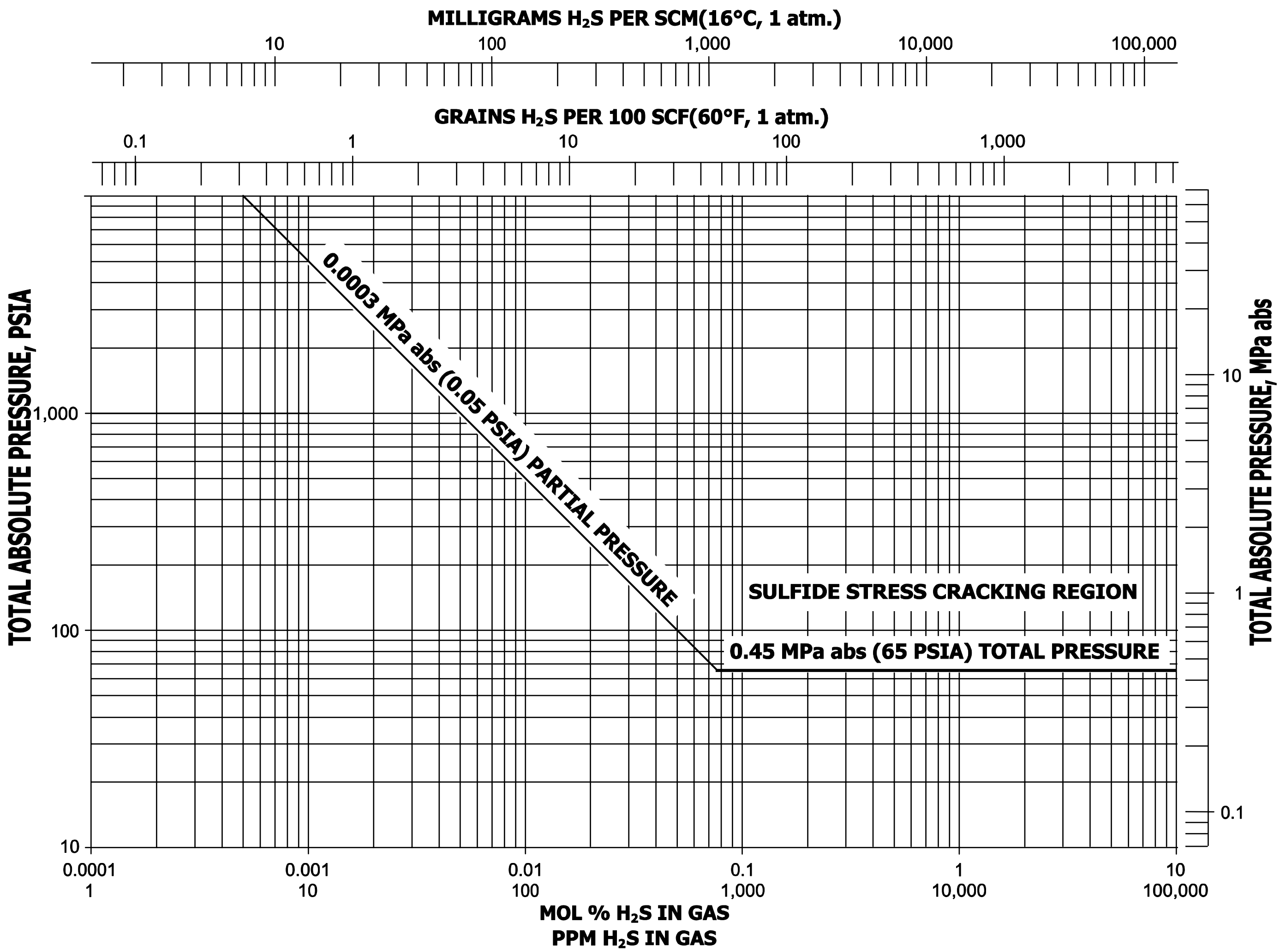

Figure A-1: Sour Gas Systems (see Paragraph 1.4)

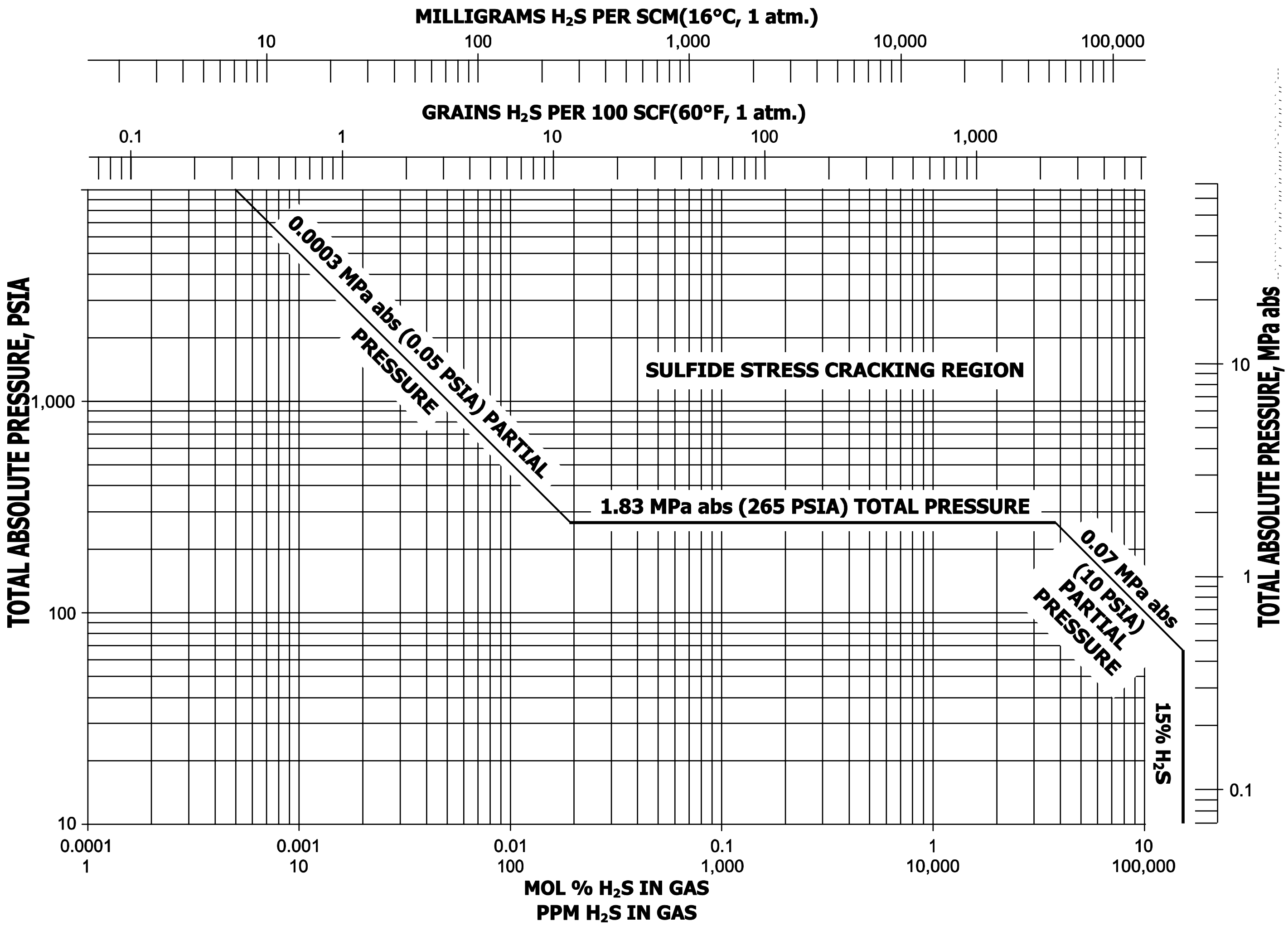

Figure A-2: Sour Multiphase Systems (see Paragraph 1.4)

Appendix B
Sample Test Data Tables

Table B1: Description of Test Levels

Test Level		I	II	III	IV	V	VI	VII
Environmental Condition	**Temperature**	25 ±3°C (77 ±5°F)	25 ±3°C (77 ±5°F)	25 ±3°C (77 ±5°F)	90 ±5°C (194 ±9°F)	150 ±5°C (302 ±9°F)	175 ±5°C (347 ±9°F)	205 ±5°C (401 ±9°F)
	CO_2 content, min.	none	none	none	0.7 MPa abs (100 psia)	1.4 MPa abs (200 psia)	3.5 MPa abs (500 psia)	3.5 MPa abs (500 psia)
	H_2S content, min.	(list)	TM0177	TM0177	0.003 MPa abs (0.4 psia)	0.7 MPa abs (100 psia)	3.5 MPa abs (500 psia)	3.5 MPa abs (500 psia)
	NaCl content, min.	(list)	TM0177	TM0177	150,000 mg/L	150,000 mg/L	200,000 mg/L	250,000 mg/L
	pH	(list)	TM0177	TM0177	(list)	(list)	(list)	(list)
	Other[(A)]	(list)	none	coupled to steel	(list)	(list)	(list)	(list)
Test Method(s)		(list)	(list the TM0177 method)	(list the TM0177 method)	(list)	(list)	(list)	(list)
Material Type and Condition		report—chemical composition, UNS number, processing history, heat treatment						
Material Properties		report—yield strength, tensile strength, % elongation, hardness						
Stress Level and Results		report—test stress level, plastic strain, etc., test results						

[(A)] Elemental sulfur/oxidants will increase SCC susceptibility.

Table B2: Test Data

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results

Appendix C: Ballot Submittal Data

This appendix gives information on data submitted for ballot for acceptance into MR0175. All of these materials have been accepted; the tables show to what limits the materials were tested. Any use beyond these limits is the responsibility of the user.

Cast UNS J93254 (CK3MCuN) in accordance with ASTM A 351/A 351M, A 743/A 743M, or A 744/A 744M in the cast, solution heat-treated condition at a hardness level of 100 HRB maximum in the absence of elemental sulfur. (See Table C1.)

Table C1

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
II and III	UNS J93254 (CK3MCuN) castings, solution heat-treated	YS[A] 300-330 MPa (43-48 ksi) UTS[B] 590-650 MPa (86-94 ksi) Elong. 47-54%	TM0177 solution, 180° u-bend loaded beyond yield, iron coupled and non-iron coupled	No failures in 720+ h
		YS 330-340 MPa (48-50 ksi) UTS 650-690 MPa (94-100 ksi) Elong. 47-48%	TM0177 tensile, loaded to yield, iron coupled and non-iron coupled	No failures in 720+ h

[A] Yield strength.
[B] Ultimate tensile strength.

UNS N08367 in the wrought, solution heat-treated or solution heat-treated and cold-worked condition to 35 HRC maximum in the absence of elemental sulfur. (See Table C2.)

Table C2

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
II and III	UNS N08367 solution heat-treated and solution heat-treated and cold-worked	YS 1,300 MPa (120 ksi) UTS 1,400 MPa (200 ksi) Elong. 11-16% Hardness 41-45 HRC	TM0177 Method A loaded to 90% of yield, iron coupled and non-iron coupled	No failures in 720+ h
V mod			4-point bent-beam, Test Level V modified: 10% NaCl, 121°C (250°F), 0.7 MPa abs (100 psia) H_2S, at 100% of yield	No failures in 720+ h

Wrought UNS S32654 in the absence of elemental sulfur, and in the annealed condition at a hardness level of 22 HRC maximum provided that it is free of cold work designed to enhance the mechanical properties. (See Table C3.)

Table C3

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
II	Wrought, annealed UNS S32654	Hardness up to 16.5 HRC	Four-point loading, 0.9-1.0 x YS, 5% NaCl + 0.5% acetic acid, RT[A] ptot[B] = pH_2S = 100 kPa abs (15 psia)	12 specimens tested, no cracks
II	Wrought, annealed, cold deformed by rolling 40% UNS S32654	Hardness up to 42.5 HRC	Four-point loading, 0.9-1.0 x YS, 5% NaCl + 0.5% acetic acid, RT ptot = pH_2S = 100 kPa abs (15 psia)	12 specimens tested, no cracks
III	Wrought, annealed UNS S32654	Hardness up to 16.5 HRC	Four-point loading, 0.9-1.0 x YS, coupling to carbon steel, 5% NaCl + 0.5% acetic acid, RT ptot = pH_2S = 100 kPa abs (15 psia)	12 specimens tested, no cracks
III	Wrought, annealed, cold deformed by rolling 40% UNS S32654	Hardness up to 42.5 HRC	Four-point loading, 0.9-1.0 x YS, coupling to carbon steel, 5% NaCl + 0.5% acetic acid, RT ptot = pH_2S = 100 kPa abs (15 psia)	12 specimens tested, no cracks

[A] Room temperature.
[B] Total pressure.

Wrought UNS S31266 processed with vacuum induction melting (VIM) or vacuum oxygen deoxidation (VOD) followed by electroslag remelting (ESR) and subsequently solution annealed and cold worked to 38 HRC maximum hardness for use up to Test Level V. (See Table C4.)

Table C4

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Stress Level	Test Results
I	Solution-annealed and cold-drawn UNS S31266	41 HRC	TM0177 Method A— 5% NaCl 0.5% acetic acid 0.10 MPa abs (15 psia) H_2S 24°C (75°F)	100 % Actual YS	720 h No failures
I	Solution-annealed and cold-drawn UNS S31266	41 HRC	TM0177 Method A — 5% NaCl 0.5% acetic acid 0.10 MPa abs (15 psia) H_2S 24°C (75°F) coupled to steel	100% Actual YS	720 h No failures
I	Solution-annealed and cold-worked by tensile straining UNS S31266	37, 36, 35 HRC	TM0177 Method A — 5% NaCl 0.5% acetic acid 0.10 MPa abs (15 psia) H_2S 24°C (75°F)	100% Actual YS	720 h No failures
I	Solution-annealed and cold-worked by tensile straining UNS S31266	37, 36, 35 HRC	TM0177 Method A — 5% NaCl 0.5% acetic acid 0.10 MPa abs (15 psia) H_2S 24°C (75°F)	100% Actual YS	720 h No failures
V	Solution-annealed and cold-drawn UNS S31266	41 HRC	TM0177 Method A — 15% NaCl 0.7 MPa abs (100 psia) H_2S 1.4 MPa abs (200 psia) CO_2 150°C (302°F)	90% Actual YS at 150°C (302°F)	720 h No failures
V	Solution-annealed and cold-worked by tensile straining UNS S31266	37, 38 HRC	TM0177 Method A — 15% NaCl 0.7 MPa abs (100 psia) H_2S 1.4 MPa abs (200 psia) CO_2 150°C (302°F)	90% Actual YS at 150°C (302°F)	720 h No failures
V mod.[A]	Solution-annealed and cold-rolled UNS S31266	38, 39 HRC	Four-point bend test — 20% NaCl 0.7 MPa abs (100 psia) H_2S 1.4 MPa abs (200 psia) CO_2 150°C (302°F)	100% Actual YS at 150°C (302°F)	720 h No failures

[A] mod. — 20% NaCl was used instead of the standard 15% NaCl as given in the normal Test Level V test solution.

Wrought UNS S34565 in the solution-annealed condition to 29 HRC maximum in the absence of elemental sulfur. (See Table C5.)

Table C5

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Stress Level	Test Results
III	Wrought, solution-annealed UNS S34565	Max. 29 HRC	TM0177, Solution A, RT, Method A	90% YS	No failures
IV	Wrought, solution-annealed UNS S34565	Max. 29 HRC	TM0177, Table B1 Test Level IV, 90°C (194°F), Method A	90% SMYS	No failures
IV	Wrought, solution-annealed UNS S34565	Max. 29 HRC	Similar to TM0198, 90°C (194°F)		No cracks

Wrought low-carbon martensitic stainless steel UNS S41425 in the austenitized, quenched, and tempered condition to 28 HRC maximum hardness in the absence of elemental sulfur. (See Table C6.)

Table C6

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Stress Level	Test Results
I	Wrought, quenched, and tempered UNS S41425	29, 27, 28 HRC	TM0177 Solution A except H_2S 0.010 MPa abs (1.5 psia) pH 3.5 RT Method A Uncoupled to steel	80% SMYS	No failures
I	Wrought, quenched, and tempered UNS S41425	29, 27, 28, 29 HRC	H_2S 0.0031 MPa abs (0.45 psia) CO_2 0.7 MPa abs (100 psia) NaCl 15% Temp. 90°C (194°F)	80% and 90% SMYS	No failures
I	Wrought, quenched, and tempered UNS S41425	29, 27, 28 HRC	H_2S 0.010 MPa abs (1.5 psia) CO_2 20 MPa abs (450 psia) NaCl 5% Temp. 175°C (348°F)	80% and 90% SMYS	No failures

Wrought UNS N08031 in the cold-worked condition to 35 HRC maximum and 3.45 MPa abs (500 psia) H_2S partial pressure maximum in the absence of elemental sulfur. (See Table C7.)

Table C7

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Stress Level	Test Results
II	Cold-worked wrought UNS N08031	36, 37, 36 HRC	TM0177 Solution A RT,[(A)] Method A	100% YS	No failures
III	Cold worked wrought UNS N08031	36, 37, 36 HRC	TM0177 Solution A RT, Method A	100% YS	No failures
V	Cold-worked wrought UNS N08031	36, 37, 36 HRC	MR0175, Table B1 Test Level V, 150°C (300°F)	100% YS	No failures
VI	Cold-worked wrought UNS N08031	36, 37, 36 HRC	MR0175, Table B1 Test Level VI, 175°C (347°F)	100% YS	No failures

[(A)] Room Temperature.

Wrought UNS N07924 in the solution-annealed and aged condition at a maximum hardness of 35 HRC for use in environments with no elemental sulfur up to 175°C (347°F), Test Level VI. (See Table C8.)

Table C8

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
II and III	UNS N07924 Wrought,solution-annealed, and aged	35-36 HRC YS: 735-776 MPa (106-112 ksi) UTS: 1,180-1,220 MPa (171-176 ksi) Elong. 4d: 34% RA[(A)]: 47-49%	TM0177 Solution Method A (tensile), loaded to 100% of YS, room temp., iron coupled and non-iron coupled	No failure in 720+ hours
VI	Same Materials	Same Properties	MR0175, Table 1 Test Level VI, 175°C (347°F) SSRT[(B)] for SCC in sour oilfield service, NACE TM0198 standard extension rate: 4×10^{-6} sec^{-1}	No SCC • TTF[(C)]/TTF air: 0.93-1.03 • Elong./Elong. air: 0.92-1.00 • RA/RA air: 0.75-0.84

[(A)] Reduction in area.
[(C)] Slow strain rate test.
[(B)] Total time to failure.

Wrought UNS N07725 in the solution-annealed and aged condition at a hardness level of 43 HRC maximum in the absence of elemental sulfur. (See Table C9.)

Table C9

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
III	UNS N07725, solution-annealed and aged	YS 1,030-1,100 MPa (149-160 ksi) UTS 1,350-1,390 MPa (196-202 ksi) Elong. 23-25% RA 33-46%	TM0177 Method A, tensile test at 100% of YS, coupled to steel, environment of Test Level III in Table B1, 25°C (77°F)	No failures in 720 h
VI	UNS N07725, solution-annealed and aged	YS 1,030-1,100 MPa (149-160 ksi) UTS 1,350-1,390 MPa (196-202 ksi) Elong. 23-25% RA 33-46%	TM0198 SSRT, environment of Test Level VI in Table B1, 175°C (347°F)	No failures, SSR[(A)] ratios 0.82-1.16, normal ductile behavior

[(A)] Slow Strain Rate.

For nondownhole applications, cast UNS N26625 (CW6MC) in accordance with ASTM A 494[43] in the cast, solution-heat-treated condition to 195 HBW maximum in the absence of elemental sulfur. (See Table C10.)

Table C10

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
II and III	UNS N26625 (CW6MC) castings, solution-heat-treated	YS 320 MPa (46 ksi) UTS 570-660 MPa (82-96 ksi) Elong. 31-63%	TM0177 solution, 180° u-bend loaded beyond yield, iron coupled and non-iron coupled	No failures in 720+ h
		YS 280-290 MPa (41-42 ksi) UTS 580-610 MPa (84-88 ksi) Elong. 59-64%	TM0177 tensile, loaded to yield, iron coupled and non-iron coupled	No failures in 720+ h

UNS S41426 tubing and casing, quenched and tempered to 27 HRC maximum and yield strength 730 MPa (105 ksi) maximum, and applied up to a maximum H_2S partial pressure of 10 kPa abs (1.5 psia) in production environments with a produced water pH ≥3.5. (See Table C11.)

Table C11

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
I	Wrought, quenched, and tempered UNS S41426	1. HRC 28.1 YS 741 MPa (108 ksi) 2. HRC 28.5 YS 738 MPa (107) ksi 3. HRC 29 YS 779 MPa (113 ksi)	TM0177, Method A 0.010 MPa abs (1.5 psia) H_2S + 0.0931 MPa abs (13.5 psia) CO_2 5% NaCl, pH 3.5, 25°C (77°F), at 80% of YS	No failures
I	Wrought, quenched, and tempered UNS S41426	1. HRC 28 YS 738 MPa (107 ksi) 2. HRC 29 YS 772 MPa (112 ksi) 3. HRC 29 YS 779 MPa (113 ksi)	TM0177 , Method A 0.0031 MPa abs (0.45 psia) H_2S +0.097 MPa abs (14 psia) CO_2 5% NaCl, 25°C (77°F), at 80% of YS	No failures
I	Wrought, quenched, and tempered UNS S41426	1. HRC 28 YS 738 MPa (107 ksi) 2. HRC 29 YS 772 MPa (112 ksi) 3. HRC 29 YS 779 MPa (113 ksi)	TM0177, Method C 0.010 MPa abs (1.5 psia) H_2S + 3.1 MPa abs (450 psia) CO_2 5% NaCl, 175°C (347°F), at 80% of YS for 738 MPa (107 ksi) and 772 MPa (112 ksi) at 90% of YS for 779 MPa (113 ksi)	No failures

Wrought UNS R20033 in the annealed or annealed and cold-worked condition to 35 HRC maximum in the absence of elemental sulfur. (See Table C12.)

Table C12

Test Level	Material Type and Condition	Material Properties	Test Method and Environment	Stress Level	Test Results
II	UNS R20033, cold-worked bar	Hardness 40 HRC	TM0177 Method A Solution A, RT	100% YS	No failure
III	UNS R20033, cold-worked bar	Hardness 40 HRC	TM0177 Method A Solution A, RT	100% YS	No failure
IV	UNS R20033, cold-worked bar	Hardness 35 HRC	TM0177 Method A MR0175, Table 1 Test Level IV, 90°C (194°F)	100% YS	No failure

UNS N07626, totally dense hot compacted by a powder metallurgy process, in the solution-annealed (927°C [1,700°F] minimum) plus aged (538 to 816°C [1,000 to 1,500°F]) condition or the direct-aged (538 to 816°C [1,000 to 1,500°F]) condition to a maximum hardness of 40 HRC and a maximum tensile strength of 1,380 MPa (200 ksi). (See Table C13.)

Table C13

Test Level	Material Type and Condition	Material Properties	Test Method, Environment	Test Results
III	UNS N07626, powder, hot compacted, direct aged	YS 1,020 MPa (148 ksi), 41 HRC	TM0177 C, C-ring tested at 100% YS, coupled to steel, environment of Test Level III in Table B1, 25°C (77°F)	No failures in 720 hours
25% NaCl + 15% H_2S + 15% CO_2 + 70% N	UNS N07626, powder, hot compacted, direct aged	YS 917 MPa (133 ksi), 40 HRC	C-ring tested at 90% YS, coupled to steel, 25°C (77°F)	No failures in 40 days
25% NaCl + 15% H_2S + 15% CO_2 + 70% N + 1 g/L S	UNS N07626, powder, hot compacted, direct aged	YS 917 MPa (133 ksi), 40 HRC	C-ring tested at 90% YS, 205°C (400°F)	No failures in 720 hours

Components manufactured from wrought, low-carbon martensitic stainless steel UNS S41427 bar in the austenitized, quenched, and double-tempered condition to 29 HRC maximum in the absence of elemental sulfur at ambient temperature provided they are heat treated in accordance with the following heat-treatment procedure. (See Table C14.)

Heat Treatment Procedure (Three-Step Process):

(1) Austenitize 900 to 980°C (1,652 to 1,796°F) and air cool or oil quench to ambient temperature.

(2) Temper at 600 to 700°C (1,112 to 1,292°F) and air cool to ambient temperature.

(3) Temper at 540 to 620°C (1,004 to 1,148°F) and air cool to ambient temperature.

Table C14

Test Level	Material Type and Condition	Material Properties	Test Method, Environment	Stress Level	Test Results(A)
I	Wrought, quenched, and double-tempered UNS S41427	(1) 30 HRC YS 751 MPa (109 ksi) (2) 29 HRC YS 682 MPa (98.9 ksi) (3) 30 HRC YS 765 MPa (111 ksi)	TM0177 Method A 1 wt% NaCl + CH_3COONa (0.04 g/L) + CH_3COOH (0.23 wt%) H_2S 10 kPa abs (1.45 psia or 0.1 bar abs), balance CO_2 pH 3.5 RT	90% of yield stress	NF
I	Wrought, quenched, and double-tempered UNS S41427	(1) 30 HRC YS 751 MPa (109 ksi) (2) 29 HRC YS 682 MPa (98.9 ksi) (3) 30 HRC YS 765 MPa (111 ksi)	TM0177 Method A 0.2% NaCl + CH_3COONa (6.8 g/L) + CH_3COOH H_2S 10 kPa abs (1.45 psia or 0.1 bar abs), balance CO_2 pH 3.5 RT	90% of yield stress	NF
I	Wrought, quenched, and double-tempered UNS S41427	(1) 30 HRC YS 751 MPa (109 ksi) (2) 29 HRC YS 682 MPa (98.9 ksi) (3) 30 HRC YS 765 MPa (111 ksi)	TM0177 Method A 15% NaCl + CH_3COONa (4.1 g/L) H_2S 7 kPa abs (1 psia or 0.07 bar abs), balance CO_2 pH 4.2 RT	85% and 90% of yield stress	NF
I	Wrought, quenched, and double-tempered UNS S41427	(1) 28 HRC YS 709 MPa (103 ksi) (2) 26.5 HRC YS 711 MPa (103 ksi)	TM0177 Method A 15% NaCl H_2S 3 kPa abs (0.44 psia or 0.03 bar abs) CO_2 700 kPa abs (100 psia or 7 bar abs) Temp. 90°C (194°F)	80% and 90% of SMYS	NF
I	Wrought, quenched, and double-tempered UNS S41427	(1) 28 HRC YS 709 MPa (103 ksi) (2) 26.5 HRC YS 711 MPa (103 ksi)	TM0177 Method A 5% NaCl H_2S 10 kPa abs (1.45 psia or 0.1 bar abs) CO_2 20,000 kPa abs (2,900 psia or 200 bar abs) Temp. 175°C (347°F)	80% and 90% of SMYS	NF

(A) NF = No failure after the 720-h test duration.

Wrought UNS N07716 to 43 HRC maximum in the solution-annealed and aged condition. (See Table C15.)

Table C15

Test Levels	Material Type and Condition	Material Properties	Test Method and Environment	Test Results
III	UNS N07716, solution-annealed and aged	YS 1,170 to 1,280 MPa (170 to 186 ksi) UTS 1,430 to 1,460 MPa (208 to 212 ksi) Elongation 14 to 24% RA 43 to 53%	TM0177 Method A, tensile test at 100% of YS, coupled to steel, environment of Test Level III in Table 1, 25°C (77°F)	No failures in 720 hours
IV	UNS N07716, solution-annealed and aged	YS 1,170 to 1,280 MPa (170 to 186 ksi) UTS 1,430 to 1,460 MPa (208 to 212 ksi) Elongation 14 to 24% RA 39 to 52	TM0198 SSR test, environment of Test Level VI in Table 1, 175°C (347°F)	No failures, SSR ratios 0.96 to 1.01

UNS J95370 in the cast, solution-heat-treated, and water-quenched condition to 94 HRB maximum in the absence of elemental sulfur. (See Table C16.)

Table C16

Test Level	**Material Type and Condition**	**Material Properties**	**Test Method, Environment**	Test Results
II	UNS J95370 cast super austenitic	Yield 420 to 499 MPa Hardness 94 HRB	Method A	No failure at 90% actual 0.2% proof stress
III	UNS J95370 cast super austenitic	As above	Method A	No failure at 90% actual 0.2% proof stress
V	UNS J95370 cast super austenitic	As above	Four-point bends according to EFC 17	No failure up to 90% actual 0.2% proof stress

Appendix D: Acceptable Materials

This appendix gives materials listings as an aid to material in the text. The text takes precedence over these tables.

TABLE D1
Acceptable Materials for Subsurface Equipment for Direct Exposure to Sour Environments (see Paragraph 1.4)

Use	Material
Drillable packer components	Ductile iron (ASTM A 536,[44] A 571/A 571M[45])
Drillable packer components	Malleable iron (ASTM A 220/A 220M,[46] A 602[47])
Compression members	Gray iron (ASTM A 48/A 48M,[48] A 278/A 278M)
All	9Cr-1Mo(A) ASTM A 276,[49] type 9 ASTM A 182/A 182M[50] grade F9 ASTM A 213/A 213M[51] grade T9

(A) 22 HRC maximum.

TABLE D2
Acceptable API and ASTM Specifications for Tubular Goods
Materials listed in this table are acceptable under environmental conditions noted.

	Operating Temperatures(B)		
For All Temperatures(A)	**For 66°C (150°F) or Greater**	**For 79°C (175°F) or Greater**	**For ≥107°C (≥225°F)**
Tubing and Casing API Spec 5CT/5CTM grades H-40,(C) J-55, K-55, M-65, C-75 (types 1, 2, 3), and L-80 (type 1) Proprietary(H) grades in accordance with Paragraph 10.1.3 UNS K12125 API 5CT/5CTM grades C-90 type 1 and T-95 type 1 **Pipe(D,E)** API Spec 5L grades A & B and grades X-42 through X-65 ASTM A 53/A 53M A 106 grades A, B, C A 333/A 333M grade 1 & 6 A 524[52] grade 1 & 2 A 381[53] Class 1 Y35-Y65 **Drill Stem Materials(F)** API Spec 5D[54] grades D, E, X-95, G-105, & S-135 (See Paragraph 12.3.1.1.)	**Tubing and Casing** API Spec 5CT/5CTM grade N-80 (quenched and tempered), grade C-95, T-95 type 2 Proprietary quenched and tempered grades with 760 MPa (110 ksi) or less maximum yield strength Casing and tubing made of CrMo low-alloy steels (AISI 41XX and its modifications) in the quenched and tempered condition at 30 HRC maximum hardness and in specified minimum yield strength (SMYS) grades of 690, 720, and 760 MPa (100, 105, and 110 ksi) (see Paragraph 10.1.3).	**Tubing and Casing** API Spec 5CT/5CTM grades H-40, N-80, P-105, P-110 Proprietary quenched and tempered grades to 965 MPa (140 ksi) maximum yield strength	 API Spec 5CT/5CTM grade Q-125(G)

(A) Impact resistance may be required by other standards and codes for low operating temperatures.
(B) Continuous minimum temperature; for lower temperatures, select from the first column.
(C) 50 MPa (80 ksi) maximum yield strength permissible.
(D) Welded grades shall meet the requirements of Sections 3 and 5 of this standard.
(E) Pipe shall have a maximum hardness of 22 HRC.
(F) For use under controlled environments as defined in Paragraph 12.2.
(G) Regardless of the requirements for the current edition of API Spec 5CT/5CTM, the Q-125 grade shall always: (1) have a maximum yield strength of 1,030 MPa (150 ksi), (2) be quenched and tempered; and (3) be an alloy based on Cr-Mo chemistry. The C-Mn alloy chemistry is not acceptable.
(H) See Paragraph 10.1 and Section 16.