

Materials and Fabrication Requirements for 2-¹/₄Cr-1Mo & 3Cr-1Mo Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service

API RECOMMENDED PRACTICE 934
FIRST EDITION DECEMBER 2000



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Materials and Fabrication Requirements for 2 1/4Cr-1Mo & 3Cr-1Mo Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen ServiceAPI

Downstream Segment

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Materials and Fabrication Requirements for 2-1/4CR-1MO & 3CR-1MO Steel Heavy Wall Pressure Vessels For High Temp., High Pressure Hydrogen Service

1 Introduction

This recommended practice applies to new heavy wall pressure vessels in petroleum refining, petrochemical and chemical facilities in which hydrogen or hydrogen-containing fluids are processed at elevated temperature and pressure. It is based on decades of industry operating experience and the results of experimentation and testing conducted by independent manufacturers, fabricators and users of heavy wall pressure vessels for this service.

Licensors and owners of process units in which these heavy wall pressure vessels are to be used may modify and/or supplement this recommended practice with additional proprietary requirements.

1.1 SCOPE

This recommended practice presents materials and fabrication requirements for new 2-1/4Cr and 3Cr steel heavy wall pressure vessels for high temperature, high pressure hydrogen service. It applies to vessels that are designed, fabricated, certified and documented in accordance with ASME Code Section VIII, Division 2, including Appendix 26, *Mandatory Rules for Cr-Mo Steels with Additional Requirements for Welding and Heat Treatment* and ASME Code Case 2151, as applicable.

Materials covered by this recommended practice are conventional steels including standard 2-1/4Cr-1Mo and standard 3Cr-1Mo steels, and advanced steels including enhanced 2-1/4Cr-1Mo, 2-1/4Cr-1Mo-1/4V, 3Cr-1Mo-1/4V-Ti-B, and 3Cr-1Mo-1/4V-Cb-Ca steels. The interior surfaces of these heavy wall pressure vessels may have an austenitic stainless steel weld overlay to provide additional corrosion resistance.

2 References

Unless otherwise specified, the most recent editions at the time of purchase order or revisions of the following codes, standards, and specifications shall, to the extent specified herein, form a part of this recommended practice.

ASME¹

Boiler and Pressure Vessel Code

Section II - Materials

Part A *Ferrous Material Specifications*

Part C *Specification for Welding Rods, Electrodes and Filler Metals*

Part D *Properties*

Section V *Nondestructive Examination*

Section VIII *Rules for Construction of Pressure Vessels*

Division 2 *Alternative Rules*

Appendix 26 *Mandatory Rules for Cr-Mo Steels with Additional Requirements for Welding and Heat Treatment*

Code Case 21513 *Chromium - 1 Molybdenum - 1/4 Vanadium - Columbium - Calcium Alloy Steel Plates and Forgings*

Code Case 2235 *Use of Ultrasonic Examination in Lieu of Radiography*

Section IX *Welding and Brazing Qualifications*

SA-20 *Specification for General Requirements for Steel Plates for Pressure Vessels*

SA-182 *Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*

SA-335 *Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service*

SA-336 *Specification for Alloy Steel Forgings for Pressure and High-Temperature Parts*

SA-369 *Specification for Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service*

SA-387 *Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum*

SA-435 *Specification for Straight-Beam Ultrasonic Examination of Steel Plates*

SA-508 *Specification for Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels*

SA-541 *Specification for Quenched and Tempered Carbon and Alloy Steel Forgings for Pressure Vessel Components*

SA-542 *Specification for Pressure Vessel Plates, Alloy Steel, Quenched-and-Tempered, Chromium-Molybdenum, and Chromium-Molybdenum-Vanadium*

SA-578 *Specification for Straight-Beam Ultrasonic Examination of Plain and Clad Steel Plates for Special Applications*

SA-832 *Specification for Pressure Vessel Plates, Alloy Steel, Chromium - Molybdenum-Vanadium*

¹ASME International, Three Park Avenue, New York, New York 10016-5990, www.asme.org.

ASNT²

SNT-TC-1A

ASTM³

G-146

Standard Practice for Evaluation of Disbonding of Bimetallic Stainless Alloy/Steel Plate for Use in High-Pressure, High-Temperature Refinery Hydrogen Service

AWS⁴

A4.2

Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal

A4.3

Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding

WRC⁵

Bulletin 342

Stainless Steel Weld Metal: Prediction of Ferrite Content

3 Definitions

3.1 DEFINITIONS

For the purposes of this recommended practice, the following definitions apply:

3.1.1 advanced steels: Enhanced 2-1/4Cr-1 Mo, 2-1/4Cr-1 Mo-1/4 V, 3Cr-1 Mo-1/4 V-Ti-B, and 3 Cr-1 Mo-1/4V-Cb-Ca steels.

3.1.2 ASME code: ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 2, including applicable addenda.

3.1.3 conventional steels: Standard 2-1/4 Cr-1 Mo and standard 3 Cr-1 Mo steels

3.1.4 final PWHT: The last post-weld heat treatment after fabrication of the vessel and prior to placing the vessel in service.

3.1.5 hot forming: Mechanical forming of vessel components above the final PWHT temperature.

3.1.6 maximum PWHT: Specified heat treatment of test specimens used to simulate all fabrication heat treatments after normalizing and initial tempering, including all intermediate heat treatments above 900°F (482°C), the final PWHT,

and a minimum of one extra PWHT for future use by the owner.

3.1.7 minimum PWHT: Specified heat treatment of test specimens used to simulate all fabrication heat treatments after normalizing and initial tempering, including all intermediate heat treatments above 900°F (482°C) and the final PWHT.

3.1.8 Step cooling heat treatment: Specified heat treatment used to simulate and accelerate embrittlement of test specimens for the purpose of evaluating the potential for temper embrittlement of alloy steels in high-temperature service.

3.2 ACRONYMS

For the purposes of this recommended practice, the following acronyms apply:

CMTR	certified material test report
DHT	dehydrogenation heat treatment
FN	ferrite number
HAZ	heat-affected zone
HB	Brinell hardness
HV	Vickers hardness
ISR	intermediate stress relief
MDMT	minimum design metal temperature
MT	magnetic particle testing
NDE	nondestructive examination
PT	penetrant testing
PWHT	post-weld heat treatment
RT	radiographic testing
UT	ultrasonic testing
WPQT	welding procedure qualification test

4 Design

4.1 Design and manufacture shall conform to the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 2. The latest edition including addenda effective through the date of the purchase agreement shall be used.

4.2 Design issues are typically covered by a manufacturer's design report that shows compliance of the design with the user's design document, ASME Code strength calculations, drawings and local stress analysis for extra loads, and special design requirements, if required.

4.3 This recommended practice is not intended to cover design issues other than those below.

4.3.1 Weld seam layouts shall provide that all welds are accessible for fabrication and in-service NDE such as RT, UT, MT, and PT.

4.3.2 Nozzle necks shall have transition to the vessel body as shown in Figure AD-560.1 and Figure AD-613.1 of the ASME Code.

²American Society of Nondestructive Testing, 1711 Arlington Lane, Columbus, Ohio 43228, www.asnt.org

³American Society for Testing and Materials, 100 Bar Harbor Dr., West Conshohocken, Pennsylvania 19428-2959, www.astm.org

⁴American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33135, www.aws.org

⁵Welding Research Council, Three Park Avenue, 27th Floor, New York, New York 10016-5902, www.forengineers.org

5 Base Metal Requirements

5.1 MATERIAL SPECIFICATIONS

5.1.1 Base metals shall be in accordance with the applicable ASME specifications indicated in Table 4–1.

5.1.2 Unless approved in advance by the owner/user, different base metals shall not be mixed in the same vessel (e.g., 2-1/4 Cr–1 Mo–1/4 V nozzles shall not be used with standard 2-1/4 Cr–1 Mo shell plates).

5.2 STEEL MAKING PRACTICE

5.2.1 In addition to steel making practices outlined in the applicable material specifications, the steels shall be vacuum degassed.

5.3 CHEMICAL COMPOSITION LIMITS

Chemical composition of the base metals shall be limited as follows in order to minimize susceptibility to temper embrittlement (these chemical composition limits apply to each heat analysis):

J-factor = (Si + Mn) x (P + Sn) x 10⁴ ≤ 100 [Si, Mn, P, and Sn in wt%]

Cu content: 0.20% maximum

Ni content: 0.30% maximum

5.4 HEAT TREATMENT

5.4.1 All product forms shall be normalized and tempered or quenched and tempered to meet the required mechanical properties. Cooling from the austenitizing temperature shall be accelerated by air blasting or liquid quenching to develop a microstructure consisting of a minimum of 90% bainite.

5.4.2 Base metals that are hot formed above 1250°F (675°C) shall be heat treated as specified in 5.4.1 after hot forming.

5.5 MECHANICAL PROPERTIES

5.5.1 Test Specimens

5.5.1.1 Location of Test Specimens

Test specimens for establishing the tensile and impact properties shall be removed from the following locations:

- Plate—from each plate transverse to the rolling direction in accordance with SA-20, except test specimens shall be taken from 1/2T.
- Forging—from each heat transverse to the major working direction in accordance with SA-182, SA-336, SA 508 or SA 541, except test specimens shall be taken at 1/2T of the pro-longation's thickness.
- Pipe—from each heat and lot of pipe, transverse to the major working direction in accordance with SA 20, except test specimens shall be taken from 1/2T.

5.5.1.2 Heat Treatment of Test Specimens

Test specimens shall be heat treated as specified in Table 5–1. If the base metal is heat treated after hot forming, test specimens shall be subjected to a simulated hot forming heat treatment prior to the heat treatment specified in Table 5-1.

5.5.2 Tensile Properties

5.5.2.1 Ambient temperature tensile properties after heat treatment specified in 5.5.1.2 shall meet the requirements of the applicable base metal specification. In addition, the following limits on the tensile properties shall apply:

Table 4–1—Base Metal Specifications

Steel		Conventional		Advanced			
Product Form	ASME Spec	Standard 2-1/4 Cr–1 Mo	Standard 3Cr–1 Mo	Enhanced 2-1/4 Cr–1 Mo ^a	2-1/4 Cr–1 Mo–1/4 V ^a	3Cr–1 Mo–1/4 V–Ti–B ^a	3Cr–1 Mo–1/4 V–Cb–Ca ^b
Plate	SA 387	Gr. 22, Cl. 2	Gr. 21, Cl. 2	–	–	–	–
	SA 542	–	–	Type B, Cl. 4	Type D, Cl. 4a	Type C, Cl. 4a	Type E, Cl. 4a
Forging	SA 832	–	–	–	Gr. 22V	Gr. 21V	Gr. 23V
	SA 182	Gr. F22, Cl. 3	Gr. F21	–	Gr. F22V	Gr. F3V	Gr. F3VCb
	SA 336	Gr. F22, Cl. 3	Gr. F21, Cl. 3	–	Gr. F22V	Gr. F3V	Gr. F3VCb
	SA 508	–	–	Gr. 22, Cl. 3	–	Gr. 3V	Gr. 3VCb
Pipe	SA 541	–	–	Gr. 22, Cl. 3	Gr. 22V	Gr. 3V	Gr. 3VCb
	SA 335	Gr. P22	Gr. P21	–	–	–	–
Pipe (Forged or Bored)	SA 369	Gr. FP22	Gr. FP21	–	–	–	–

Note: ^a Covered in Table 26-100.1 of Appendix 26 of the ASME Code. ^b Covered in ASME Code Case 2151.

Tensile strength shall not exceed the following limits:

- a. Conventional steels: 100 ksi (690 N/mm²)
- b. Advanced steels: 110 ksi (760 N/mm²)

Yield strength shall not exceed the following limits:

- a. Conventional steels: 90 ksi (620 N/mm²)
- b. Advanced steels: 90 ksi (620 N/mm²)

5.5.2.2 Elevated temperature tensile tests, when required by the purchaser, shall be performed at the equipment design temperature. Test specimens shall be in the maximum PWHT condition. Acceptance values shall be as specified by the owner/user.

5.5.3 Impact Properties

5.5.3.1 Average impact values at -20°F (-29°C) of three Charpy V-notch test specimens heat treated in accordance with 5.5.1.2 shall not be less than 40 ft-lb (55 J) with no single value below 35 ft-lb (47 J). The percent ductile fracture and lateral expansion in mils shall also be reported.

5.5.3.2 Step Cooling Tests

5.5.3.2.1 Prior to the start of fabrication, step-cooling tests shall be performed on each heat of base metal to determine its susceptibility to temper embrittlement, unless waived by the purchaser.

Two sets of Charpy V-notch test specimens, with a minimum of 24 specimens per set, shall be prepared and subjected to the following heat treatments:

Set 1—Minimum PWHT only, to establish a transition temperature curve before step cooling.

Set 2—Minimum PWHT plus the step cooling heat treatment specified in 5.5.3.2.3, to establish a transition temperature curve after step cooling.

5.5.3.2.2 Step cooling heat treatment shall be as follows:

1. Heat to 600°F (316°C), heating rate not critical;
2. Heat at 100°F (56°C)/hour maximum to 1100°F (593°C);
3. Hold at 1100°F (593°C) for 1 hour;
4. Cool at 10°F (6°C)/hour maximum to 1000°F (538°C);
5. Hold at 1000°F (538°C) for 15 hours;
6. Cool at 10°F (6°C)/hour maximum to 975°F (524°C);
7. Hold at 975°F (524°C) for 24 hours;
8. Cool at 10°F (6°C)/hour maximum to 925°F (496°C);
9. Hold at 925°F (496°C) for 60 hours;
10. Cool at 5°F (3°C)/hour maximum to 875°F (468°C);
11. Hold at 875°F (468°C) for 100 hours;
12. Cool at 50°F (28°C)/hour maximum to 600°F (316°C);
13. Cool to ambient temperature in still air.

5.5.3.2.3 After the Charpy V-notch test specimen sets are heat treated, each set of specimens shall be impact tested at eight selected test temperatures to establish a transition temperature curve. One of the tests shall be performed at -20°F (-29°C). Three specimens shall be tested at each test temperature. The transition temperature curve shall be established from at least two test temperatures on both the upper and lower shelf and a minimum of four intermediate test temperatures.

5.5.3.2.4 The 40 ft-lb (55 J) transition temperatures shall be determined from the transition temperature curves established from the two sets of Charpy V-notch specimens. The impact properties shall meet the following requirement:

$$\text{CvTr40} + 2.5 \text{ DCvTr40} \leq 50^{\circ}\text{F} (10^{\circ}\text{C}), \text{ where}$$

CvTr40 = 40 ft-lb (55 J) transition temperature of the base metal subjected to the minimum PWHT only.

DCvTr40 = the shift of the 40 ft-lb (55 J) transition temperature of material subjected to the minimum PWHT plus the step cooling heat treatment.

6 Welding Consumable Requirements

6.1 MATERIAL REQUIREMENTS

6.1.1 The deposited weld metal, from each lot or batch of welding electrodes and each heat of filler wires, and each combination of filler wire and flux, shall match the nominal chemical composition of the base metal to be welded.

6.1.2 The following chemical composition limits shall be controlled to minimize temper embrittlement.

$$\text{X-bar} = (10\text{P} + 5\text{Sb} + 4\text{Sn} + \text{As}) / 100 \leq 15$$

[P, Sb, Sn, and As in ppm]

Cu: 0.20% maximum

Ni: 0.30% maximum

6.1.3 Low hydrogen welding consumables, including fluxes, having a maximum of 10 ml of diffusible hydrogen for every 100 grams of weld metal, per AWS A4.3, shall be used. They shall be baked and stored in accordance with manufacturer's instructions, i.e., electrode oven, to reduce moisture content and to ensure their low hydrogen nature.

6.2 MECHANICAL PROPERTIES

6.2.1 Tensile Properties

The tensile properties of the deposited weld metal shall meet those of the base metal in accordance with 5.5.2.

Table 5–1—Heat Treatment of Test Specimens

	Tensile Test	Impact Test	Step Cooling Test
Conventional Steels	Maximum PWHT	Minimum PWHT or Maximum PWHT	Minimum PWHT
Advanced Steels	In accordance with Para. 26-300 in Appendix 26 of the Code or Code Case 2151, as applicable.	In accordance with Para. 26-300 in Appendix 26 of the Code or Code Case 2151, as applicable.	Minimum PWHT

6.2.2 Impact Properties

Prior to the start of fabrication, each lot of electrodes, heat of filler wire, and combination of lot of flux and heat of wire, shall be screened by impact testing of weld deposit to show resistance to temper embrittlement as follows:

- Conventional steels: Step cooling tests shall be performed as specified for the base metal in 5.5.3.2. The impact properties shall meet the requirements of 5.5.3.2.5.
- Advanced steels: Impact testing shall be performed in accordance with Para. 26-300 of the Code or Code Case 2151, as applicable. Step cooling tests shall be in accordance with 5.5.3.2.

7 Welding, Heat Treatment and Production Testing

7.1 GENERAL WELDING REQUIREMENTS

7.1.1 Base metal surfaces prior to welding or applying weld overlay shall consist of clean metal surface prepared by machining, grinding or blast cleaning.

7.1.2 All welded joints including non-pressure attachments to the vessel body shall:

- Have full penetration joint design;
- Be located so that full ultrasonic examination of welds can be made after fabrication and after installation is complete (in cases where this is not practical, the manufacturer shall propose alternate NDE methods to verify weld quality); and
- Be made sufficiently smooth to facilitate nondestructive examination (MT, PT, UT or RT), as applicable.

7.1.3 All welding shall be completed prior to final PWHT except welding of internal attachments to the austenitic stainless steel overlay. For these attachment welds, a WPQT or mockup test shall be performed to verify that this does not produce a HAZ in the base metal.

7.1.4 All weld repairs to base metal, weld joints and weld overlay shall be performed using a repair welding procedure qualified in accordance with 7.2.1 or 7.3.3, as applicable.

7.2 BASE METAL WELDING

7.2.1 Welding Procedure Qualification

7.2.1.1 Welding procedures shall be qualified in accordance with the following:

- Conventional steels—Section IX of the ASME Code.
- Advanced steels—Section IX and Para. 26-400 in Appendix 26 or Code Case 2151 of the ASME Code, as applicable.

7.2.1.2 Base metal for welding procedure qualification tests shall be made from the same ASME base metal specification and steel making process, and shall have the same chemical composition, heat treatment and mechanical property requirements as specified for the vessel. The welding electrodes, wire and flux shall be of the same type and brand as those used in production.

7.2.1.3 Charpy V-notch impact testing shall be performed on weld metal and HAZ of the heat-treated test plate in both the minimum PWHT and maximum PWHT conditions. These impact tests shall be performed for each welding procedure and shall meet the impact test temperature and acceptance requirements in 5.5.3.1.

7.2.1.4 Step cooling tests shall be performed on the weld metal and HAZ for each welding procedure as specified for the base metal in 5.5.3.2.

7.2.1.5 Two Vickers hardness traverses of the weld joint shall be made on a weld sample in the minimum PWHT condition. These hardness traverses shall be performed at $1/16$ in. (1.5 mm) from the internal and external surfaces as shown in Figure 7-1. The HAZ readings shall include locations as close as possible (approximately 8 mils [0.2 mm]) to the weld fusion line. Each traverse includes ten hardness readings for a total of 20 hardness readings per weld sample. The hardness shall not exceed 235 HV10.

7.2.1.6 A tensile test, transverse to the weld, shall be performed on a weld joint of the heat treated test plate in the maximum PWHT condition and shall meet the ambient temperature properties specified for the base metal in 5.5.2.

7.2.1.7 All WPSs/PQRs shall be approved by the purchaser prior to fabrication.

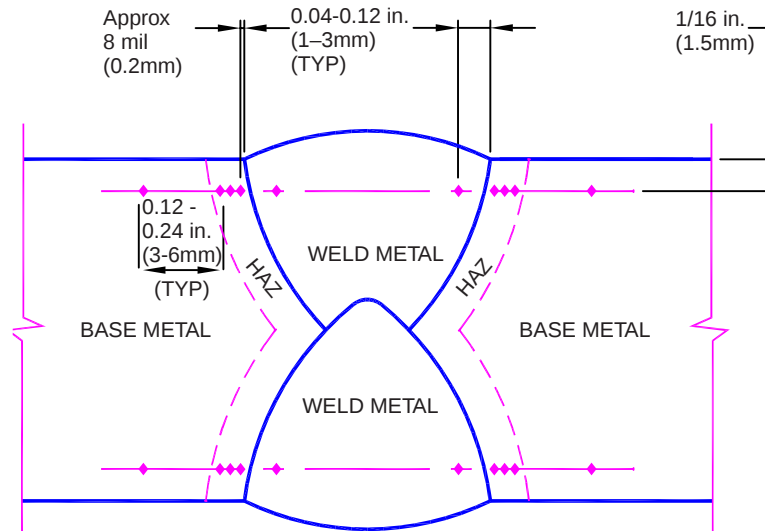


Figure 7-1—Location of Vickers Hardness Indentations

7.2.2 Preheat and Heat Treatments During Base Metal Welding

7.2.2.1 Preheat

All base metal shall be heated to a minimum of 300°F (150°C) for conventional steels and 350°F (177°C) for advanced steels prior to and during all welding, rolling, thermal cutting and gouging operations (except during weld overlay—see 7.3.4). The preheat temperature shall be maintained until the final PWHT, or an intermediate stress relief (ISR) or dehydrogenation heat treatment (DHT) is performed, as approved by the purchaser. For butt welding and attachment welding, this preheat temperature shall be maintained through the entire plate thickness for a distance of at least one plate thickness on either side of the weld, but need not extend more than 4 in. (100 mm) in any direction from the edges to be welded.

7.2.2.2 ISR/DHT

7.2.2.2.1 ISR or DHT should be performed only after careful consideration of the metallurgical factors and possible risks. For example, the temperatures and times used for the ISR must balance the needs to reduce stress and soften the metal, with the concern of using up too much of the tempering time allowed for the steel. The DHT, if it is permitted at

all, typically is used only for the non-restrained welds, such as the shell welds or the shell to head welds.

7.2.2.2.2 Intermediate Stress Relief (ISR)

An ISR soak in a furnace shall be performed at the metal temperature shown below for at least one hour per inch (25.4 mm) of thickness, with a two hour minimum:

- Conventional steels: 1100°F (593°C) minimum
- Advanced steels: 1200°F (649°C) minimum

7.2.2.2.3 Dehydrogenation Heat Treatment (DHT)

The manufacturer shall make a written request for purchaser's approval to use a low temperature DHT in lieu of an ISR. The manufacturer's request shall include detailed information and data concerning hydrogen controls for procurement and handling of welding consumables, hydrogen content of weld metals and HAZs after the DHT, and nondestructive examination of weld joints. The purchaser may require the manufacturer to demonstrate high sensitivity ultrasonic examination procedures to detect flaws at weld joints after using a DHT. The DHT shall be performed at a minimum metal temperature of 570°F (300°C) for a duration to be agreed upon between the fabricator and the purchaser. In no case shall the duration be less than one hour.

7.2.3 Production Testing of Base Metal Welds

7.2.3.1 Chemical Composition of Production Welds

7.2.3.1.1 The chemical composition of the weld deposit representing each different welding procedure shall be checked by either laboratory chemical analysis or by using a portable analyzer of equivalent accuracy and precision.

7.2.3.1.2 The chromium, molybdenum, vanadium and columbium content (as applicable) of the weld deposits shall be within the ranges specified in ASME Section II, Part C for the specified electrodes.

7.2.3.2 Hardness of Weld Deposit and Adjacent Base Metal

7.2.3.2.1 After final PWHT (see 7.4), hardness determinations shall be made for each pressure-retaining weld using a portable hardness tester.

7.2.3.2.2 The hardness test results shall be the average of three readings and shall be taken in the weld metal and adjacent base metal.

7.2.3.2.3 Hardness values shall not exceed:

- a. Conventional steels: 225 HB, or equivalent
- b. Advanced steels: 235 HB, or equivalent

7.2.3.2.4 Hardness tests shall be performed on each 3-meter length of weld, or fraction thereof, and on the side exposed to the process environment, when possible.

7.2.3.3 Weld Impact Tests

7.2.3.3.1 Production test plates subjected to the minimum PWHT shall meet Article T-2 of the ASME Code. Additional production test plate material subjected to the maximum PWHT shall also be tested and shall meet the requirements of Article T-2. The impact test temperature and acceptance criteria shall be in accordance with 5.5.3.1.

7.2.3.3.2 Production test plates subjected to the minimum PWHT shall be impact tested before and after step cooling in accordance with the requirements of 5.5.3.2, unless waived by the purchaser.

7.3 WELD OVERLAY

The following special requirements shall apply:

7.3.1 Material Requirements

The ferrite content of austenitic stainless steel weld overlay shall be between 3 FN and 10 FN, as determined in accordance with WRC Bulletin 342, prior to any PWHT.

7.3.2 Disbonding Tests

7.3.2.1 When required by the owner/user, a method to evaluate the weld overlay for susceptibility to hydrogen disbonding shall be agreed to between the fabricator and owner/user. The owner/user shall define testing requirements and acceptance criteria. An example of a standard disbonding test may be found in ASTM G 146. As a minimum, the test shall represent actual operating conditions (hydrogen pressure, temperature and cooling rates) to which the equipment will be subjected during service.

7.3.2.2 Results of disbonding tests shall be available, prior to fabrication, for each welding procedure to be used on the vessel shell rings and heads. Previously qualified disbonding test results can be submitted for review by the owner/user if representative of the proposed WPS and operating conditions.

7.3.3 Weld Overlay Procedure Qualification

7.3.3.1 The selected weld overlay process and the number of layers shall be qualified in accordance with ASME Section IX.

7.3.3.2 Procedure qualification tests shall be made on base metal of the same ASME specification as specified for the vessel, but either plate or forging may be used. Thickness of the test specimen shall not be less than one half the thickness of the vessel base metal or 2 in. (50 mm.), whichever is less. The welding electrode, wire and flux used for the weld overlay procedure qualification shall be the same type and brand to be used in production.

7.3.3.3 The qualification test plates shall be subjected to the maximum PWHT condition.

7.3.3.4 The chemical composition of the weld overlay shall be checked by chemical analysis of samples taken at minimum thickness qualified in accordance with Figure QW-462.5(a) of the ASME Code, Section IX. It shall meet the filler metal specification for the final layer. The chemical composition, determined by these samples, should be used to calculate the ferrite content which shall be between 3 FN and 10 FN.

7.3.4 Preheat and Heat Treatments During Weld Overlay

Base metal shall be preheated in accordance with 7.2.2.1 for the first layer of weld overlay. The maximum interpass temperature shall be 480°F (250°C). Provided that subsequent still-air cooling is applied, intermediate stress relief (ISR) may be omitted after overlay welding. No preheating is required for the second and any subsequent layers of weld overlay.

7.3.5 Production Testing of Weld Overlay

7.3.5.1 Chemical Composition of Weld Overlay

The chemical composition of the weld overlay shall be checked by laboratory chemical analysis of a sample taken from a minimum of $\frac{1}{8}$ in. (3.2 mm) below the overlay surface. This composition shall meet the required chemistry of the specified overlay material (C, Cr, Ni, Cb, Mo, V and Ti as applicable). At least one analysis for each shell ring and head, and one for each manual welding process for nozzles, shall be required.

7.3.5.2 Ferrite Content of Weld Overlay

7.3.5.2.1 A magnetic instrument calibrated to AWS A4.2 shall be used to check the ferrite content of the production weld overlay prior to any PWHT.

7.3.5.2.2 Calibration for the steel backing material in accordance with Appendix A7, Paragraph A7.1 of AWS A4.2 may be used.

7.3.5.2.3 A minimum of six ferrite readings shall be taken on the surface at each of the following locations:

- a. At least ten locations, selected at random, shall be checked for each shell ring and head.
- b. One location for each girth seam of each nozzle, at each end, and each Category A, B, and D weld.

7.3.5.2.4 The value of all ferrite readings at each location shall be between 3 FN and 10 FN.

7.4 FINAL PWHT

7.4.1 The fabricated vessel shall be post-weld heat treated as a whole in an enclosed furnace whenever possible. When vessel size does not allow PWHT as a whole in a furnace, PWHT may be performed sectionally according to AF-410 of the ASME Code.

7.4.2 The PWHT temperature shall be strictly controlled, measuring both the vessel skin and furnace temperatures using thermocouples, including any portion of the vessel outside of the furnace. Any section of the vessel outside the furnace shall be insulated such that the temperature gradient is not harmful. Thermocouple arrangements shall be established for each heat treatment. The skin temperature shall be measured and controlled on the inside and outside of the vessel.

Continuous time-temperature records of all PWHT operations shall be documented to meet the requirements of AF-415 of the ASME Code.

8 Nondestructive Examination (NDE)

8.1 All NDE personnel shall be qualified in accordance with ASNT Recommended Practice No. SNT-TC-1A. Personnel interpreting and reporting results shall also be qualified to the same practice.

8.2 NDE PRIOR TO FABRICATION

8.2.1 Ultrasonic Testing (UT)

8.2.1.1 All base metal plates shall be ultrasonically examined with 100% scanning in accordance with ASME Section V, SA 435, Supplementary Requirement S1, before forming.

8.2.1.2 All forgings for shell rings, nozzles and manways shall be ultrasonically examined with 100% scanning in accordance with AM-203.2 of the ASME Section VIII, Division 2.

8.2.2 Magnetic Particle Testing (MT) or Dye Penetrant Testing (PT)

8.2.2.1 Entire surfaces of all forgings, including welding edges, shall be examined by MT in accordance with Article 9-1 or by PT in accordance with Article 9-2 of the ASME Code. Examination shall be after finish machining but before welding.

8.2.2.2 Entire surfaces of all formed plates to be welded for shell rings and heads, including those for weld overlay, shall be examined by either MT or PT, as noted in 8.2.2.1.

8.3 NDE DURING FABRICATION

8.3.1 All pressure-retaining base metal welds, including weld build-up deposits, root passes and attachment welds, shall be tested after back gouging and before weld overlay by MT in accordance with Article 9-1 of the ASME Code.

8.3.2 Temporary attachments shall be minimized. All areas where temporary attachments have been removed shall be examined by MT or PT in accordance with Article 9-1 or Article 9-2 of the ASME Code, as applicable.

8.4 NDE AFTER FABRICATION AND PRIOR TO FINAL PWHT

8.4.1 Base Metal Welds

8.4.1.1 All pressure-retaining butt welds and vessel to support skirt welds shall be fully examined by RT in accordance with Article I-5 of the ASME Code before final PWHT.

8.4.1.2 When RT is not practical for nozzle and skirt attachment welds, UT may be applied in lieu of RT.

8.4.1.3 UT may be applicable in lieu of RT when the UT procedure fulfills the requirements of Code Case 2235.

8.4.2 Weld Overlay

8.4.2.1 Spot UT, four strips approximately 3.2 in. (80 mm) wide along the full length of the vessel shell and one (1) strip approximately 3.2 in. (80 mm) wide across each head, shall be performed on weld overlay. UT shall be in accordance with ASME Section V, SA 578, Supplementary Requirement S7.

8.5 NDE AFTER FINAL PWHT

8.5.1 Base Metal Welds

8.5.1.1 All pressure-retaining base metal welds, including nozzles, shall be fully examined by UT in accordance with Article 9-3 of the ASME Code.

8.5.1.2 All accessible welds shall be examined by MT. An AC yoke method shall be used to prevent arc strikes. PT may be substituted for MT whenever MT is impractical.

8.5.2 Weld Overlay

8.5.2.1 All austenitic stainless steel weld overlay, and attachments to the overlay, shall be examined by PT in accordance with Article 9-2 of the ASME Code.

8.5.2.2 Spot UT as described in 8.4.2.1 shall be performed.

9 Hydrostatic Testing

9.1 All pressure retaining welded joints shall be free from any scale and other foreign matter before testing. All dirt, scale, sand, and other foreign material shall be removed from the vessel.

9.2 Test water shall not contain more than 50 ppm chlorides.

9.3 During the hydrostatic testing, the vessel metal temperature shall be at least 30°F (17°C) above the MDMT, or 60°F (15°C), whichever is warmer.

9.4 The vessel shall be drained and thoroughly dried immediately after testing.

10 Preparation for Shipping

10.1 Immediately after completion of final examination of the vessel, the interior of the vessel shall be cleaned and dried.

10.2 All openings shall be sealed with a steel cover and gasket, and the vessel shall be filled with a minimum 5 psig (34.5 kPa) pressure of dry nitrogen gas. The nitrogen pressure shall be maintained during transportation, erection and pre-commissioning.

10.3 For preservation during transportation, all exposed machined surfaces, such as flange faces, bolting, and stainless steel surfaces, shall be protected by applying a suitable grease, rust preventative oil or coating.

11 Documentation

The following documentation for all pressure-retaining parts, including welding consumables, shall be completed prior to the start of fabrication and shall be available for examination by the purchaser at the time of inspection. This documentation shall be submitted to the purchaser at the completion of the project.

- a. CMTRs showing all chemical composition and mechanical test results.
- b. All heat treatment data showing hold time and temperature for PWHT, ISR and DHT.
- c. J-factors.
- d. X-bars.
- e. All impact test results before and after step cooling.
- f. All hot tensile test results.
- g. Welding procedure specifications.
- h. Procedure qualification records.

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