

CPM-SU-5011-F

MATERIALS AND FABRICATION REQUIREMENTS FOR DUPLEX STAINLESS STEEL

APPLICATION: ONSHORE

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CONTENTS

1.0	Scope	3
2.0	References	3
2.1	Purchaser Documents	3
2.2	Industry Codes and Standards	3
2.3	Conflict Resolution and Order of Precedence	4
3.0	Acronyms	4
4.0	Materials	5
5.0	Welding and Fabrication	6
5.1	Joint Preparation	6
5.2	General Welding Requirements	7
5.3	Welding Procedure Specifications and Qualification Requirements	9
5.4	Dissimilar Metal Welds	12
5.5	Repairs	13
5.6	Tube-to-Tubesheet Joint Requirements	13
5.7	Post Weld Heat Treatment	14
6.0	Tube and Pipe Bends	14
7.0	Inspection and Testing	14
7.1	Liquid Penetrant Examination	14
7.2	Radiographic Examination	14
7.3	Ferrite Checks	15
7.4	Positive Material Identification	15
7.5	Hydrostatic Testing	15
8.0	Documentation	15
Appendix A	Requirements for Welded Tubes	16
Appendix B	Requirements for Tube-to-Tubesheet Welding	17
Appendix C	Requirements for Tube Bending	18
Appendix D	Requirements for Severe Sour Service or Hydrogen Charging Service	20
Appendix E	Requirements for Offshore and Produced Brine Service	21

1.0 SCOPE

1. The requirements included in this specification apply to piping and equipment fabricated from duplex stainless steel types 2205 and 2507 (Unified Numbering System [UNS] materials S32205 and UNS S32750), and are intended to supplement other Purchaser specifications and Code requirements for stainless steel piping and equipment.
2. Purchaser may approve the use of this specification for fabrication of other duplex stainless steels including UNS S32760 as an alternative to UNS S32750. As needed, Purchaser shall provide a supplement to this specification that includes any changes appropriate to the alloy(s) used.

2.0 REFERENCES

1. The following documents are referenced herein and are considered part of this specification.
2. Unless otherwise specified in [Section 2.1](#) or [Section 2.2](#), use the latest edition of the referenced documents.

2.1 Purchaser Documents

CPM-PU-5074 Positive Material Identification Program for Source PMI

2.2 Industry Codes and Standards

American Society of Mechanical Engineers (ASME)

B31.3 Process Piping

Boiler Pressure Vessel Code (BPVC)

Section V, Nondestructive Examination

Section VIII, Division 1, Rules for Construction of Pressure Vessels

Section VIII, Division 2, Alternative Rules – Rules for Construction of Pressure Vessels

Section IX, Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators – Welding and Brazing Qualifications

ASTM International (ASTM)

A182/A182M Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service

A240/A240M Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

A276 Standard Specification for Stainless Steel Bars and Shapes

A450/A450M Standard Specification for General Requirements for Carbon and Low Alloy Steel Tubes

A479/A479M Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and other Pressure Vessels

A789/A789M Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service

A790/A790M	Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe
A803/A803M	Standard Specification for Seamless and Welded Ferritic Stainless Steel Feedwater Heater Tubes
A815/A815M	Standard Specification for Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings
A923	Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels
A928/A928M	Standard Specification for Ferritic/Austenitic (Duplex) Stainless Steel Pipe Electric Fusion Welded with Addition of Filler Metal
A995/A995M	Standard Specification for Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts
E309	Standard Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation
E562	Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count
G48	Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution

Det Norske Veritas (DNV)

RP-F112	Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection
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NACE International (NACE)

MR0103	Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refinery Environments
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2.3 Conflict Resolution and Order of Precedence

1. Where this specification conflicts with other applicable Purchaser specifications, this specification shall take precedence.
2. Any exceptions to these requirements shall be authorized by the Purchaser in writing.

3.0 ACRONYMS

CMTR—Certified Materials Test Report

EFW—Electric Fusion Welding

ET—Eddy Current Test

FCAW—Flux Cored Arc Welding

FCAW-G—Flux Cored Arc Welding with Shielding Gas

GMAW—Gas Metal Arc Welding

GTAW—Gas Tungsten Arc Welding

HAZ—Heat-Affected Zone

PMI—Positive Material Identification

PQR—Procedure Qualification Record

PT—Liquid Penetrant Examination

PWHT—Post Weld Heat Treatment

RT—Radiographic Examination

SAW—Submerged Arc Welding

SMAW—Shielded Metal Arc Welding

SMYS—Specified Minimum Yield Strength

WPQ—Welder Performance Qualification

WPS—Welding Procedure Specification

4.0 MATERIALS

1. All duplex stainless steel materials shall be either UNS S32205 (type 2205, which can be dual stamped S31803/S32205) or UNS S32750 (type 2507, “super duplex”) and shall satisfy the requirements listed below. The use of UNS S32760 material as an alternative to UNS S32750 shall be permitted with Purchaser authorization.
 - a. Materials shall be furnished in the annealed and water quenched condition.
 - b. Materials shall be bright annealed or else, after final anneal and water quench, all surfaces shall be either machined or pickled.
 - c. Surfaces shall be free of heat tint and discoloration.
 - d. Each heat treat lot of material shall be tested in accordance with ASTM A923 test methods A and C.
 - e. The corrosion rate determined in ASTM A923 test method C shall not exceed 10 mdd and the results shall be recorded in the Certified Materials Test Report (CMTR).
 - f. Materials shall be free of sigma and other deleterious minor phases.
 - g. Duplex stainless materials and welding consumables shall be provided with CMTRs.
2. Bars and shapes shall be supplied in accordance with ASTM A276 or ASTM A479.
3. Plate materials shall be supplied in accordance with ASTM A240.
4. Seamless pipe material shall be supplied in accordance with ASTM A790.
5. Welded pipe shall conform to ASTM A928, Class 1 or 3 with 100 percent RT requirements.
 - a. Welded pipe shall be heat treated and water quenched after welding.
 - b. Welding of pipe without the addition of filler material shall not be permitted.
6. Seamless fittings shall be supplied in accordance with ASTM A182 or A815.
7. Welded fittings shall conform to ASTM A182 or A815, except that the weld shall be made with filler metal. Fittings shall be heat treated and water quenched after welding.
8. Tubes shall be seamless in accordance with ASTM A789 unless welded tubes are specified in writing by Purchaser.
 - a. When welded tubes are specified, the requirements of [Appendix A](#) shall apply.

- b. Two tubes from each lot shall be tested as outlined in [Section 4.0 items 1d](#) and [e](#), above.
 - 1) When a batch-type furnace is used for final anneal, a lot shall include only those tubes of the same heat, size, and wall thickness that are heat treated in the same furnace charge.
 - 2) When a continuous furnace is used for final anneal, a lot shall include all tubes of the same heat (i.e., heat treated in the same furnace at the same temperature, same time at temperature, and same furnace speed.)
- 9. Castings shall not be permitted without specific authorization from Purchaser, and shall be limited to valve bodies, pump cases, and other complex shapes.
 - a. When permitted, castings shall be supplied in accordance with ASTM A995, Grade 4A (UNS J92205) or 5A (UNS J93404).
 - b. Any needed weld repairs to casting base material shall be authorized by the Purchaser and shall comply with the requirements of this document regardless of repair size, extent, or classification as “minor” or “major.”

5.0 WELDING AND FABRICATION

The requirements of this section shall apply to welding performed by the fabricator, but shall not apply to welds made by the mill that are inherent to the material specification and product form (e.g., longitudinal welds in ATM A928 pipe).

5.1 Joint Preparation

- 1. Duplex stainless steel may be cut using the plasma-arc process, machining, or grinding with discs used only on duplex stainless steel.
 - a. Carbon-arc gouging shall not be used for any metal removal.
 - b. If plasma-arc cutting is used, the inside surface shall be thoroughly cleaned of all spatter.
 - c. If plasma-arc cutting is used for weld beveling preparation, sufficient metal shall be removed by grinding or machining to remove any heat-affected zone (HAZ).
 - d. Final surface preparation shall be obtained by machining or grinding.
 - e. During machining operations, only a cutting fluid compatible with duplex stainless steel (i.e., with no halogen content) shall be used.
- 2. Before any welding takes place, the following conditions shall be met:
 - a. Weld bevels shall be examined using liquid penetrant for edge defects and laminations.
 - b. The internal and external surfaces of the material shall be visually inspected for nicks, dents, general damage, or other surface defects. Any small burrs, nicks, or other irregularities on the weld bevel shall be repaired, if possible, by light grinding.
 - c. Any suspected edge defects or laminations shall be reported to Purchaser before proceeding with investigation or repairs.
 - d. Repairs by welding shall not be permitted without prior agreement from Purchaser. Refer to [Section 5.5](#) for requirements for repair welding.
- 3. Weld joints shall be wiped clean with acetone, or other Purchaser-accepted solvent, prior to welding.

4. Backup strips or rings shall not be used.
5. Joint alignment clamps shall have contact points that have been weld overlayed with an alloy material that will not contaminate or damage the duplex stainless steel in any way.

5.2 General Welding Requirements

1. All welds, including tack welds, shall be made with filler metal by gas tungsten arc welding (GTAW), gas metal arc welding (GMAW) (spray or pulse), flux cored arc welding with gas shielding (FCAW-G), or shielded metal arc welding (SMAW), following qualified weld procedure specifications.
 - a. Submerged arc welding (SAW) shall be acceptable for use on materials greater than 1 inch thick.
 - b. Flux cored arc welding (FCAW) without the addition of gas shielding shall not be permitted.
 - c. All filler metal shall contain 0.14 to 0.20 wt. % nitrogen for UNS S32205 materials and 0.23 to 0.28 wt. % nitrogen for UNS S32750 materials.
 - d. [Table 1](#) lists acceptable consumables; other consumables shall not be used unless authorized by Purchaser.
2. Minimum preheat shall be 50°F (10°C) and shall be used as a means to remove moisture and avoid condensation of the weld joint.
 - a. Preheat may be utilized to control the cooling rate when qualified and documented in the procedure qualification record (PQR) in accordance with [Section 5.3 item 4](#).
 - b. The addition of a minimum preheat temperature may be needed to reduce the cooling rate when a relatively small weld is required on a large section to obtain the required microstructure.
 - c. Preheating (when needed) should be performed with either electrical resistance heating or natural gas torch.

Table 1: Acceptable Consumables (1 of 2)

Duplex Type	Welding Process	Electrode / Filler Brand – Trade Name	AWS Class
2205 (S31803/S32205)	SMAW	Sandvik – 22.8.3 L Avesta – 2205 ESAB – OK 67.55 Metrode – Ultramet 2205 Bohler – Fox CN 22/9 N-B	E2209-15
2205 (S31803/S32205)	GTAW / GMAW	Sandvik – 22.8.3.L Avesta – 2205 ESAB – OK Tigrod 16.86 Metrode – ER329N Bohler – CN 22/9 N-IG	ER2209
2507 (S32750)	SMAW	Sandvik – 25.10.4 L Avesta – 2507/P100 ESAB – OK 68.55 Metrode – 2507XKS	E2594-15

Table 1: Acceptable Consumables (2 of 2)

Duplex Type	Welding Process	Electrode / Filler Brand – Trade Name	AWS Class
2507 (S32750)	GTAW / GMAW	Sandvik – 25.10.4 L Avesta – 2507/P100 ESAB – OK Tigrod 16.88 Metrode – 2507 Metrode – Zeron 100X Bohler – CN 25/9 CuT-IG	ER2594
Note: SAW and FCAW consumables are subject to Purchaser acceptance.			

3. Heat input shall be 15–65 kJ/inch (0.6–2.5 kJ/mm) for UNS S32205 materials and 15–38 kJ/inch (0.6–1.5 kJ/mm) for UNS S32750 materials.
4. Maximum interpass temperature shall not exceed the limits shown in [Table 2](#). Temperature measurements shall be taken on the parent metal surface, directly adjacent to the weld groove, using a contact thermometer with an instant digital display supplemented with temperature-indicating crayons of the non-halogen-containing type.

Table 2: Maximum Interpass Temperature Limits

Thickness	Maximum Interpass Temperature	
	Duplex Stainless Steel (UNS S32205)	Super Duplex Stainless Steel (UNS S32750)
< 1/8 in. (3 mm)	120°F (50°C)	120°F (50°C)
< 1/4 in. (6 mm)	160°F (70°C)	160°F (70°C)
< 3/8 in. (9.5 mm)	210°F (100°C)	210°F (100°C)
≥ 3/8 in. (9.5 mm)	300°F (150°C)	250°F (120°C)

5. Single-sided welds shall be made with a GTAW root pass and back purged until at least 1/4 inch (6 mm) of weld metal thickness has been deposited.
 - a. Backing gas shall be either nitrogen, argon, or a mixture with a purity of at least 99.95 percent to achieve the desired ferrite/austenite balance in the weld root, and may vary with the filler metal brand that is used.
 - b. The oxygen content of the back-purged volume shall be less than 0.5 percent (5000 ppm).
6. 100 percent argon or argon with up to 2 percent nitrogen addition shall be used as shielding gas when applicable.
7. Under no circumstances shall the welding arc be struck outside the weld bevels. Stray arc strikes on the base metal or on the completed weld shall be avoided. If this occurs, the arc strike shall be removed by grinding and the ground area shall be inspected with liquid penetrant.
8. During production welding, calibrated equipment for measuring the following variables shall be available at all times to confirm that the heat input and other parameters from the welding procedure specification are being followed:
 - a. Welding current (amperage)
 - b. Arc voltage

- c. Interpass temperatures (digital) supplemented with temperature-indicating crayons
 - d. Oxygen content of backing gas
 - e. Wire feed speed (GMAW and SAW)
 - f. Welding travel speed
 - g. Shielding and backing gas flow rate
9. Where removal of weld metal is required in preparation for back welding, details shall be provided in the welding procedure specification (WPS) to ensure the complete removal of oxides from cut surfaces without contaminating the material.
 - a. Plasma gouging or grinding shall be the preferred methods.
 - b. Carbon-arc gouging shall not be used.
10. Liquid penetrant examination shall be performed on the final prepared and cleaned areas prior to back welding and again after back welding.
11. All welds, including tack welds for fitup, shall be performed by certified welders using accepted procedures and materials.
12. All filler metal and flux shall be of the same type and brand (i.e., same manufacturer) as that used in weld procedure qualification. Batch certification test reports shall be provided for each consumable heat/lot to be used on production welds.
13. Only SMAW electrodes from newly opened, hermetically sealed containers shall be used. SAW fluxes shall be dried before use in accordance with the flux manufacturer's requirements.
14. Weld maps shall be incorporated on drawings and shall be submitted with the applicable weld procedures for review and authorization to proceed.
15. Nondestructive examination maps shall be incorporated on drawings and shall be submitted with the applicable joint locations for review and authorization to proceed.
16. Any weld not identified by the welder's identification stamp shall be rejected unless it is shown (at Supplier's expense) to be of acceptable quality.

5.3 Welding Procedure Specifications and Qualification Requirements

WPSs and procedure qualification requirements (PQRs) shall be qualified and documented in accordance with ASME BPVC (also referred to as "ASME Code"), Section IX, and the following requirements. The completed WPS shall describe all the Section IX variables and any additional requirements from this section for each welding process used in the WPS.

1. Test coupons used for welding procedure qualifications shall satisfy the material requirements of [Section 4.0](#) and shall be of the specific UNS number to be qualified.

Note Base materials used for PQRs do not require corrosion testing per [Section 4.0](#), [items 1.d.](#) and [e.](#)

2. Weld consumable manufacturer(s) and trade name(s) shall be considered essential variables and shall require re-qualification for any change in production welding usage from that qualified.

3. The following WPS/PQR qualification thickness limits shall apply:
 - a. For qualification thicknesses less than 5/8 inch (16 mm), the thickness range qualified for the WPS is the minimum thickness of the test coupon (t) to 2t or 5/8 inch (16 mm) maximum (whichever is less).
 - b. Any qualification thicknesses in the range of 5/8 inch (16 mm) to 1 1/8 inches (28.6 mm) inclusive qualifies the WPS for the entire 5/8 inch (16 mm) to 1 1/8 inch (28.6 mm) range.
 - c. For qualification thicknesses greater than 1 1/8 inches (28.6 mm), the thickness range qualified for the WPS is the thickness of the test coupon (t) up to a maximum of 1.2t.

Note *More stringent qualification thickness and heat input limits apply to equipment classified for severe sour service. Refer to [Appendix D](#).*

4. Preheat in excess of 100°F (38°C) shall be considered an essential variable requiring re-qualification for any added preheat up to the interpass temperature limitations per [Table 2](#).
5. The maximum interpass temperature used in qualification shall not exceed the limits shown in [Table 2](#) and shall be considered an essential variable for qualification of the WPS.
6. The following WPS/PQR qualification minimum and maximum heat input limitations shall apply:
 - a. The maximum heat input qualified on a PQR for a given thickness range shall not be exceeded on the WPS.
 - b. In all cases, the minimum and maximum heat input shall not exceed the ranges per [Section 5.2 item 3](#).
 - c. For qualification thicknesses from 5/8 inch (16 mm) to 1 1/8 inches (28.6 mm), the minimum heat input qualified shall be the higher of 15 kJ/inch (0.6 kJ/mm) or 50 percent of the maximum used for qualification.
 - d. For qualification thicknesses greater than 1 1/8 inches (28.6 mm), the minimum and maximum heat input to be used in production shall be qualified.
7. The current, voltage, and travel speed ranges for each size (diameter) of filler metal shall be shown on the WPS. The combination of each current, voltage, and travel speed variable in production welding shall not exceed the maximum heat input limitations.
8. The backing gas composition, when applicable, is an essential variable for qualification of the WPS and shall be in accordance with [Section 5.2 item 5](#). Supplier shall submit details of the method and equipment to be used for monitoring oxygen content as part of the WPS.
9. The shielding gas composition, when applicable, is an essential variable for qualification of the WPS and shall be in accordance with [Section 5.2 item 6](#).
10. For automatic welding, the specific make/model of welding equipment shall be considered an essential variable and shall require re-qualification for any change in production welding usage from that qualified.
11. Details of any required tack welding shall be included in the WPS. Tack welds shall not be completed at the root of single-sided welds.
12. Repair welding procedure specifications and procedure qualification records shall meet the requirements of [Section 5.5](#).

13. The minimum number of mechanical test specimens required for a welding procedure qualification test weld shall be in accordance with ASME Code, Section IX, plus the quantities shown in [Table 3](#).

Table 3: Charpy Impact and Metallurgical Sample Requirements

Test	Quantity
Charpy V-notch at -40°F (-40°C)	As required in item 16a , below:
Weld centerline	3 tests
Fusion line	3 tests
Fusion line + 3/32 inch (2.3 mm)	3 tests
Fusion line + 3/16 inch (4.5 mm)	3 tests
Cross-section from each weld procedure qualification test:	1 section for each WPS
Ferrite measurements	As required in item 16b below
Photomicrographs and macro-examination	As required in item 16c below
Hardness testing	As required in item 17 below

14. Charpy impact testing shall be in accordance with ASME Code, Section VIII, Division 1, UG-84.
15. The percent ferrite of the welding procedure qualification test weld surface shall be determined using the point count method as modified in [item 16b](#), below.
16. Acceptance standards for supplementary welding procedure qualification tests shall be as follows:
- Charpy tests:
 - The average absorbed energy value obtained for a set of three full-size 0.4 inch × 0.4 inch (10 mm × 10 mm) specimens shall be at least 37 ft-lb (50 J) with no individual value less than 30 ft-lb (40 J).
 - For sub-size specimens, the absorbed energy shall be reduced in linear proportion to the through-thickness specimen dimension.
 - Lateral expansion measurements shall be reported for information.
 - Ferrite tests (modified point counting per ASTM E562):
 - For ferrite assessment during procedure qualification tests, metallurgical sections shall be polished and electrolytically etched at 7–8 V in 40 percent NaOH to clearly reveal the two-phase austenite/ferrite microstructure.
 - The area being point counted—whether parent material, weld metal, or HAZ—shall be examined and photographed under a microscope at a sufficient magnification to fill the field of view and to be able to clearly discriminate between the constituent phases.
 - A magnification of 400X minimum shall be required.
 - The photographs shall be overlaid with a grid of at least 100 points and the percentage ferrite shall be calculated from the number of points that fall on the ferrite phase and the total number of points used.
 - The ferrite content shall be measured on one of the metallurgical cross-sections using the point counting technique at the following locations:
 - In the parent metal, one measurement on each side of the weld at mid thickness (total of 2).

- b) In the heat affected zone on each side of the weld, in the region of the root pass (total of 2).
 - c) In the weld metal, 3 measurements near the vertical centerline of the weld—one in the cap, one in the root, and one at mid thickness (total of 3).
 - 6) Ferrite content at these locations shall be 40–60 percent in the base metal and heat-affected zone, and 35–60 percent in the weld metal.
 - c. Photomicrographs and macro-examination:
 - 1) Photomicrographs at 400X minimum shall be provided to Purchaser for each location at which a phase balance assessment is performed.
 - 2) Photomicrographs shall show a typical austenite/ferrite microstructure.
 - 3) Macro-examination shall provide evidence that the weld is sound and free from cracks and other defects with full penetration and fusion between weld passes and parent metal.
- 17. Hardness testing shall be required on all weld procedure qualification records.
 - a. Hardness readings of the weld metal, HAZ, and base material shall be taken in Vickers with a 10 kg load.
 - b. At least 8 readings at a depth of 0.100 inch (2.5 mm) below the inside and below the outside surfaces shall be recorded for the base metal and HAZ on each side of the weld plus the weld deposit.
 - c. Hardness shall not be above HV310 for UNS S32205 or HV330 for UNS S32750.

5.4 Dissimilar Metal Welds

- 1. If dissimilar metal welds between UNS S32205 or UNS S32750 and carbon steel or 300 series stainless steel are required, manufacturer shall submit a qualified WPS for written acceptance.
 - a. The duplex stainless steel portion of the dissimilar weldment shall comply with all the requirements of [Section 5.0](#) of this specification.
 - b. As part of the welding procedure qualification, a microhardness survey shall be completed across the weld to make sure there are no hardness values that exceed those recommended by NACE MR0103.
 - c. In addition, the tensile strength of the completed joint shall equal or exceed that of the lower strength material.
 - d. The AWS classification weld consumables listed in [Table 4](#) shall be preferred for dissimilar metal welds, and shall comply with the acceptable manufacturer per [Table 1](#).

Table 4: Weld Consumables

Welded To	2205	2507
316L/304L or Carbon steel	E2209-15 ER2209	E2594-15 ER2594

- 2. Because the yield strength of UNS S32205 is higher than either carbon or 300 series stainless steel, the weld procedure qualification shall be performed using longitudinal bends or transverse bends using a wrap-around bend fixture rather than standard traverse bends as permitted by the ASME Code.

3. Dissimilar welds between duplex stainless steels (either UNS S32205 or UNS S32750) and UNS N08825 shall be prohibited.
4. Dissimilar welds between duplex stainless steels (either UNS S32205 or UNS 32750) and any other material shall not be permitted without Purchaser's written acceptance.
5. Nb-bearing filler materials shall not be used for dissimilar metal welds.

5.5 Repairs

1. Welds (or casting base metal, when authorized) requiring repairs shall have a specific repair procedure accepted by Purchaser, which includes information on the technique for removing and verifying removal of defects.
2. A weld procedure specification for the repair shall be qualified in accordance with the ASME Code and shall meet the additional requirements for qualification as stated herein.
 - a. For partial-thickness repairs, cap repairs, casting base metal repairs, and double-sided repairs, previously qualified procedures may be used.
 - b. For single-sided root repairs, requalification simulating the repair shall be required.
3. Only one weld repair shall be allowed.
4. If an additional repair is required, the complete weld and heat affected zone shall be cut out.
 - a. Rejected welds shall either be cut out or repaired at manufacturer's expense.
 - b. Repair welds shall be reinspected by the same techniques.

5.6 Tube-to-Tubesheet Joint Requirements

1. Tube-to-tubesheet joints shall be as follows:
 - a. Tube-to-tubesheet joints shall be made by hydro expanding or rolling. Alternatively, the user may specify seal or strength welding of these joints.
 - b. When welding is specified, the following shall be submitted by manufacturer for review and acceptance prior to start of fabrication:
 - 1) Procedures for making the tube-to-tubesheet joint.
 - 2) A detailed WPS and PQR for the welding.
 - c. The tube-to-tubesheet welding requirements in [Appendix B](#) and in [Section 5.2](#) shall apply to tube-to-tubesheet seal welding, where applicable.
 - d. Tube-to-tubesheet seal welds shall be made using either the GTAW or SMAW process with the addition of filler metal. The weld throats and legs (minimum leak paths) shall not be less than the thickness of the tube wall.
2. Rolled tube-to-tubesheet joints shall be as follows:
 - a. A detailed hydro expanding or rolling procedure shall be submitted for review and acceptance prior to start of fabrication
 - b. Manufacturer shall supply a list of exchangers that have been provided with hydro expanded or rolled tube-to-tubesheet joints operating at pressures equal to or higher than the exchanger being fabricated.
 - c. Maximum tube wall thickness reduction allowed shall be 5 percent.
 - d. The tube ends shall be expanded to within .125 inch (3.175 mm) of the shell side face of the tubesheet. Tube expansion shall not extend past the tubesheet.

5.7 Post Weld Heat Treatment

1. Post weld heat treatment (PWHT) shall be prohibited unless specified by Purchaser.
2. If Purchaser specifies PWHT, Supplier shall submit a heat treating procedure for acceptance.

6.0 TUBE AND PIPE BENDS

1. Pipe bends shall not be permitted without written agreement from Purchaser.
2. If the manufacturer proposes hot or cold bend, the following information shall be included in the proposed procedure:
 - a. Heat treating process.
 - b. Heating temperature range.
 - c. Temperature monitoring method.
 - d. Bending parameters.
 - e. Cooling method.
 - f. Post bending heat treatment.
 - g. Inspection and testing—including number and location of wall thickness measurements and microstructure of test bends from each combination of diameter and wall thicknesses the manufacturer proposes to bend.
3. Tube bending requirements shall be as detailed in [Appendix C](#).

7.0 INSPECTION AND TESTING

7.1 Liquid Penetrant Examination

1. All welds shall undergo liquid penetrant examination (PT) in accordance with ASME Code, Section V, Article 6, using solvent removable penetrant in accordance with paragraph T-662.
2. PT materials shall be the non-halogen type acceptable for use on stainless steels.
3. PT of welds shall include a band of base metal at least one inch (25 mm) wide on each side of the weld and both faces of the joint where accessible.
4. The evaluation of indications and acceptable criteria shall be in accordance with ASME Code, Section VIII, Division I, Appendix 8.
5. PT shall be required after rolling on tube-to-tubesheet weld joints where access permits an accurate evaluation.

7.2 Radiographic Examination

1. All butt welds (long seams and round seams) shall be 100 percent radiographic examined (RT) in accordance with ASME Code, Section VIII, Division 1, paragraph UW-51.
2. Butt welds that cannot be RT shall be shear wave ultrasonically examined in accordance with ASME Code, Section VIII, Division 1, paragraph UW-53.
3. Fluorescent intensifying screens shall not be used.
4. Initial radiographs and written reports of interpretations shall be made as soon as possible after completion of individual welds to permit evaluation of welder skill and general weld quality in the early stages of fabrication.

7.3 Ferrite Checks

1. The percent ferrite content of all accessible completed external surfaces of production welds shall be checked using a Fischer Feritescope. Where possible, checks shall be conducted on the process side of the weld.
2. A minimum of two tests shall be made on each weld—one near the beginning and one near the end of the weld. In addition, the following requirements shall apply:
 - a. Seam welds on large vessels shall have at least one check for every 3 feet (1 m) of weld length.
 - b. Circumferential weld 6 inches (152.4 mm) in diameter and larger shall be checked in four quadrants, 90 degrees apart.
3. The ferrite content of production welds shall be in the 30–65 volume percent range unless the requirements of [Appendix D](#) for severe sour service or hydrogen charging are invoked, in which case the required range shall be 35–60 percent ferrite.
 - a. No reading shall be outside the specified range.
 - b. Out-of-range values shall require additional checks and the need for repair shall be assessed by Purchaser on a case-by-case basis.
 - c. Purchaser's inspector shall be consulted on the choice of locations for additional checks.
 - d. Results of all ferrite checks shall be documented by Supplier and included in Supplier's final NDE report.

7.4 Positive Material Identification

Each heat of base material and each lot of welding consumable shall be subjected to positive material identification (PMI) prior to use, in accordance with CPM-PU-5074-A.

7.5 Hydrostatic Testing

1. Only potable water with no more than 100 ppm chlorides shall be used for hydrostatic testing.
2. Piping and equipment shall be completely drained and blown dry immediately after testing is completed.

8.0 DOCUMENTATION

Supplier shall submit the following documentation to Purchaser:

1. Code certificates
2. Mill test reports
3. WPS and supporting PQR
4. Welder performance qualification (WPQ) records
5. Welders stamp I.D.s and assignments
6. Nondestructive examination procedures and personnel qualifications
7. Nondestructive examination results
8. Hydrostatic test records
9. Temperature charts from heat treatment
10. Weld maps

APPENDIX A
REQUIREMENTS FOR WELDED TUBES

When welded tubes are permitted, they shall be supplied in accordance with ASTM A789 and the following additional requirements.

1. Two tubes shall be taken from each lot following final solution anneal for examination.
 - a. Volume percent ferrite content shall be determined in the electric fusion welded (EFW) seam and adjacent base metal.
 - b. The microstructure shall be revealed by an electrolytic etch at 7–8 V in 40 percent KOH. Ferrite content, determined using the point count test method given in ASTM E562 (minimum grid size of 100 points) or other quantitative metallographic methods such as image analysis, shall be 40 to 60 volume percent for base metal and 35 to 60 volume percent for the weld area.
2. A minimum of 3 Vickers (10 Kg load) hardness readings shall be taken on the tube wall cross-section, spaced 120 degrees apart.
 - a. One hardness reading shall be made in the EFW seam.
 - b. No hardness reading shall exceed 310 HV10.
 - c. Distance from the center of the impression to the edge of the ring shall be at least 2.5 times the width of the impression.
3. EFW tubing shall be furnished with certification of eddy current testing (ET) and a 150 psig (10.5 kg/cm²) air under water test.
4. ET shall be conducted after the final solution anneal.
5. The cross-section of each straight tube shall be 100 percent ET using the magnetic saturation technique in accordance with ASTM A450 and E309.
6. The calibration standard for ET shall be constructed from a tube of the same material and heat treatment to be used in production and shall conform to the requirements of ASTM A803, Supplementary Requirement S2.
7. Repair welding of tubes shall not be permitted after the final heat treatment.

APPENDIX B
REQUIREMENTS FOR TUBE-TO-TUBESHEET WELDING

Tube-to-tubesheet welding procedure specifications shall be qualified in accordance with the requirements of ASME Code, Section IX, QW-193, and the following notes:

1. The test assembly shall simulate all steps of the production joint, including both tube expansion and welding, as applicable.
 - a. If production welding is to be performed through the plug sheet, this shall also be simulated in the test assembly.
 - b. Details of the test assembly and proposed fabrication sequence shall be provided for Purchaser review and acceptance prior to the start of the qualification test.
 - c. In addition to the macro-examination required by ASME Code, Section IX, QW-193.1.3, the microstructure and ferrite content of one randomly selected weld shall be assessed using the procedures detailed in ASTM E562 as modified in [Section 5.3, item 16b](#).
2. Hardness (Hv10) readings shall be taken in the HAZ, weld deposit, and tubesheet base metal.
 - a. A minimum of six readings in each of the above areas shall be taken on each of four of the tube-to-tubesheet joints prepared for metallographic examination.
 - b. Hardness shall not be above 310.
3. Dissimilar metal tube-to-tubesheet welds shall be prohibited.

APPENDIX C
REQUIREMENTS FOR TUBE BENDING

1. All straight tube furnished for U-bending shall be in the solution-annealed condition.
2. Purchaser shall advise fabricator of the heat treatment condition required for U-bent tubes.
3. Purchase order and applicable drawings shall state which heat treatment condition is required for each row of U-bent tubes. Three conditions are permissible:
 - a. Cold bent with no subsequent heat treatment:
 - b. Locally heat-treated U-bend, made either by local heating for hot bending or by local heating after cold bending.
 - c. Full length solution anneal after bending:
4. Cold bent tubes with no subsequent heat treatment (condition 3.a above) shall be subject to the following requirements:
 - a. Tubing U-bends shall be made cold and not subjected to a post-bending heat treatment.
 - b. Cold bent tubes shall not exceed 15 percent strain or have a bend radius less than 3 tube diameters for S32205 or 4 tube diameters for S32750, as measured at the tube centerlines.
 - c. A bending qualification procedure shall be performed as follows:
 - 1) A radially oriented ring sample shall be removed from the bend apex of a U-tube sample having the smallest diameter bend.
 - 2) Three microhardness Hv10 values shall be taken as close to the extrados as possible.
 - 3) The distance from the center of the impression to the edge of the ring shall be at least 2.5 times the width of the impression.
 - 4) Hardness shall not be above Hv 310.
5. Hot bending or local heat treatment (when specified) after cold bending shall be performed as follows:
 - a. Tubes shall be heated by induction or electric resistance and held within the temperature range 1870–2010°F (1020–1100°C) for S32205, and 1880–2060°F (1025–1125°C) for S32750 as permitted by ASTM A789, Table 2, followed by a rapid cool below 600°F (315.6°C) using forced air, inert gas, or water.
 - b. Total time above 600°F (315.6°C) shall be less than 5 minutes.
 - c. The full tube bend and a minimum of 6 inches (152.4 mm) of each leg beyond the tangent point of the bend shall be heated to the required bending temperature.
 - d. The controlling temperature shall be measured using a thermocouple or calibrated optical pyrometer.
 - e. The ID and OD of the tube bends shall be free of heat tint and surface oxides. This may be accomplished using an inert gas purge during heating or cooling above 600°F (315.6°C) or by pickling.
 - f. If using electric-resistance heating methods where electrodes are clamped to the tubes, clamped areas shall be visually examined for arc burns. Any burn indications shall be cause for rejection of the entire tube.

- g. A qualification test for the bending and heat treatment procedure shall be performed on a minimum of one U-tube sample of the smallest diameter bend and evaluated as follows:
 - 1) Bending and heat treatment of the sample shall be performed in conformance with all production bending procedures, utilizing the same method of heating, cooling (e.g., from the OD only), feeding, etc.
 - 2) A radially oriented ring sample, approximately 1 inch (25.4 mm) long, shall be removed from the bend apex.
 - 3) A metallographic examination shall be performed to establish volume percent ferrite content (the sample cross-section shall be polished and etched to clearly reveal a two-phase austenite/ferrite microstructure [see ASTM A923 Method A for etching guidelines]).
 - 4) Ferrite content—determined using the point count test method described in ASTM E562 (minimum grid size of 100 points) or other quantitative metallographic method such as image analysis—shall be 40 to 60 volume percent.
 - 5) The ring sample shall then be tested in accordance with the requirements of ASTM A923. The tube bend shall be free of sigma and other deleterious phases.
- 6. Full length solution anneal after bending (when specified) shall be performed as follows:
 - a. Supplier shall submit a detailed procedure for performing the heat treatment.
 - b. 100 percent of each tube shall be heated to the temperature range 1870–2010°F (1020–1100°C) for S32205, and 1880–2060°F (1025–1125°C) for S32750, as permitted by ASTM A789, Table 2, and followed by a rapid cool below 600°F (315.6°C) using forced air, inert gas, or water.
 - c. The controlling temperature shall be measured using a thermocouple or calibrated optical pyrometer.
 - d. The ID and OD of the tube bends shall be free of heat tint and surface oxides. This may be accomplished using an inert gas purge during heating and cooling above 600°F (315.6°C) or by pickling.
 - e. A qualification test for the bending and heat treatment procedure shall be performed on a minimum of one U-tube sample of the smallest diameter bend and evaluated as follows:
 - 1) Bending and heat treatment of the sample shall be performed in conformance with all production bending procedures, utilizing the same method of heating, cooling (e.g., from the OD only), feeding, etc.
 - 2) A radially oriented ring sample, approximately 1 inch (25.4 mm) long, shall be removed from the bend apex.
 - 3) A metallographic examination shall be performed to establish volume percent ferrite content (the sample cross-section shall be polished and etched to clearly reveal a two-phase austenite/ferrite microstructure [see ASTM A923 Method A for etching guidelines]).
 - 4) Ferrite content—determined using the point count test method described in ASTM E562 (minimum grid size of 100 points) or other quantitative metallographic method such as image analysis—shall be 40 to 60 volume percent.
 - 5) The ring sample shall then be tested in accordance with the requirements of ASTM A923. The tube bend shall be free of sigma and other deleterious phases.
- 7. Permissible variations in U-tube dimensions shall be in accordance with ASTM A803. Surface defects that violate minimum wall requirements shall be cause for rejection.

APPENDIX D
REQUIREMENTS FOR SEVERE SOUR SERVICE OR
HYDROGEN CHARGING SERVICE

The following requirements apply to equipment in severe sour service or hydrogen charging environments. Purchaser shall advise fabricator when these requirements apply.

1. Equipment shall be designed to meet the applicable limits on stress and strain per DNV RP F112.
 - a. Pressure equipment designed in accordance with ASME Code, Section VIII, Division 1 (vessels), or ASME B31.3 (piping) codes, satisfies the linear elastic stress criteria of DNV RP F112 and, thus, no further recourse to the DNV recommended practice is necessary.
 - b. ASME B31.3 design limits on sustained and thermal expansion stresses meet the linear elastic stress requirements of DNV RP F112.
 - c. Upset conditions (typically seismic and wind loads) evaluated under ASME Code, Section VIII, Division 1, and ASME B31.3, shall limit the combined upset case membrane plus bending stress to the duplex material specified minimum yield strength (SMYS), corrected for temperature effects if necessary.
 - d. Application of the ASME Code, Section VIII, Division 2, or pipeline design codes that stipulate a pressure design basis greater than 0.45 times SMYS shall, in addition, require that DNV RP F112 stress and strain limits are satisfied. The Supplier shall submit a detailed analysis plan for Owner acceptance prior to the application of the cited codes.
2. Formed (spun or dished) heads shall be solution annealed and water quenched after forming.
3. Tube bends and pipe bends shall be either locally heat treated or full-length solution annealed after bending, followed by rapid quenching by water, inert gas, or air in accordance with [Appendix C](#). Local furnace heat treatment of bends is not permitted.
4. Header boxes for air-cooled heat exchangers shall comply with the following:
 - a. The design concept shall be in accordance with ASME Code, Section VIII, Division 1 lethal service details with either a hub tubesheet per Figure UW-13.3 or a seamless header per Figure 13-2(1)(3), 13-2(b)(1), 13-2(b)(3), or Figure 13-2(c).
 - b. Header box plates shall be cut so that the principal rolling direction of the plate is transverse to the longitudinal seam of the box.
 - c. Longitudinal header box seams shall be background flush on the side facing the process so that there is no stress concentration and zero undercut at the weld toe. The ground surface shall be 125 RMS finish or better, with grind marks oriented transverse to the weld axis.
5. More stringent WPS/PQR qualification thickness limits apply for severe sour service (per [Section 5.3 item 3](#)). The maximum thickness range qualified shall be 1.2 times the actual test coupon thickness used for the PQR, and the minimum thickness qualified shall be the actual test coupon thickness.

APPENDIX E

REQUIREMENTS FOR OFFSHORE AND PRODUCED BRINE SERVICE

The following requirements apply to equipment in offshore and brine services. Purchaser shall advise fabricator when these requirements apply.

1. Minimum pitting resistance equivalent number (PREN) shall be 36 for UNS S31803/S32205 and 40 for UNS S32750 materials, using the following formula:

$$\text{PREN} = \% \text{Cr} + (3.3 \times \text{Wt. \% Mo}) + (16 \times \text{Wt. \% N})$$

2. Corrosion testing shall be performed on all plate and nozzle weld procedure qualifications.
 - a. Test specimens shall be prepared and tested in accordance with ASTM G48, Method A.
 - b. Test exposure time shall be 24 hours.
 - c. Cut edges shall be prepared according to ASTM G48.
 - 1) The whole specimen shall be pickled before being weighed and tested.
 - 2) Pickling may be performed for five minutes at 140°F (60°C) in a solution of 20 percent HNO₃ + 5 percent HF.
 - d. Duplex stainless (22 percent chrome) shall be tested at 72°F (22°C) and super duplex (25 percent chrome) at 104°F (40°C).
 - e. The measured corrosion rate shall not exceed 4 g/m²/day.
 - f. No pitting shall be visible at 20X magnification.