Engineering Standard

SAES-A-301 30 March 2005

Materials Resistant to
Sulfide Stress Corrosion Cracking

Saudi Aramco DeskTop Standards

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1 Scope

1.1 This standard presents metallic material requirements for resistance to sulfide stress cracking (SSC) for petroleum production, drilling, gathering and flowline equipment, field processing facilities, and refining facilities (see Table 7) to be used in hydrogen sulfide (H_2S)-bearing hydrocarbon service (liquid, gas, and/or multiphase). 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 should be mitigated by corrosion inhibition or materials selection, which are outside the scope of this standard (See SAES-L-133). For example, some lower-strength steels used for pipelines and vessels may be subjected to failure by blister cracking or hydrogen-induced (stepwise) cracking as a result of hydrogen damage associated with general corrosion in the presence of H_2S. Also, austenitic stainless steels and even more highly alloyed materials may fail by a type of chloride stress corrosion cracking that is promoted by elevated temperature, aggravated in some cases by the presence of H_2S.

1.2 The requirements in this standard are established by Saudi Aramco and are based on the contents of NACE MR0175 "Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Service", 2002 edition. All statements, text, and information given by Saudi Aramco represents its opinion alone and do not necessarily represent the position of the National Association of Corrosion Engineers (NACE International).

1.3 This standard includes a variety of materials that might be used for any given component. The selection of a specific material for use shall be made on the basis of operating conditions that include but not limited to: pressure, temperature, system corrosiveness, fluid properties, and level of applied and residual stress.

Commentary Note:

Although this standard covers materials intended for sour service, it is not to be construed as implying that products conforming to these requirements will be resistant to SSC in sour environments under all conditions. Improper design, manufacturing, installation, or handling can cause resistant materials to become susceptible to SSC.

1.4 This entire Standard may be attached to and made a part of purchase orders.

2 Conflicts and Deviations

2.1 Any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs) or industry standards, codes and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department, Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this standard in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department, Saudi Aramco, Dhahran.

3 References

The selection of material and equipment, and the design, construction, maintenance, and repair of equipment and facilities covered by this standard shall comply with the latest edition of the references listed below, unless otherwise noted.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedure

SAEP-302	*Instructions for Obtaining a Waiver of a Mandatory Saudi Aramco Engineering Requirement*

Saudi Aramco Engineering Standard

SAES-L-133	*Corrosion Protection Requirements for Pipelines/Piping*

3.2 Industry Codes and Standards

SAE International

AMS 4779	*Nickel Alloy, Brazing Filler Metal 94Ni -3.5Si - 1.8B 1800 to 1950°F (982 to 1066°C) Solidus-Liquidus Range (UNS N99640)*

American Petroleum Institute

API RP 945	*Avoiding Environmental Cracking in Amine Units*
API RP 7G	*Drill Stem Design and Operating Limits*
API SPEC 5CT	*Casing and Tubing*
API SPEC 5CTM	*Casing and Tubing (Metric Units)*

API SPEC 6A	*Wellhead and Christmas Tree Equipment*
API SPEC 5L	*Line Pipe*

American Society of Mechanical Engineers

ASME SEC VIII D1	*Rules for Construction of Pressure Vessels*
ASME SEC IX	*Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators*

American Society for Testing and Materials

ASTM A53/A53M	*Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless*
ASTM A105/A105M	*Standard Specification for Carbon Steel Forgings for Piping Applications*
ASTM A106	*Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service*
ASTM A193/A193M	*Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*
ASTM A194/A194M	*Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service, or Both*
ASTM A203/A203M	*Standard Specification for Pressure Vessel Plates, Alloy Steel, Nickel*
ASTM A217	*Specification for Steel Castings, Martenisitic Stainless and Alloy for Pressure-Containing Parts Suitable for High Pressure Service*
ASTM A234/A234M	*Standard Specification for Piping Fittings of Wrought Carbon and Alloy Steel for Moderate and High Temperature Service*
ASTM A278/A278M	*Standard Specification for Gray Iron Castings for Pressure - Containing Parts for Temperatures up to 650°F*
ASTM A333/A333M	*Standard Specification for Seamless and Welded Steel Pipe for Low- Temperature Service*

ASTM A334/A334M	*Standard Specification for Seamless and Welded Carbon and Alloy- Steel Tubes for Low-Temperature Service*
ASTM A350/A350M	*Standard Specification for Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components*
ASTM A351/A351M - 94	*Specification for Castings, Austenitic, Austenitic-Ferritic (Duplex) for Pressure-Containing Parts*
ASTM A353/A353M	*Standard Specification for Pressure Vessel Plates, Alloy Steel, 9 Percent Nickel, Double-Normalized and Tempered*
ASTM A370	*Standard Test Methods and Definitions for Mechanical Testing of Steel Products*
ASTM A395/A395M	*Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures*
ASTM A420/A420M	*Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service*
ASTM A487	*Standard Specification for Steel Castings Suitable for Pressure Service*
ASTM A494	*Standard Specification for Castings, Nickel and Nickel Alloy*
ASTM A689	*Standard Specification for Carbon and Alloy Steel Bars for Springs*
ASTM A743/A743M	*Standard Specification for Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application*
ASTM A744/A744M	*Standard Specification for Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service*
ASTM A747/A747M	*Standard Specification for Steel Castings, Stainless, Precipitation Hardening*
ASTM B26/B26M	*Standard Specification for Aluminum-Alloy Sand Castings*

ASTM E10 — *Standard Test Method for Brinell Hardness of Metallic Materials*

ASTM E18 — *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials"*

ASTM E140 — *Standard Hardness Conversion Tables for Metals -Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, Knoop Hardness, and Scleroscope Hardness*

Military Specification

MIL-S-13165 — *Shot Peening of Metal Parts*

National Association of Corrosion Engineers

NACE TM0177 — *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments*

NACE RP0472 — *Methods and Controls to Prevent In-Service Environmental Cracking in Carbon Steel Weldments in Corrosive Petroleum Refining Environments*

NACE RP0475 — *Selection of Metallic Materials to Be Used in All Phases of Water Handling for Injection into Oil-Bearing Formations*

4 Applications

4.1 This standard applies to all components of equipment exposed to sour environments; where failure by SSC 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, and subsurface pumps are covered in greater detail in other international specifications and standards and are outside the scope of this standard.

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

1) metal chemical composition, strength, heat treatment, and microstructure;
2) hydrogen ion concentration (pH) of the environment;

3) H_2S concentration and total pressure;

4) total tensile stress (applied plus residual);

5) temperature; and

6) time.

4.3 This Standard shall apply for hydrocarbon (liquid, gas, and multiphase) systems containing water as a liquid and H_2S exceeding the limits defined in Paragraph 4.4 for upstream facilities and Paragraph 4.5 for refining facilities. It should be noted that highly susceptible materials may fail in less severe environments.

4.4 All gas, gas condensate, crude oil, and product lines and associated processing facilities 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) as noted in Figures 1 and 2.

4.5 All refinery service environments containing free water (liquid), to the following service conditions:

4.5.1 >50 ppmw dissolved H_2S in the free water or,

4.5.2 free water pH < 4 and some dissolved H_2S present, or

4.5.3 free water pH > 7.6 and 20 ppmw dissolved hydrogen cyanide (HCN) in the water and some dissolved H_2S, or

4.5.4 0.05 psia or greater partial pressure H_2S in the gas with a gas phase.

Commentary Note:

The high-pH sour environments differentiate refinery sour service from upstream oil and gas production environments.

4.6 This Standard need not apply when the following conditions exist:

4.6.1 Low-pressure gas: Exclusion of a low-pressure gas system for paragraph 4.4 is applicable only for carbon steel systems. Alloy steel used in low-pressure gas systems are not excluded from requirements of paragraph 4.4 and shall be evaluated based on the allowable partial pressure of H_2S listed in this document for the specific alloy.

4.6.2 Low-pressure oil and gas multiphase systems: When the total pressure is less than 1.8 MPa abs (265 psia), the maximum gas:oil ratio (SCF:bbl) is 5,000 or less, and the H_2S content is less than 15 mol% and the H_2S partial pressure is less than 0.07 MPa abs (10 psia) as shown in Figure 2.

4.7 This Standard need not apply (user shall determine) for the following:

4.7.1 Salt-water wells and salt-water handling facilities. These are covered by NACE Standard RP0475.

Commentary Note:

NACE RP0475 "Selection of Metallic Materials to Be Used in All Phases of Water Handling for Injection into Oil-Bearing Formations" addresses materials for water with hydrogen sulfide (H_2S), some materials named in RP0475 may not agree in metallurigical condition or hardness in SAES A-301. These differences reflect the differences in the effects of the environments covered by the two documents.

4.7.2 Weight-loss corrosion and corrosion fatigue.

4.7.3 Other hydrogen-induced or environmental cracking mechanisms other than SSC.

4.8 Control of SSC

SSC may be controlled by any or all of the following measures:

a) using the materials and processes described in this standard;

b) controlling the environment; or

c) isolating the components from the environment.

Commentary Note:

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

4.9 Materials included in this standard are resistant to, but not necessarily immune to, SSC under all service conditions. The acceptable materials and manufacturing processes listed in this standard should give satisfactory resistance to SSC in sour environments when the materials are (1) manufactured to the heat treatment and mechanical properties specified, (2) alloy composition within specification limits, and (3) used under the conditions specified.

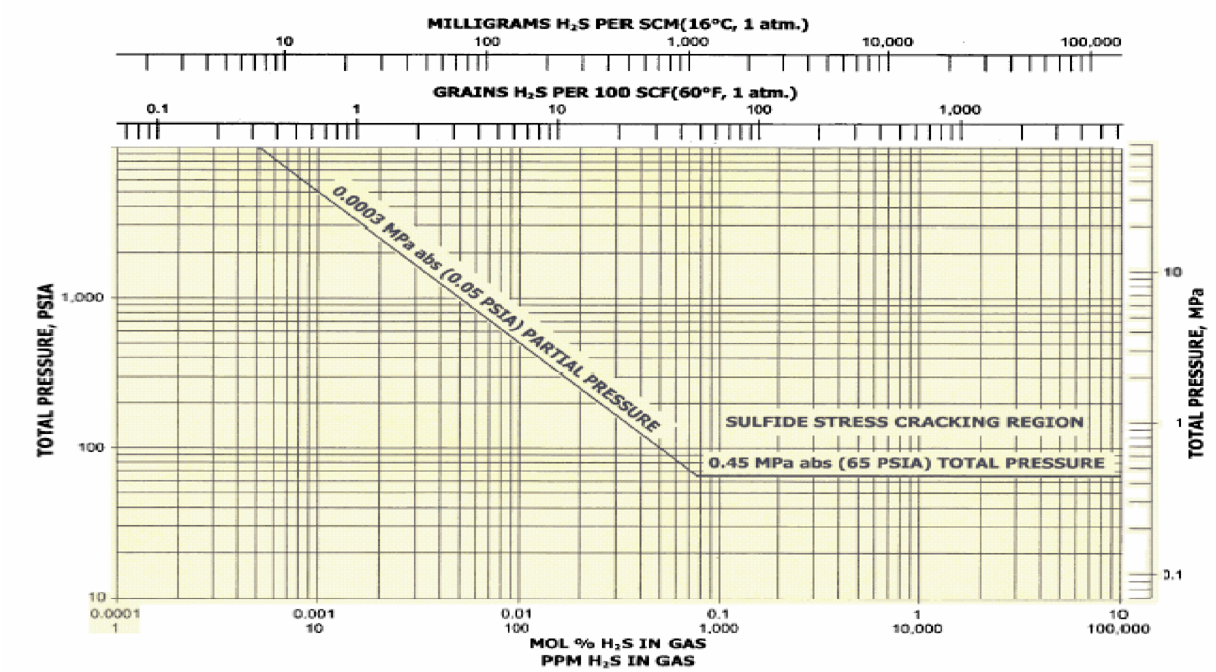

Figure 1: Sour Gas Systems

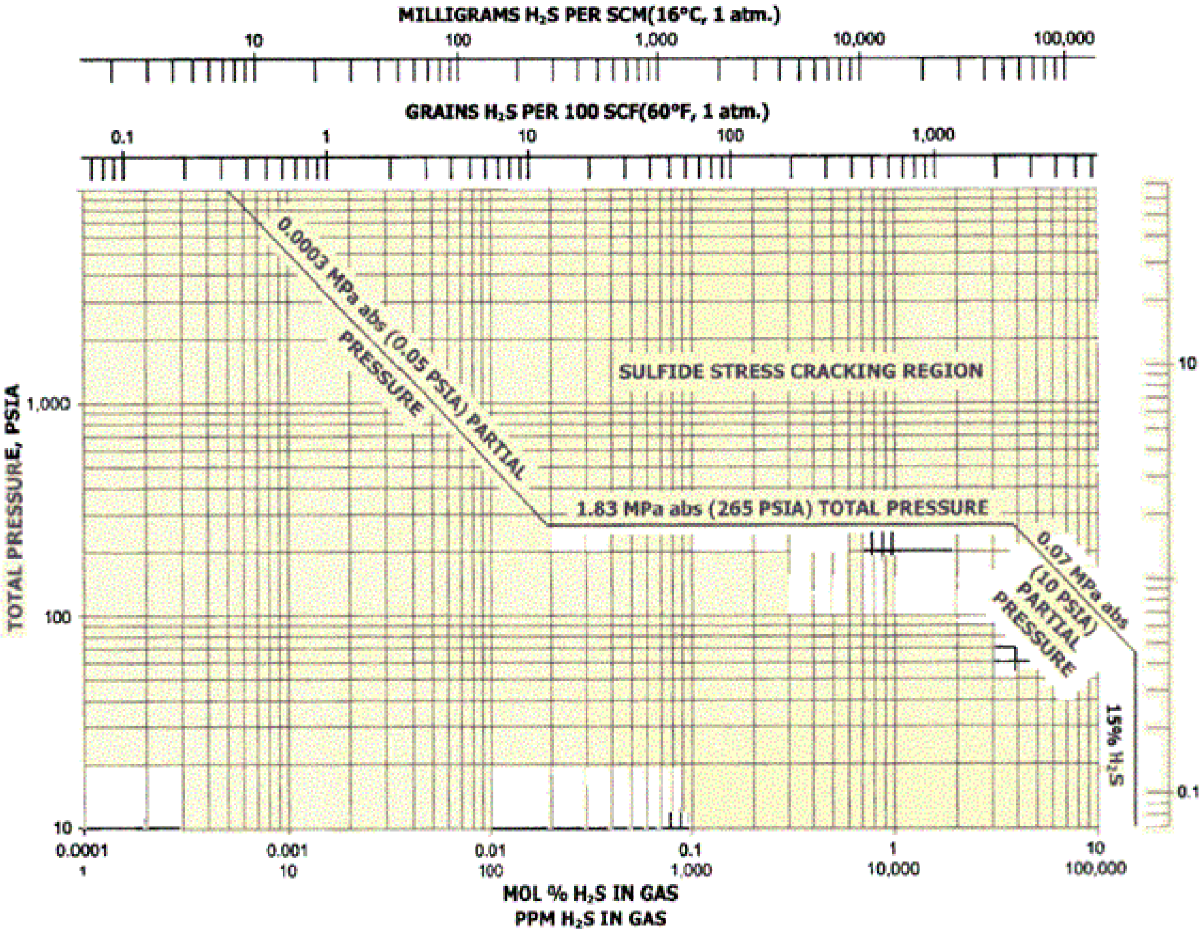

Figure 2: Sour Multiphase Systems

Metric Conversion Factor: 1 Mpa abs = 145.089 psi

5 Ferrous Metals

5.1 General

Ferrous metals shall meet the requirements of this section if they are to be exposed to sour environments. The presence of environmental limitations (e.g., H_2S partial pressure, sulfur content, chloride content, and temperature) and/or mechanical strength limitations for some corrosion-resistant alloy (CRA) materials does not mean that those materials do not resist stress corrosion cracking as well as those materials in the same class that do not have such limitations.

The susceptibility to SSC of most ferrous 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.

5.2 Carbon and Alloy Steels

5.2.1 All carbon and alloy steels are acceptable at 22 HRC maximum hardness provided they (1) contain less than 1% nickel, (2) meet the criteria of Paragraphs 5.2.2, 7.3, and Section 8, and (3) are used in one of the following heat-treat 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.

Forgings produced in accordance with the requirements of ASTM A105/A105M are acceptable, provided the hardness does not exceed 187 HB maximum.

5.2.2 Alloy steels included under the ASME Boiler and Pressure Vessel Code Section IX P-numbers are listed in Table 6 are acceptable at the indicated maximum hardness levels.

5.2.3 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 SEC VIII D1, except that the minimum stress-relief temperature shall be 595°C (1,100°F). The component shall have a hardness not to exceed HRC 22.

This requirement does not apply to pipe grades listed in Table 4 or cold work imparted by pressure testing according to the applicable code. Cold-rotary straightened pipe is acceptable only where permitted in API specifications. Cold-worked line pipe fittings of ASTM A53 Grade B, ASTM A106 Grade B, API SPEC 5L Grade X-42 or lower-strength grades with similar chemical compositions are acceptable with cold strain equivalent to 15% or less, provided the hardness in the strained area does not exceed 190 HB.

5.3 Free-Machining Steels

Free-machining steels shall not be used.

5.4 Cast Iron

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

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

5.5 Austenitic Stainless Steels

***Note**: These materials may be subject to chloride stress corrosion cracking in certain environments.*

5.5.1 Austenitic stainless steels with chemical compositions as specified in accordance with the standards listed in Table 2, either cast or wrought are acceptable at a hardness of 22 HRC maximum in the annealed condition, provided they are free of cold work designed to enhance their mechanical properties. 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., Si 2.0% max. Other alloying elements are permitted. Free-machining austenitic stainless steel products (containing alloying elements such as lead, selenium, or sulfur to improve machinability) are not acceptable.

Commentary Note:

The chemical composition of the cast "austenitic" stainless steels often vary from those of their fully austenitic wrought counterparts in order to optimize castings characteristics.

5.5.2 Austenitic stainless steel UNS S20910 is acceptable at 35 HRC maximum hardness in the annealed or hot-rolled (hot/cold-worked) condition, provided it is free of subsequent cold work designed to enhance its mechanical properties.

5.5.3 Austenitic stainless steel alloy UNS N08020 is acceptable in the annealed or cold-worked condition at a hardness level of 32 HRC maximum.

5.5.4 Cast CN7M meeting ASTM A351, A743, or A744 is acceptable for non-downhole applications in the following conditions:

***Note**: There are no industry standards that address these melting and casting requirements.*

1) solution-annealed at 1,121°C (2,050°F) minimum or solution-annealed at 1,121°C (2,050°F) minimum and welded with AWS E320LR or ER320LR;

2) the castings must be produced from argon-oxygen decarburization (AOD) refined heats or re-melted AOD refined heats. The use of scraps, such as turnings, chips and returned materials is prohibited unless melting is followed by AOD refining;

3) the CN7M composition listed in ASTM A351, A743, or A744 shall be further restricted to 0.03% maximum carbon, 1.00% maximum silicon, 3.0 to 3.5% copper, 0.015% maximum sulfur, 0.030% maximum phosphorus and 0.05% maximum aluminum; and

4) at a hardness level of 22 HRC maximum.

5.5.5 Wrought austenitic stainless steel UNS S31254 is acceptable in the annealed or cold-worked condition at a hardness level of 35 HRC maximum.

5.5.6 Solution-annealed and cold-worked austenitic stainless steel UNS N08367 is acceptable at a maximum hardness of 35 HRC for use in sour environments at any temperature up to 150°C (302°F) only if: no free elemental sulfur is present, the salinity is less than 5,000 mg/L, and the H_2S partial pressure does not exceed 310 kPa (45 psi).

5.5.7 Wrought UNS S32200 is acceptable in the annealed or annealed plus cold-worked condition at a hardness level of 34 HRC maximum when the service environment is less than 170°C (338°F), contains less than 100 kPa (14.6 psi or 1 bar) H_2S, and does not contain elemental sulfur.

5.5.8 Wrought stainless steel UNS N08926 is acceptable in the annealed or cold-worked condition at a hardness level of 35 HRC maximum for use in Environment V according to Table 1. Alloy UNS N08926 has been shown resistant at temperatures up to 121°C (250°F) in sour environments containing 60,700 mg/chloride (10% NaCl), 0.7 MPa (101.5 psi) H_2S, 1.4 MPa (203 psi) CO_2.

5.5.9 Cast UNS J93254 (CK3MCuN) in accordance with ASTM A351, A743, or A744 is acceptable in the cast, solution heat-treated condition at a hardness level of 100 HRB maximum in the absence of elemental sulfur in service conditions per test levels II and III shown in Table 1.

5.5.10 UNS N08367 is acceptable in the wrought, solution heat-treated or solution heat-treated and cold-worked condition to 35 HRC maximum in the absence of elemental sulfur in service conditions per test level V shown in Table 1.

5.5.11 Wrought UNS S32654 is acceptable 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 to service conditions per test level III shown in Table 1.

5.5.12 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 is acceptable to 38 HRC maximum hardness for use up to Environment V according to Table 1.

5.5.13 Wrought UNS S34565 is acceptable in the solution-annealed condition to 29 HRC maximum in the absence of elemental sulfur to service conditions per test level IV shown in Table 1.

5.6 Ferritic Stainless Steels

Ferritic stainless steels are acceptable at a 22 HRC maximum hardness, provided they are in the annealed condition and meet the criteria of Section 7. Acceptable ferritic stainless steels are listed in Table 2.

5.7 Martensitic Stainless Steels

Commentary Note:

> *Valve manufacturers generally do not use these materials for valve stems or other highly stressed components in sour service.*

5.7.1 Martensitic stainless steels, as listed in Table 2, either cast or wrought, are acceptable at 22 HRC maximum hardness provided they are heat-treated in accordance with Paragraph 5.7.1.1 and meet the criteria of Section 7. 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 TM0177 test solution that are lower than those for other materials included in this standard.

5.7.1.1 Heat-Treatment Process Procedure (Three-Step Process)

1) Normalize or austenitize and quench.
2) Temper at 620°C (1,150°F) minimum; then cool to ambient temperature.
3) Temper at 620°C (1,150°F) minimum, but lower than the first tempering temperature; then cool to ambient temperature.

5.7.1.2 Subsequent to cold deformation (see Paragraph 5.2.2) the material shall be furnace stress relieved at 620°C (1,150°F) minimum to 22 HRC maximum hardness.

5.7.2 Low-Carbon Martensitic Stainless Steels

5.7.2.1 Cast and wrought low-carbon martensitic stainless steels meeting the chemistry requirements of ASTM A487 Grade CA6NM and UNS S42400 are acceptable to 23 HRC maximum provided they are heat treated in accordance with the following:

Heat-Treat Procedure (Three-Step Process)

1) Austenitize at 1,010°C (1,850°F) minimum and air or oil quench to ambient temperature.
2) Temper at 648° to 690°C (1,200° to 1,275°F) and air cool to ambient temperature.
3) Temper at 593° to 620°C (1,100° to 1,150°F) and air cool to ambient temperature.

5.7.2.2 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 with an H_2S content limited to 0.010 MPa (1.5 psia), CO_2 20 MPa (450 psia), NaCl 5%, temperature 175ºC (348ºF)

***Note**: The hardness correlation tabulated in ASTM E140 does not apply to CA6NM or UNS S42400. When hardness is measured in Brinell units, the permissible BHN limit is 255 maximum, which has been empirically determined to be equivalent to 23 HRC for these alloys.*

5.8 Precipitation-Hardening Stainless Steels

5.8.1 Wrought UNS S17400 martensitic precipitation-hardening stainless steel is acceptable at 33 HRC maximum hardness provided it has been heat treated in accordance with Paragraph 5.8.1.1 or Paragraph 5.8.1.2. Precipitation-hardening 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 TM0177 test solution that are lower than those of other materials included in this standard.

5.8.1.1 Double-Age at 620°C (1,150°F)

1) Solution anneal at 1,040°C ±14°C (1,900°F ±25°F) and air cool, or suitable liquid quench, to below 32°C (90°F).
2) Harden at 620°C ±14°C (1,150°F ±25°F) for 4 hours minimum at temperature and cool in air.
3) Cool material to below 32°C (90°F) before the second precipitation-hardening step.
4) Harden at 620°C ±14°C (1,150°F ±25°F) for 4 hours minimum at temperature and cool in air.

5.8.1.2 Heat-Treat Procedure (Three-step Process)

1) Solution anneal at 1,040°C ±14°C (1,900°F ±25°F) and air cool, or suitable liquid quench, to below 32°C (90°F).
2) Harden at 760°C ±14°C (1,400°F ±25°F) for 2 hours minimum at temperature and cool in air to below 32°C (90°F) before second precipitation-hardening step.
3) Precipitation-harden at 620°C ±14°C (1,150°F ±25°F) for 4 hours minimum at temperature and cool in air.

5.8.2 Austenitic precipitation-hardening stainless steel with chemical composition in accordance with UNS S66286 is acceptable at 35 HRC maximum hardness provided it is in either the solution-annealed and aged or solution annealed and double-aged condition.

5.8.3 Wrought UNS S45000 martensitic precipitation-hardening stainless steel is acceptable at 31 HRC maximum hardness provided it has been heat treated in accordance with the following:

Heat-Treat Procedure (Two-Step Process)

1) Solution anneal.

2) Precipitation-harden at 620°C (1, 150°F) minimum for 4 hours.

5.9 Duplex Stainless Steels

5.9.1 The wrought duplex (austenitic/ferritic) stainless steels listed in Table 2 are acceptable at a maximum hardness limit of 28 HRC in the solution-annealed condition.

5.9.2 Cast duplex (austenitic/ferritic) stainless steel Z 6 CNDU 28.08 M, NF A 320-55 French National Standard is acceptable at hardness levels of 17 HRC maximum in the annealed and quenched condition provided the ferrite content is 25 to 40%. The annealing shall be at a temperature of 1,150 ±10°C (2,100 ±20°F) and shall be followed by a rapid quench to avoid the precipitation of sigma phase.

5.9.3 Wrought duplex stainless steel UNS S32404 (0.1% to 0.2% nitrogen) is acceptable at 20 HRC maximum in the solution-annealed condition.

5.9.4 Solution-annealed and cold-worked UNS S31803 is acceptable for use at any temperature up to 232°C (450°F) in sour environments if the partial pressure of H_2S does not exceed 0.002 MPa abs (0.3 psia), the yield strength is not greater than 1,000 MPa (160 ksi), and its hardness is not greater than 36 HRC.

5.9.5 Wrought duplex stainless steel UNS S32750 is acceptable at 32 HRC maximum in the solution-annealed condition in sour environments up to 232°C (450°F) if the partial pressure of H_2S does not exceed 0.01 MPa abs (1.5 psia).

5.9.6 Wrought duplex stainless steel UNS S32760 is acceptable in the solution-annealed and cold-worked condition at a maximum hardness of 34 HRC for use in sour environments containing up to 120,000 mg/L chloride ion if the partial pressure of H_2S does not exceed 0.020 MPa abs (3.0 psia). If the chloride ion concentration is always less than 15,000 mg/L and the pH of the aqueous phase is always greater than 5.6, then the material condition is acceptable if the partial pressure of H_2S does not exceed 0.10 MPa (15 psia).

5.9.7 Cast duplex stainless steel UNS J93380 is acceptable in the solution-annealed and quenched condition at a maximum hardness of 24 HRC for use in sour environments containing up to 120,000 mg/L chloride ion if the partial pressure of the H_2S does not exceed 0.020 MPa

(3.0 psia). If the chloride ion concentration is always less than 15,000 mg/L and the pH of the aqueous phase is always greater than 5.6, then this material is acceptable if the partial pressure of H_2S does not exceed 0.10 MPa (15 psia).

5.9.8 Wrought UNS S31260 is acceptable in the solution-annealed and cold-worked condition for use to 232°C (450°F) in sour service if the partial pressure of H_2S does not exceed 7 kPa (1.0 psia), if the service environment does not contain elemental sulfur, if the yield strength of the material is 1,100 MPa (160 ksi) maximum, and if the hardness is 36 HRC maximum.

5.9.9 Wrought UNS S39274 is acceptable in the solution-annealed and cold-worked condition for use in to 232°C (450°F) in sour service if the partial pressure of H_2S does not exceed 10 KPA (1.5 psia), if the service environment does not contain elemental sulfur, if the yield strength of the material is 1,100 MPA (160 ksi) maximum, and if the hardness is 36 HRC maximum.

5.9.10 Cast duplex stainless steel UNS J93404 is acceptable in the annealed and quenched condition to 265 HB maximum to an H_2S partial pressure of 10 kPa (1.5 psi) maximum at 110°C (230°F)

5.9.11 Wrought duplex stainless steel UNS S39277 is acceptable in the solution-annealed condition to 28 HRC maximum for use in sour environments having no elemental sulfur and containing 91,000 mg/L maximum chloride ion if the partial pressure of H_2S does not exceed 0.020 MPA (3 psia) maximum. If the pH of the aqueous phase in always greater than 4.5, then this material is acceptable for use in sour environments containing 91,000 mg/L maximum chloride ion if the partial pressure of H_2S does not exceed 0.070 MPa (10 psia) maximum.

Commentary Note:

In acidic pH environments (less than pH 5.5), duplex stainless steels have experienced very high general weight loss corrosion rates. Caution needs to be exercised to consider ALL in-service environments this material may be exposed to including upset conditions.

6 Nonferrous Metals

Notes:

a) These materials may be subject to SSC failure when highly stressed and exposed to sour environments or some well-stimulation fluids;

b) *Some of the materials may be susceptible to failure by hydrogen embrittlement when strengthen by cold work and stressed in the transverse direction;*

c) *Plastic deformation in service may increase the SSC susceptibility of these alloys.*

6.1 General

Nonferrous metals referenced in this section and meeting the stated requirements for both condition and hardness are acceptable for use in sour environments. The presence of environmental (H_2S partial pressure, sulfur content, chloride content, and temperature) and/or mechanical strength limitations for some corrosion-resistant alloy (CRA) materials does not mean that those materials do not resist stress corrosion cracking as well as those materials in the same class that do not have such limitations. See also Table 3.

6.1.1 Nickel-Copper Alloys

6.1.1.1 UNS N04400, ASTM A494 Grades M-35-1 and M-35-2, and UNS N04405 are acceptable to 35 HRC maximum.

6.1.1.2 UNS N05500 is acceptable 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.

6.1.2 Nickel-lron-Chromium Alloys

UNS N08800 is acceptable to 35 HRC maximum.

6.1.3 Nickel-lron-Chromium-Molybdenum Alloys

6.1.3.1 UNS N08825, UNS N06007, wrought UNS N06250, wrought UNS N06255, and wrought UNS N06975 are acceptable to 35 HRC maximum; UNS N06950 is acceptable to 38 HRC maximum; and UNS N06985 is acceptable to 39 HRC maximum.

6.1.3.2 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;

5) hot-finished and aged to 40 HRC maximum.

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

6.1.3.3 UNS N08024 is acceptable to 32 HRC maximum.

6.1.3.4 UNS N08028 is acceptable in the solution-annealed and cold-worked condition to 33 HRC maximum.

6.1.3.5 Nickel-iron-chromium-molybdenum-tungsten alloy UNS N06030 is acceptable in the solution-annealed or solution-annealed plus cold-worked condition to a maximum hardness of 41 HRC.

6.1.3.6 UNS N07048 is acceptable in the solution-annealed, solution-annealed and aged, or direct-aged condition to 40 HRC maximum.

6.1.3.7 Wrought UNS N07773 is acceptable in the solution-annealed and aged condition to 40 HRC maximum when the service environment does not contain elemental sulfur, and approved up to 149°C (300°F) in the presence of elemental sulfur.

6.1.3.8 Wrought UNS N09777 is acceptable in the solution-annealed and aged condition to 40 HRC maximum when the service environment does not contain elemental sulfur, and approved up to 121°C (250°F) in the presence of elemental sulfur.

6.1.3.9 UNS N08535 is acceptable in the solution-annealed and cold-worked condition to 35 HRC maximum.

6.1.3.10 Wrought UNS N08042 is acceptable in the solution-annealed or solution-annealed plus cold-worked condition to 31 HRC maximum when the service environment does not contain elemental sulfur.

6.1.3.11 UNS N06952 is acceptable in the solution-annealed or solution-annealed plus cold-worked condition to 35 HRC maximum when the service environment does not contain elemental sulfur.

6.1.3.12 Cast UNS N08826 is acceptable to 87 HRB maximum when solution-annealed and followed by a thermal stabilization anneal for use in sour environments without elemental sulfur. Cast UNS N08826 is acceptable to 87 HRB for use in sour environments with elemental sulfur up to 121°C (250°F).

6.1.3.13 Wrought UNS N08032 is acceptable in the solution-annealed or solution-annealed plus cold-worked condition to 27 HRC maximum when the service environment is less than 150°C (302°F) and does not contain elemental sulfur.

6.1.3.14 Wrought UNS N08031 is acceptable in the cold-worked condition to 35 HRC maximum and 3.45 MPa (500 psi) H_2S partial pressure maximum in the absence of elemental sulfur.

6.1.3.15 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).

6.1.3.16 Wrought UNS R20033 is acceptable in the annealed or annealed and cold-worked condition to 35 HRC maximum in the absence of elemental sulfur.

6.1.4 Nickel-Chromium Alloys

6.1.4.1 UNS N06600 is acceptable to 35 HRC maximum.

6.1.4.2 UNS N07750 is acceptable to 35 HRC maximum in each of the four following conditions:

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

6.1.5 Nickel-Chromium-Molybdenum Alloys

6.1.5.1 UNS N06002 and UNS N06625 are acceptable to 35 HRC maximum.

6.1.5.2 UNS N10002, UNS N10276, ASTM A 494 Grade CW-12 MW, and UNS N06059 are acceptable in the solution-annealed or solution-annealed plus cold-worked condition to 35 HRC maximum.

6.1.5.2.1 Wrought alloys UNS N06022 and UNS N06686 are acceptable in the solution-annealed or solution-annealed plus cold-worked-condition to 40 HRC maximum.

6.1.5.2.2 Alloy UNS N10276 is also acceptable in the cold-worked and unaged condition at 45 HRC maximum when used at a minimum temperature of 121°C (250°F).

6.1.5.3 Wrought UNS N07718 is acceptable in each of the five 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;
4) solution-annealed and aged to 40 HRC maximum;
5) cast, solution-annealed, and aged condition to 40 HRC maximum.

6.1.5.4 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 870°C (1,400° to 1,600°F) for a maximum of 4 hours to 40 HRC maximum.

6.1.5.5 UNS N06110 and wrought UNS N06060 are acceptable in the annealed or cold-worked condition to 40 HRC maximum.

6.1.5.6 UNS N07716 and wrought UNS N07725 are acceptable to 40 HRC maximum in the solution-annealed and aged condition.

Wrought UNS N07725 is acceptable in the solution-annealed and aged condition at a hardness level of 43 HRC maximum in the absence of elemental sulfur.

6.1.5.7 UNS N07626, totally dense hot compacted by a powder metallurgy process, is acceptable in the solution-annealed (925°C [1,700°F] minimum) plus aged condition (525° to 825°C [1,000° to 1,500°F]) or the direct-aged (525° to 825°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).

6.1.5.8 Cast CW2M meeting ASTM A494 is acceptable for non-downhole applications in the following conditions (there are no industry standards that currently address these melting and casting requirements):

1) solution-annealed at 1,232°C ±14°C (2,250°F ±25°F) or solution-annealed at 1,232°C ±14°C (2,250°F ±25°F) and welded with AWS ENiCrMo-7, ERNiCrMo-7, ENiCrMo-10, or ERNiCrMo-10;

2) the castings must be produced by argon-oxygen decarburization (AOD) refined heats, AOD refined heats, or virgin remelt stock. The use of scrap, such as turnings, chips, and returned material is prohibited unless followed by AOD refining;

3) the CW2M composition listed in ASTM A 494 shall be further restricted to 0.015% maximum sulfur and 0.05% maximum aluminum; and

4) at a hardness level of 22 HRC maximum.

6.1.5.9 UNS N08135 is acceptable in the solution-and cold-worked condition to of 33 HRC when the service environment does not contain elemental sulfur or to 137°C (250°F) maximum in the presence of elemental sulfur.

6.1.5.10 For non-downhole applications, cast UNS N26625 (CW6MC) in accordance with ASTM A494 is acceptable in the cast, solution-heat-treated condition to 195 HB maximum in the absence of elemental sulfur.

6.1.6 Cobalt-Nickel-Chromium-Molybdenum Alloys

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

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

6.1.6.3 Wrought UNS R31233 is acceptable in the solution-annealed condition to 33 HRC maximum.

6.1.7 Cobalt-Nickel-Chromium-Tungsten Alloy

UNS R30605 is acceptable to 35 HRC maximum.

6.2 Other Alloys

6.2.1 Materials described in this section and listed in Table 3 are acceptable.

6.2.1.1 Aluminum-based alloys.

6.2.1.2 Copper alloys. Copper alloys may undergo accelerated mass-loss corrosion in sour oilfield and refinery environments, particularly if oxygen is present.

6.2.1.3 Commercially pure tantalum. UNS R05200 is acceptable in the annealed and gas tungsten arc-welded annealed conditions to 55 HRB maximum.

6.2.1.4 Titanium alloys. 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 galvanically coupled to certain active metals (i.e., carbon steel) in H_2S-containing aqueous media at temperatures greater than 80°C (176°F). Some titanium alloys may be susceptible to crevice corrosion and/or SSC in chloride environments. Hardness has not been shown to correlate with susceptibility to SSC. However, hardness has been included for alloys with high strength to indicate the maximum testing levels at which failure has not occurred.

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

6.2.1.4.2 UNS A58640 is acceptable to 42 HRC maximum.

6.2.1.4.3 UNS R50400 is acceptable to 100 HRB maximum.

6.2.1.4.4 UNS A56260 is acceptable to 45 HRC maximum in each of the three following conditions:

1) annealed;

2) solution-annealed;

3) solution-annealed and aged.

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

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

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

7 Fabrication

7.1 General

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

7.2 Overlays – Carbon and Alloy Steels

7.2.1 Overlays applied to carbon and alloy steel steels by thermal processes such as welding, silver brazing, or spray metallizing systems are satisfactory 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 temperatures are 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 a hardness not to exceed 22 HRC maximum.

7.2.2 Tungsten-carbide alloys and ceramics are satisfactory for sour service, subject to the conditions of paragraph 7.2.1.

7.2.3 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 7.2.1.

7.2.4 The materials listed in Sections 5 and 6 are acceptable as weld overlays, provided they meet the provisions of Paragraph 7.2.1.

7.2.5 Overlays of cobalt-chromium-tungsten alloys, nickel-chromium-boron, and nickel-boron (as specified in SAMS 4779) hardfacing alloys are acceptable, subject to the conditions of Paragraph 7.2.1.

Commentary Note:

Hard-facing and wear-resistant materials do not have to match the hardness of the substrate material.

7.3 Welding

7.3.1 Welding procedures shall be used to produce weldments that comply with the hardness requirements specified for the base metal in Sections 5 and 6. Welding procedures shall be qualified in accordance with the applicable Saudi Aramco Welding Standards and Specifications, AWS, API, ASME, or other appropriate industry code. Welders using this procedure shall be familiar with the procedure and shall be capable of making welds that comply with the procedure.

7.3.1.1 Tubular products listed in Table 4 with specified minimum yield strength of 360 MPa (52 ksi) or less and pressure vessel steels classified as P-No 1, Group 1 or 2, in Section IX of the ASME Code and listed in Table 4 meet the requirements of Paragraph 7.3.1 in the as-welded condition. Welding procedure qualifications, in accordance with AWS, API, ASME, or other appropriate specifications, shall be performed on any welding procedure that is used.

7.3.1.2 Welding procedure qualifications on carbon steels that use controls other than thermal stress relieving to control the hardness of the weldment shall also include a hardness traverse across the weld, HAZ, and base metal to ensure that the procedure is capable of producing a hardness of 22 HRC (BHN 237) maximum in the condition in which it is used.

7.3.1.3 Weld procedure qualifications on carbon steels used for fabrication and repair of refinery equipment and that use controls other than thermal stress relieving to control the hardness of the weldment shall also include a hardness traverse across the weld, HAZ, and base metal to ensure that the procedure is capable of producing a hardness of HRB 94 (BHN 200) maximum in the condition in which it is used.

7.3.1.4 Alloy steel and martensitic stainless steel weldments shall be stress relieved at a minimum temperature of 620°C (1,150°F) to produce a hardness of 22 HRC maximum.

7.3.1.5 Dissimilar metal welds (DMW) are not permitted in sour service including seal welding of threaded joints of dissimilar metal connections.

7.3.2 Welding rods, electrodes, fluxes, filler metals, and carbon and alloy steel welding consumables with more than 1 % nickel shall not be used for welding carbon and alloy steels as indicated in Paragraph 5.2.1.

7.4 Identification Stamping

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

7.4.2 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 subsequently stress relieved at 595°C (1,100°F) minimum.

7.5 Threading

7.5.1 Machine-Cut Threads

Machine-cut threading processes are acceptable.

7.5.2 Cold-Formed (Rolled) Threads

Subsequent to cold forming threads, the threaded component shall meet the heat-treat conditions and hardness requirements given in either Section 5 or 6 for the parent alloy from which the threaded component was fabricated.

7.6 Cold-Deformation Processes

7.6.1 Cold-deformation processes such as burnishing that do not impart cold work exceeding that incidental normal machining operations, such as turning or boring, rolling, threading, drilling, etc., are acceptable.

7.6.2 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 Military Specification MIL-S-13165.

8 Bolting

8.1 General

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

8.2 Exposed Bolting

8.2.1 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 8.2.1.1, 8.2.1.2 or 8.2.1.3. Designers and users should be aware that it may be necessary to derate the pressure rating in some cases when using low-strength bolts. For API 6A flanges using exposed bolting, see API SPEC 6A.

8.2.1.1 Acceptable nuts and bolting materials shall meet the requirements of Section 5 or Section 6.

8.2.1.2 Bolting materials that meet the specifications of ASTM A193 Grade B7M, 550 MPa (80,000 psi) minimum yield strength, and 22 HRC maximum are acceptable.

8.2.1.3 Nuts shall meet the specifications of ASTM A194 Grade 2HM (22 HRC maximum) or Paragraph 8.2.1.1.

8.2.2 Zinc or cadmium coatings shall not be used on bolts, nuts, cap screws, or other fasteners in sour environments.

8.2.3 The following restrictions apply to UNS S17400 when used for pressure-retaining bolting:

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

b) When UNS S17400 is used for pressure-retaining bolting in the single-H1150M condition, a maximum hardness limit of 26 HRC shall apply.

8.3 Non-exposed Bolting

8.3.1 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 A193 Grade B7.

8.3.2 To be considered "non-exposed", the bolting must be used externally on flanges or other parts that are not directly exposed to sour environments, and must be exposed to the atmosphere at all times.

9 Platings and Coatings

9.1 General

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

9.1.2 Metallic coatings (electroplated or electroless), conversion coatings, and plastic coatings or linings are not acceptable for preventing SSC of base metals. The use of such coatings for other purposes is outside the scope of this standard.

9.2 Nitriding

Nitriding with a maximum case depth of 0.15 mm (0.006 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 is not acceptable.

10 Special Components

10.1 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 4.1 provides guidelines to determine the applicability of the standard to specific uses.

10.2 Bearings

10.2.1 Bearings directly exposed to sour environments shall be made from materials in Sections 5 and 6.

10.2.2 Bearings made from other materials must be isolated from the sour environment in order to function properly, except as noted in Paragraph 10.3.

10.3 Bearing Pins

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.

10.4 Springs

10.4.1 Springs directly exposed to the sour environment shall be made from materials described in Sections 5 and 6.

10.4.2 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 of 55 HRC maximum when aged for a minimum of 4 hours at a temperature no lower than 548°C (1,200°F).

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

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

10.5 Instrumentation and Control Devices

10.5.1 Instrumentation and control device components directly exposed to sour environments shall be made from materials in Sections 5 through 10.

Paragraph 5.5.1 is not intended to preclude the use of AISI Type 316 stainless steel compression fittings and instrument tubing even though they will not satisfy the requirements stated in Paragraph 5.5.1.

10.5.2 Diaphragms, Pressure-Measuring Devices, and Pressure Seals

10.5.2.1 Diaphragms, pressure-measuring devices, and pressure seals directly exposed to a sour environment shall be made from materials in Sections 5 and 6.

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

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

10.5.2.4 Pressure seals shall comply with the requirements of Sections 5 and 6 and Tables 2 and 3 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 products.

10.5.3 Wrought UNS N08904 is acceptable for use as instrument tubing in the annealed condition of 180 HB 10 maximum.

10.6 Seal Rings

10.6.1 Seal rings directly exposed to a sour environment shall be made from materials in Sections 5 and 6.

10.6.2 Austenitic stainless steel API compression seal rings made of centrifugally cast ASTM A351 Grade CF8 or CF8M chemical compositions are acceptable in the as-cast or solution-annealed condition to 160 HB (83 HRB) maximum.

10.7 Snap Rings

10.7.1 Snap rings directly exposed to a sour environment shall be made from applicable materials in Sections 5 and 6, except as noted in Paragraph 10.7.2.

10.7.2 Precipitation-hardening 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:

Heat-Treatment Procedure (Three-Step Process)

1) Temper at 620°C (1,150°F) for 4 hours, 15 minutes. Cool to room temperature in still air.

2) Retemper at 620°C (1,150°F) for 4 hours, 15 minutes. Cool to room temperature in still air.

3) Temper at 560°C (1,050°F) for 4 hours, 15 minutes. Cool to room temperature in still air.

10.8 Special Process Wear-Resistant Parts

10.8.1 Cobalt -chromium -tungsten and nickel-chromium-boron alloys, whether cast, powder metallurgy processed, or thermo-mechanically processed, are acceptable.

10.8.2 Tungsten-carbide alloys are acceptable whether cast or cemented are acceptable.

Commentary Note:

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

11 Valves and Chokes

11.1 General

Materials shall meet the requirements of this section if they are to be exposed to sour environments. Valves and chokes shall be manufactured from materials in accordance with Sections 5 through 10.

11.2 Shafts, Stems, and Pins

11.2.1 Shafts, stems, and pins shall be manufactured from materials in accordance with Sections 5 through 10.

11.2.2 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 an anneal.

11.3 Internal Valve and Pressure Regulator Components

Cast CB7Cu-1 in the H1150 DBL condition in accordance with ASTM A747 is acceptable for non-pressure-containing, internal valve, and pressure regulator components at 310 HB maximum (30 HRC maximum). Precipitation-hardening 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 TM0177 that are lower than other materials included in this standard.

12 Wells, Flow Lines, Gathering Lines, Facilities, Field Processing Plants, and Refineries

12.1 General

Materials used for production facilities, field processing installations and refineries shall meet the requirements of this section if they are to be exposed to sour environments (defined in Paragraphs 5.2 and 5.3) and shall be fabricated in compliance with Section 7.

12.2 Wells

12.2.1 Tubular Components

12.2.1.1 Casing or tubing directly exposed to sour environments shall meet the requirements of Table 4.

12.2.1.2 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.

12.2.1.3 API 5CT Grade L-80 Type 13 Cr tubing and casing are acceptable up to a maximum H_2S content of 100 ppm in production environments with a produced water pH $\geq$3.5. (This pH represents the minimum estimated, measured, or calculated pH of the normally produced water, not the pH encountered temporarily as a result of inhibited acid injection.)

12.2.1.4 API 5CT Grades C-90 Type 1 and T-95 Type 1 are acceptable for casing and tubular components.

12.2.1.5 UNS S42500 (15 Cr) is acceptable as tubing and casing in the quenched and double-tempered condition (see below) 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 below 9.653 kPa abs (1.40 psia) and the pH of any produced aqueous phase is above 3.5. The quench and temper process shall conform to the following limitations:

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 (1,150°F) minimum, then cool to ambient

12.2.1.6 UNS S41426 tubing and casing are acceptable when 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, 0.1 bar) in production environments with a produced water pH ≥ 3.5 (this pH represents the minimum estimated, measured, or calculated pH of the normally produced water, not the pH encountered temporarily as a result of inhibited acid injection).

12.2.2 Casing and tubular components made of Cr-Mo alloy steels (AISI 41 XX and 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 103 MPa (15 ksi) higher than SMYS. SSC resistance shall be measured using TM0177 Test Method A, and the minimum threshold stress shall be 85% of SMYS. For these 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. However, the primary application for these steels is for protective casing in wells with less than 7 kPa abs (1 psia) H_2S partial pressure.

12.2.3 Tubulars and Tubular Components

12.2.3.1 Tubulars and tubular components made of alloy steels in the Cr, Mo series (AISI 41XX and its modifications) are acceptable at a 26 HRC maximum hardness, provided they are in the quenched and tempered condition.

Commentary Note:

Careful attention to chemical composition and heat treatment is required to ensure SSC resistance of these alloys at greater than 22 HRC. Accordingly, it is common practice, when using these alloys at above 22 HRC, for the user to conduct SSC tests to determine susceptibility to SSC damage.

12.2.3.2 If tubulars and tubular components are cold straightened at or below 510°C (950°F), they shall be stress relieved at a minimum of 480°C (900°F). If tubulars and 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 595°C (1,100°F). Cold forming the connections of high-strength tubulars with hardnesses above 22 HRC shall require thermal stress relieving at a minimum temperature of 595°C (1,100°F).

Commentary Note:

Downhole cold expansion of tubulars, casing, or other downhole equipment is outside the scope of this document.

12.3 Subsurface Equipment

12.3.1 Gas Lift Equipment

Gas lift equipment normally handles gas that is free of H_2S. However, if sour gas is used, surface and subsurface equipment shall comply with the requirements of Sections 5 through 10. Casing and tubing shall comply with the requirements of Paragraph 12.2.1.

12.3.2 Other Artificial Lift Equipment

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

12.3.3 Packers and Other Subsurface Equipment

12.3.3.1 Materials listed in Tables 2 through 5 and covered in Sections 5 through 10 are acceptable.

12.3.3.2 Type 420M (chemistry in accordance with API 5CT Grade L-80 Type 13Cr) is acceptable for completion equipment when air or oil quenched and tempered to 22 HRC maximum and applied up to a maximum H_2S partial pressure of 10 kPa abs (1.5 psia, 0.1 bar) in production environments with a produced water pH ≥ 3.5. (This pH represents the minimum estimated, measured, or calculated pH of the normally produced water, not the pH encountered temporarily as a result of inhibited acid injection.)

12.3.4 Slips - Slips are outside the scope of this standard.

12.4 Wellheads

Wellhead components directly exposed to sour environments shall be manufactured in accordance with the requirements of Sections 5 through 10. Wellhead components that are not directly exposed to the sour environment or that are exposed to the controlled drilling environment (see Paragraph 13.2.2) are outside the scope of this standard.

12.5 Flow Lines and Gathering Lines

Materials and fabrication procedures shall comply with the requirements of Sections 5 through 10 and Tables 2 through 4.

12.6 Production and Refinery Facilities

12.6.1 Oil and Gas Processing, Refinery, and Injection Facilities

Materials and fabrication procedures shall comply with the requirements of Sections 5 through 10 and Tables 2 through 4.

12.6.2 Cryogenic Gas Processing Plants

The use of alloy steels containing more than approximately 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 A333 Grades 3, 4, 7, 8, and 9; A334; A203; A420 Grades WPL-3 WPL-6, and WPL-8; A350 Grade LF 3; A353; and A689.

12.6.3 Water Injection and Water Disposal

Materials selection for water-handling facilities is outside the scope of this standard. Refer to NACE RP0475 for material selection and weldments in water injection and disposal systems.

12.7 Compressors and Pumps

12.7.1 Materials exposed to the sour environment shall comply with the requirements of Sections 5 through 10, except as noted in Paragraphs 12.7.2 and 12.7.3.

12.7.2 Gray cast iron (ASTM A278 Class 35 or 40) and nodular iron (ASTM A395) are acceptable as compressor cylinders, liners, pistons, and valves. Aluminum alloy 355, temper T-7 (ASTM B26), is acceptable for pistons. Aluminum, soft carbon steel, and soft, low-carbon iron are acceptable as gaskets in compressors handling sour gas.

12.7.3 AISI 4320 and a modified version of 4320 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 procedure:

Heat-Treatment Procedure (Three-Step Process):

1) Austenitize and quench

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

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

12.8 Pipe Fittings

12.8.1 Carbon steels meeting the requirements of ASTM A105 or A234 Grades WPB and WPC are acceptable in the hot-worked condition to the following maximum hardness: A105 (187 HB); and A234 WPB and WPC (197 HB).

12.8.2 If carbon steel ASTM A234 Grades WPB and WPC pipe fittings are cold worked during manufacture by rolling, forging, or any other manufacturing process which results in a permanent outer fiber deformation greater than 5%, the cold working must be followed by normalizing or thermal stress-relief heat treatment. If thermal stress relief is applied, it should be performed in accordance with ASME Code, Section VIII, Division 1, except that the minimum stress-relief temperature shall be 595°C (1,100°F). After thermal heat treatment subsequent to cold work, the hardness of normalized or stress-relieved ASTM A234 Grade WPB or WPC carbon steel pipe fittings shall not exceed 200 HB.

13 Drilling and Well-Servicing Equipment

13.1 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 7, except as otherwise indicated herein.

13.2 Control of Drilling and Well-Servicing Environments

13.2.1 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 alloy steels in Section 5. When such materials and components are required for drilling formations or are operating in environments containing H_2S, the primary means for avoiding SSC is control of the drilling or well-servicing environment. As service stresses and material hardnesses increase, drilling fluid control becomes increasingly important.

13.2.2 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.

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

13.3 Drilling Equipment

13.3.1 Drill Stem

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

Tubular steel components meeting API specifications listed in Table 4 are acceptable if the drilling environment is controlled (see Paragraph 13.2). For optimum SSC resistance, steel components having specified minimum yield strengths greater than 660 MPa (95 ksi) should be heat-treated by quenching and tempering.

13.3.1.2 Welding of Tool Joints to Drill Pipe

The weld and heat-affected zone (HAZ) shall be heat treated by austenitizing, cooling to a temperature below the transformation range, and tempering at a minimum tempering temperature of 595°C (1,100°F).

13.3.1.3 Hardsurfacing

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.

13.3.2 Drill Bits

Drill bits are outside the scope of this standard.

13.3.3 Other Drilling Components

Other drilling components (slush pumps, swivels, kelly cocks, etc.) shall be manufactured from materials in compliance with Sections 6 through 11. 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 13.2.2) are outside the scope of this standard.

13.4 Blowout Preventer (BOP)

13.4.1 Blowout preventer body and parts (excluding ram and ram shear blades) shall meet the requirements of Sections 5 through 10.

13.4.2 Blowout Preventer Shear Blades

High-strength and high-hardness steels are required for ram shear blades to shear drill pipe during drilling emergency conditions. However, the user shall be advised that these materials are highly susceptible to SSC.

13.4.3 Rams

Alloy steels, processed in accordance with Sections 5 through 10, are acceptable for rams. 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.

13.5 Choke Manifolds and Choke and Kill Lines

Choke manifolds and choke and kill lines shall comply with the requirements of Sections 5 through 10.

13.6 Drill Stem Testing

3.6.1 Drill stem testing is not ordinarily conducted in a controlled drilling environment. Materials for drill stem testing shall comply with the requirements of Sections 5 through 10 and Paragraph 12.2 when testing without a controlled drilling environment.

13.6.2 Materials shown in Table 4 can also be used with operational procedures that take into consideration the factors enumerated in Paragraph 4.2, 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).

13.7 Formation-Testing Tools

Materials for formation-testing tools shall comply with the requirements of Sections 5 through 10 and Paragraph 12.2.

13.8 Floating Drilling Operations

13.8.1 Blowout Preventers (BOP)

Blowout preventers shall comply with the requirements of Paragraph 13.4.

13.8.2 Drilling Riser Systems

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, bailor 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 5 through 10 and Paragraph 12.2.1.1.

13.8.3 Choke and Kill Lines

Materials for the choke and kill lines and manifolds shall comply with the requirements of Sections 5 through 10.

13.9 Well-Servicing Equipment

13.9.1 Work String

Work strings used during well servicing when sour fluids are to be encountered shall comply with the requirements of Paragraph 13.8.1. Work strings that are to be exposed to controlled drilling fluid environments only, are outside the scope of this standard.

13.9.2 Blowout Preventers

Blowout preventers shall comply with the requirements of Paragraph 13.4.

13.9.3 Choke and Kill Lines

Choke and kill lines and manifolds shall comply with the requirements of Sections 5 through 10.

13.9.4 Production Test Facilities

Production test facilities shall comply with the requirements of Sections 5 through 10.

13.9.5 Wire Line Lubricator Assembly

Wire line lubricator and auxiliary equipment shall comply with the requirements of Sections 5 through 10 and Paragraph 12.2.1.1.

14 Material Selection and Testing Subcommittee

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Revision Summary

30 March 2005 New Saudi Aramco Engineering Standard.

Table 1 - Description of Test Levels

Test Level		I	II	III	IV	V	VI	VII
Environmental Condition	**Temperature**	**25±3ºC (77±5ºF)**	**25±3ºC (77±5ºF)**	**25±3ºC (77±5ºF)**	**90±5ºC (194±9ºF)**	**150±5ºC (302±9ºF)**	**175±5ºC (347±9ºF)**	**205±5ºC (401±9ºF)**
	CO_2 content,min	None	none	none	0.7 Mpa abs (100 psia)	1.4 Mpa abs (100 psia)	3.5 Mpa (500 psia)	3.5 Mpa (500 psia)
	H_2S content	(list)	TM0177	TM0177	0.003 Mpa abs (100 psia)	0.7 Mpa abs (200 psia)	3.5 Mpa (500 psia)	3.5 Mpa (500 psia)
	NaCI 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	(list)	none	none	(list)	(list)	(list)	(list)
Test Method(S)		(list)						
Material Type and Condition		describe-chemical composition, UNS number, process history						
Material Properties		describe-yield strength, tensile strength, % elongation, hardness						
Stress Level and Results		describe-test stress level, plastic strain, etc., test results						

Table 2 - Stainless Steels Acceptable for Direct Exposure to Sour Environments

Materials listed in this table should be used only under conditions noted in the text of this standard.

Ferritic	**Martensitic**	**Precipitation-Hardening**	**Austenitic**	**Duplex (Austenitic/Ferritic)(D) Wrought condition only**
AISI 405 430	AISI 410 501	ASTM A 453 Gr 660(A) A 638 Gr 660(A)	AISI 302 304 304L 305 308 309 310 316 316L 317 321 347	UNS S31260 UNS S31803 UNS S32404 UNS S32550 UNS S32760 UNS S39274 UNS S39277
ASTM A 268 TP 405, TP 430, TP XM 27, TP XM 33	ASTM A 217 Gr CA 15 A 268 Gr TP 410 A 743 Gr CA 15M A 487 CI CA 15M A 487 CI CA6NM UNS S42400	UNS S17400 UNS S45000 UNS S66286	ASTM A 182 A 193(B) Gr B8R, B8RA, B8, B8M, B8MA A 194(B) Gr 8R, 8RA, 8A, 8MA A 320(B) Gr B8, B8M A 351 Gr CF3, CF8, CF3M, CF8M, CN7M(C) A 743 Gr CN7M(D) A 744 Gr CN7M(D) B 463 B 473	Cast Duplex Z 6 CNDU 28.08M NF A 320-55 French National Standard UNS J93380 UNS J93404
(A) See paragraph 5.8.2. (B) Carbide solution-treated. (C) As modified by paragraph 5.5.4. (D) Aging over 260°C (500°F) may reduce low-temperature toughness and reduce resistance to environmental cracking.				

Table 3 - Nonferrous Materials Acceptable for Direct Exposure to Sour Environments

Materials listed in this table should be used only under conditions and noted in the text of this standard.

Nickel-Copper Alloy			Nickel-Iron-Chromium Alloys		Nickle-Iron-Chromium Molobdenum Alloys		Nickel-Chromium Alloys				Coating, Overlays and Special Process Parts
UNS N05500	UNS N04400		UNS N08800		UNS N06007	UNS N08825	UNS N06600		UNS N07750		
SAE/AMS	ASTM	SAE/AMS	ASTM	SAE/AMS	ASTM	ASTM	ASTM	SAE/AMS	ASTM	SAE/AMS	Co-Cr-W Alloys
4676	B127	4544	B163	5766	B366	B163	B163	5540	B 637	5542	as in AWS
	B163	4574	B366	5871	B581	B366	B166	5580		5582	A5.13-80
	B164	4575	B407		B582	B423	B167	5665		5598	Ni-Cr-B Alloys as
	B366	4730	B408		B619	B424	B366	7232		5667	in AWS A5.13-80
	B564	4731	B409		B622	B425	B516			5668	Tungsten Carbide
		7233	B514		B626	B704	B517			5669	Alloys Ni-B alloys
			B515			B705	B564			5670	as in SAMS 4779
			B564							5671	Ceramics
										5698	
	A494				**UNS N06250**					5699	
	Gr M-				**UNS N06255**						
	35-1				**UNS N06686**						
	Cr M-				**UNS N06952**						
	35-2				**UNS N07048**						
					UNS N07773						
					UNS N08024						
					UNS N08028						
					UNS N08042						
					UNS N08535						
					UNS N08826						
					UNS N09777						
					UNS N09925						
					UNS R20033						
	UNS N04405										

Table 3 - Continued
Nickel-Chromium-Molybdenum

UNS N06625		**UNS N10002**		**UNS N10276**		**UNS N07718**		**UNS N06002**	
ASTM	SAE/AMS	ASTM	SAE/AMS	ASTM	ASTM	SAE/AMS	ASTM	SAE/AMS	**UNS N06022**
B336	5581	A597Gr4	5388	B366	B637	5383	A567	5390	**UNS N06030**
B443	5599		5389	B574	B670	5589	Gr 5	5536	**UNSN06059**
B444	5666	A494	5530	B575		5590	B366	5587	**UNS N06060**
B446	5837	Gr CW-12MW	5750	B619		5596	B435	5588	**UNS N06110**
B564		Gr CW2M		B622		5597	B572	5754	**UNS N06686**
B704				B626		5662	B619	5798	**UNS N06975**
B705						5663	B622	5799	**UNS N06985**
						5664	B626	7237	**UNS N07031**
						5832			**UNS N07716**
									UNS N07725
									UNS N08135

Cobalt-Nickel-Chromium-Molybdenum Alloys		**Cobalt-Nickel-Chromium-Tungsten-Alloys**	**Cobalt-Nickel-Chromium-Molybdenum-Tungsten Alloys**	**Other Alloys**		
		UNS R30605	UNS R30260	Aluminum Based Alloys	Tantalum UNS R05200	Titanium Alloys
UNS R30035	UNS R30003					
UNS R03004	UNS R30159					UNS R50400
				Copper Alloys		UNS R53400
						UNS R56260
						UNS R56323
	UNS R31233					UNS R56403
						UNS R56404
						UNS R58640

Table 4 - Acceptable API and ASTM Specifications for Tubular Goods

All materials complying with Section 5 or listed in Table 2 and 3 are acceptable.
Materials listed in this table are acceptable under environmental conditions noted.

Operating Temperatures

For All Temperatures	For 65°C (150°F) or Greater	For 80°C (175°F) or Greater	For > 170°C (>225°F)
Tubing and Casing	**Tubing and Casing**	**Tubing and Casing**	
API SPEC 5CT Grs H-40,[(C)] J-55, K-55, M-65, C-75 (types 1,2,3), and L-80 (type 1) Proprietary Grades in accordance with Paragraph 10.2.3 UNS K12125 API 5CT Grades C-90 Type 1 and T -95 Type 1 Pipe~[(D,E,J)] API SPEC 5L Grs A & B and Grs X-42 through X-65 ASTM A53 A106 Gr A, B, C A333 Gr 1 & 6 A524 Gr 1 & 2 A381 Cl1 Y35-Y65 Drill Stem Materials[(F)] API SPEC 50 Grs D, E, X-95, G-105, & S-135	API Spec 5CT Gr N-80 API SPEC 5CT Gr N-80 (0&T[(1)]) & Gr C-95, T-95 type 2 Proprietary 0&T[(I)] Grs with 110 ksi[(H)] or less maximum yield strength	API Spec 5CT Grs H-40, API SPEC 5CT Grs H-40, N-80, P-105, & P-110 Proprietary 0&T[(I)] Grs to 140 ksi[(H)] maximum yield strength	API SPEC 5CT Gr 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 Column 1.

(C) 80 ksi(H) 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 11.2.

(G) Regardless of the requirements for the current edition of API SPEC 5CT, the Q-125 grade shall always (1) have a maximum yield strength of 150 ksi; (H) (2) be quenched and tempered; and (3) be an alloy based on Cr-Mo chemistry. The C-Mn alloy chemistry is not acceptable.

(H) 1 MPa = 0.145 ksi.

(I) Quenched and tempered.

(J) All piping shall be API 5L PSL-2.

Table 5 - Acceptable Materials for Subsurface Equipment for Direct Exposure to Sour Environments

All materials complying with Section 5 and listed in Tables 2 through 4 are acceptable.

Use	Material
Drillable packer components	Ductile iron (ASTM A536, A571)
Drillable packer components	Malleable iron (ASTM A220, A602)
Compression members	Gray iron (ASTM A48, A278)
All	9Cr-1 MO(A)
	ASTM A199 Gr T9
	ASTM A200 Gr T9
	ASTM A276, Type 9
	ASTM A182 Gr F9
	ASTM 213 Gr T9

Table 6 - Maximum Hardness Requirements for P-Numbered Alloy Steels

Alloy Steel	Maximum Hardness Requirements
P-No. 3	225 HBW max.
P-No. 4	225 HBW max.
P-No. 5A	235 HBW max
P-No. 5B (except 9Cr-1Mo-V grades)	235 HBW max
P-No. 5B¯9Cr-1Mo-V grades (F91, P91, T91, WP91, Grade 9, C12A)	248 HBW max
P-No. 5C	235 HBW max
P-No. 6	235 HBW max
P-No. 7	235 HBW max
P-No. 10A	225 HBW max.
P-No. 10B	225 HBW max.
P-No. 10C	225 HBW max.
P-No. 10F	225 HBW max.
P-No. 11	225 HBW max.

Table 7 - Typical Refinery Equipment Susceptible to Sulfide Stress Cracking

(**Note:** This list is not all-inclusive)

Crude Unit – Atmospheric and Vacuum	Atmospheric Tower Overhead System	Coolers Accumulators
	Vacuum Tower Overhead System	Coolers Accumulators
	Light Ends Recovery Section	Debutanizers Waste Gas Scrubbers Sour Water Collection System
Catalytic Cracking Units	Main Fractionator Overhead System	Overhead Lines Coolers/Condensers Accumulators Coalescers Adsorbers
	Wet Gas System	Compressor Suction Drum Accumulators Coolers
	Light Ends Recovery Section	Deethanizers Debutanizers Accumulators
Hydro-Processing Units	Feed System	Feed Surge Drums
	Reactor Effluent Section	High Pressure/Low Pressure Separators
		Trim Coolers
	Fractionation Section	Stripper Towers Reflux Drums
	Gas Treating Section	Amine Absorber
		Off Gas Absorber
		Flash Tower
	Recycle Gas Section	Knock Out Pots Condensers
Coker Units	Coker Fractionator Overhead System Coker Light Ends Recovery Section	Similar to FCCU
		Similar to FCCU
Other	Sour Water Recovery Units	Sour Water Stripper Column Overhead System
	Amine Regenerator Systems	Amine Regenerator Tower
		Accumulator Drum
		Quench Tower
	Gas Recovery Plants	Similar to Light Ends Recovery above
	Sulfur Recovery Units	Acid Gas Knock Out Drums Condensers Blow Down Drums

Appendix A: Definitions

Age Hardening: Hardening 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).

Alloy Steel: An iron-based alloy containing carbon (usually less than 2.0%) and with manganese (usually not less than 0.25%), that contains specified minimum quantities for one or more alloying elements other than manganese, silicon, and copper, and that does not specify a minimum chromium content greater than or equal to 10%.

Annealing: Heating to and holding at a temperature appropriate for the specific material and then cooling at a suitable rate, for such purposes as reducing hardness, improving machinability, or obtaining desired properties (also see Solution Heat Treatment).

Austenite: The face-centered crystalline phase of iron-base 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).

Autofrettage: A technique whereby residual compressive stresses are created at the interior of a thick-walled component by application and release of internal pressure that causes yielding of the metal near the ID or bore of the component.

Blowout Preventers (BOP): 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 (HB): 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 E10.

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): Metal that is obtained 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 with alloy binders of primarily cobalt or nickel.

Chloride Stress Corrosion Cracking: Failure by cracking under the combined action of tensile stress and corrosion in the presence of chlorides and water.

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. Contrast with hot working.

Corrosion Resistant Alloy (CRA) Categories: Alloy categories that permit a broad-based description of similar alloys. A CRA category 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/safety factor in accordance with the applicable industry code and/or manufacturer's standard.

Dissimilar Metal Weld: Any weld joint between a ferritic steel and either austenitic stainless steel or nickel based alloy.

Double Tempering: A 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 (Austenitic/Ferritic) 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 any permanent strain remaining upon complete release of stress.

Ferrite: A 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. (See also Solution Heat Treatment.)

Heat-Affected Zone (HAZ): That portion of the base metal that was not melted during brazing, cutting, or welding, but whose microstructure and properties were 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 of 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.

Hot Rolling: Hot working a metal through dies or rolls to obtain a desired shape.

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.

Lower Critical Temperatures: In ferrous metals, the temperatures 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 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.

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 one other than iron.

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

Partial Pressure: The partial pressure of each component is equal to the total 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 a ferrous metal by austenitizing and then cooling rapidly enough so that some or all of the austenite transforms to martensite.

PREN: Pitting Resistance Equivalent Number – A number calculated form heat analysis of intentionally added alloying elements as shown in equation (1). The PREN is used in this standard as a means to group alloys and does not indicate comparable corrosion-resistance properties in sour service.

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

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 (HRC): A hardness value obtained by use of a cone-shaped diamond indentor and a load of 150 kg, in accordance with ASTM E18.

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

Slush Pump: Pump normally used to circulate drilling fluids through the drill stem into the annulus of the 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 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 or 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) at a temperature of 16°C (60°F).

Stress Corrosion Cracking (SCC): Cracking of metal produced by the combined action of corrosion and tensile stress (residual or applied).

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 (SSC): Brittle failure by cracking under the combined action of tensile stress and corrosion in the presence of water and H_2S.

Surface Hardening: See Case Hardening.

Tempering: In heat treatment, 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 A370). 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 (pipe) having a longitudinal hole that is used in drilling/production operations for conveying fluids.

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 (HAZ), 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 A370).

Appendix B: Alloy Cross Reference and Location in Standard

UNS Number	Trade Name	Location in Standard (Paragraph)	Location in Standard (Table)
A03550	A03550 Al Alloy Casting	12.7.2	3
F12401	Cast Iron	12.7.2	No Table
F12803	Cast Iron	12.7.2	No Table
F32800	Cast Iron	12.7.2	No Table
G43200	AISI 4320	12.7.3	No Table
HF	Overlay	7.2.2	NA
HF	WC	7.2.2	NA
HF	AMS 4779	7.2.2	NA
HF	AWS 5.13-80	7.2.5	NA
HF	AWS 5.13-80	10.8.2	NA
J91150	CA 15	5.7.1	2
J91151	CA 15M	5.7.1	2
J91540	CA 6 NM	5.7.2	2
J92500	CF-3	5.5.1	2
J92600	CF-8	5.5.1	2
J92600	CF-8	10.6.2	No Table
J92800	CF-3M	5.5.1	2
J92900	CF-8M	5.5.1	2
J92900	CF-8M	10.6.2	No Table
J93254	Cast 254 SMO	5.5.9	No Table
J93345	Escoloy	10.8.1	No Table
J93380	Z100	5.9.7	2
J93404	958	5.9.10	2
J95150	CN7M	5.5.4	No Table
K03504	ASTM A105 Forgings	5.2.1	No Table
K90941	9Cr 1Mo	No Text	5
N04400	Monel 400	6.1.1.1	3
N04405	Monel Alloy R-405	6.1.1.1	
N05500	Monel K 500	6.1.1.2	3
N06002	Alloy X	6.1.5.1	3
N06007	Alloy G	6.1.3.1	3
N06022	C-22	6.1.5.2.1	3
N06030	G-30	6.1.3.5	3
N06059	59	6.1.5.2	3
N06060	SM6020Mo	6.1.5.5	3
N06110	Allcor	6.1.5.5	3
N06250	SM2050	6.1.3.1	3
N06255	SM2550	6.1.3.1	3

UNS Number	Trade Name	Location in Standard (Paragraph)	Location in Standard (Table)
N06600	Alloy 600	6.1.4.1	3
N06625	Inconel 625	6.1.5.1	3
N06686	Alloy 686	6.1.5.2.1	3
N06950	G-50	6.1.3.1	3
N06952	Alloy 52	6.1.3.11	3
N06975	G-2	6.1.3.1	3
N06985	G-3	6.1.3.1	3
N07031	Pyromet Alloy 31	6.1.5.4	3
N07048		6.1.3.6	No Table
N07090	Nimonic 90	10.4.4	No Table
N07626	Inconel 625LCF	6.1.5.7	No Table
N07716	625 Plus	6.1.5.6	3
N07718	Alloy 718	6.1.5.3	3
N07725	725	6.1.5.6	3
N07750	X-750	6.1.4.2	3
N07750	X-750	10.3.3	No Table
N07773	PH3	6.1.3.7	3
N07924		6.1.3.15	No Table
N08020	20 Cb3	5.5.3	2
N08024	20Mo-4	6.1.3.3	3
N08028	Alloy 28	6.1.3.4	3
N08031	Alloy 31	6.1.3.14	No Table
N08032	Alloy 32	6.1.3.13	No Table
N08042	Alloy 42	6.1.3.10	3
N08135	SM2035	6.1.5.9	3
N08367	AL6XN	5.5.6	No Table
N08367	AL6XN	5.5.10	No Table
N08535	SM2535	6.1.3.9	3
N08800	Alloy 800	6.1.2.1	3
N08825	Incoloy 825	6.1.3.1	3
N08826	825 Cast	6.1.3.12	3
N08904	904L	10.5.3	No Table
N08926	1925hMo	5.5.8	No Table
N09925	Alloy 925	6.1.3.2	3
N09777	PH7	6.1.3.8	3
N10001 (CW2M)	Hastelloy B	6.1.5.8	3
N10002	Alloy C	6.1.5.2	3
N10276	Alloy C-276	6.1.5.2	3
N26625	Inconel Alloy 625	6.1.5.10	No Table
N99640	Overlay	7.2.5	No Table
N99644	Overlay	7.2.5	No Table

UNS Number	Trade Name	Location in Standard (Paragraph)	Location in Standard (Table)
N99645	Overlay	7.2.5	No Table
N99646	Overlay	7.2.5	No Table
R05200	Tatalum	6.2.1.4	3
R20033	Nicorfer 3033 (VDM)	6.1.3.16	3
R30001	AMS 4779 (Cobalt based)	7.2.5	No Table
R30003	Elgiloy (Cobalt based)	6.1.6.1	3
R30003	Elgiloy	10.4.2	No Table
R30004	Havar (Cobalt based)	6.1.6.1	3
R30004	Havar	10.5.2.2	No Table
R30006	HS-6	7.2.5	No Table
R30012	Stellite 12	7.2.5	No Table
R30035	MP-35N	6.1.6.1	3
R30035	MP-35N	6.1.6.2	3
R30035	MP-35N	10.4.2	No Table
R30159	MP-135	10.5.2.4	4
R30260	Duratherm 2602	10.5.2.3	No Table
R30605	L-605	6.1.7	3
R31233	Ultimet	6.1.6.3	3
R50400	Grade 2	6.2.1.4.3	3
R53400	Grade 12	6.2.1.4.1	3
R56260	Ti-6246	6.2.1.4.4	3
R56323	Grade 28	6.2.1.4.7	3
R56403	Grade 25	6.2.1.4.5	3
R56404	Grade 29	6.2.1.4.6	3
R58640	Beta-C	6.2.1.4.2	3
S15700	PH 15-7 Mo	10.7.2	No Table
S17400	17-4PH	5.8.1	3
S20910	22-13-4	5.5.2	2 (B8R & B8RA)
S20910	22-13-4	11.2.2	No Table
S30200	302 SS	5.5.1	2
S30400	304 SS	5.5.1	2
S30403	304L SS	5.5.1	2
S30500	305 SS	5.5.1	2
S30800	308 SS	5.5.1	2
S30900	309 SS	5.5.1	2
S31000	310 SS	5.5.1	2
S31254		5.5.5	No Table
S31260	DP-3 Duplex SS	5.9.8	No Table
S31266		5.5.12	No Table
S31600	316 SS	5.5.1	2

UNS Number	Trade Name	Location in Standard (Paragraph)	Location in Standard (Table)
S31603	316 L	5.5.1	2
S31700	317 SS	5.5.1	2
S31803	2205 Duplex	5.9.1	2
S31803		5.9.4	No Table
S32100		5.5.1	2
S32200		5.5.7	No Table
S32404		5.5.1	2
S32550	255 Duplex SS	5.9.1	2
S32654		5.5.11	No Table
S32750	2507 Duplex SS	5.9.5	No Table
S32760		5.9.6	2
S34565		5.5.13	No Table
S34700		5.5.1	2
S39274	DP-3W	5.9.9	2
S39277	AF 918 Duplex	5.9.11	2
S41000	410	5.7.1	2
S41425	S/W 13 Cr	5.7.2.2	No Table
S41426	13 CrS (Downhole Tubing)	12.2.1.6	No Table
S42000 (13 Cr)	420 (API 5CT)	12.2.1.3	5
S42400	F6 NM	5.7.2	2
S42500	15 Cr Downhole Components)	12.2.1.5	No Table
S43000		5.7.1	2
S44625		5.7.1	2
S44626	26-1 Ti	5.7.1	2
S45000	450	5.8.3	2
S50100	1505 PH	5.7.1	2
S66286	A286	5.8.2	2

UNS Number	Trade Name	Location in Standard (Paragraph)	Location in Standard (Table)
ASTM Number (chemical composition only)			
CB7Cu-1 (ASTM A 747)		11.3.1	No Table
CN7M (ASTM A 351,			
A 743, A 744)		5.5.4	No Table
CW2M (ASTM A 494)		6.1.5.8	No Table
CK3MCuN (ASTM A351,		5.5.9	No Table
A 743, A 744)			
Others			
Z 6 CNDU 28.08 M			2
(NF A 320-55			
French National Std.			