Materials and Fabrication of $1^1/_4$Cr-$^1/_2$Mo Steel Heavy Wall Pressure Vessels for High-pressure Hydrogen Service Operating at or Below 825 °F (440 °C)

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Contents

Introduction

This recommended practice (RP) applies to new fabrication of 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 purchasers 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.

Materials and Fabrication of 1 $^1/_4$Cr-$^1/_2$ Mo Steel Heavy Wall Pressure Vessels for High-pressure Hydrogen Service Operating at or Below 825 °F (440 °C)

1 Scope

This recommended practice (RP) covers materials and fabrication requirements for new 1$^1/_4$Cr-$^1/_2$Mo steel heavy wall pressure vessels and heat exchangers for high-temperature, high-pressure hydrogen service. It applies to vessels that are designed, fabricated, certified, and documented in accordance with ASME Section VIII, Division 1 or Division 2. This document may also be used as a resource for equipment fabricated of 1Cr-$^1/_2$Mo Steel.

This document may also be used as a resource when planning to modify an existing heavy wall pressure vessel.

The interior surfaces of these heavy wall pressure vessels may have an austenitic stainless steel or ferritic stainless steel weld overlay or cladding to provide additional corrosion resistance.

For this recommended practice, "heavy wall" is defined as a shell thickness 2 in. (50 mm) or greater, but less than or equal to 4 in. (100 mm) at the time of mill heat treatment. At shell or head thicknesses greater than 4 in. (100 mm), 1$^1/_4$Cr-$^1/_2$Mo plates and forgings have been shown to have difficulty meeting the toughness requirements given in this document. Thick 1$^1/_4$Cr-$^1/_2$Mo forgings, such as integrally reinforced nozzles, flanges, tube sheets, channel covers, etc., can especially have difficulty meeting specified properties. 2$^1/_4$Cr-1Mo plates and forgings can be used as an alternative to ensure properties are met. Although outside of its scope, this document can be used as a resource for vessels down to 1 in. (25 mm) or lower in shell thickness, with changes defined by the purchaser.

Multilayer vessels are outside the scope of this document.

This recommended practice is not intended for use for equipment operating above 825 °F (440 °C) or in the creep range. API RP 934-E covers these higher-temperature applications.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Recommended Practice 582, *Welding Guidelines for the Chemical, Oil, and Gas Industries*

API Recommended Practice 934-A, *Materials and Fabrication of 2$^1/_4$Cr-1Mo, 2$^1/_4$Cr-1Mo-$^1/_4$V, 3Cr-1Mo, and 3Cr-1Mo-$^1/_4$V Steel Heavy Wall Pressure Vessels for High-temperature, High-pressure Hydrogen Service*

API Recommended Practice 934-E, *Recommended Practice for Materials and Fabrication of 1$^1/_4$Cr-$^1/_2$Mo Steel Pressure Vessels for Service above 825 °F (440 °C)*

ASME [1] *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*

ASME *Boiler and Pressure Vessel Code*, *Section V-Nondestructive Examination*

ASME *Boiler and Pressure Vessel Code*, *Section VIII-Rules for Construction of Pressure Vessels, Division 1*

[1] ASME International, 3 Park Avenue, New York, New York 10016, www.asme.org.

ASME *Boiler and Pressure Vessel Code*, *Section VIII-Rules for Construction of Pressure Vessels, Division 2: Alternative Rules*

ASME *Boiler and Pressure Vessel Code*, *Section IX-Welding and Brazing Qualifications*

ASME Code Case 2718, *Alternative Minimum Test Temperature for Hydrostatic Testing*

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

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

ASME SA-263, *Standard Specification for Corrosion-Resisting Chromium Steel-Clad Plate, Sheet, and Strip*

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

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

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

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

ASME SA-530, *Standard Specification for General Requirements for Specialized Carbon and Alloy Steel Pipe*

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

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

ASNT [2] RP SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*

AWS [3] A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*

AWS A4.3, S*tandard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

WRC [4] Bulletin 452, *Recommended Practices for Local Heating of Welds in Pressure Vessels*

WRC Bulletin 519, *Stainless Steel Weld Metal Prediction of Ferrite Content: An Update of WRC Bulletins 318 and 342*

[2] American Society for Nondestructive Testing, Inc., 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228, www.asnt.org.
[3] American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, www.aws.org.
[4] Welding Research Council, 3 Park Avenue, 27th Floor, New York, New York 10016, www.forengineers.com.

3 Terms, Definitions, and Abbreviations

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

3.1 Terms and Definitions

3.1.1
ASME Code
ASME *Boiler and Pressure Vessel Code, Section VIII, Division 1 and Division 2*, including applicable addenda and *Code Cases*.

3.1.2
final PWHT
The last postweld heat treatment after fabrication of the vessel and prior to placing the vessel in service.

3.1.3
hot forming
Mechanical forming of vessel components above the final PWHT temperature.

3.1.4
Larson-Miller parameter (LMP)
Parametric relationship proportional to the aggregate heat treatment temperature(s) and duration(s). The LMP can be used to assess the effect of individual or multiple heat treatment(s) on a specific material property such as strength or toughness. The LMP is employed to evaluate cumulative effects from exposures to varying temperatures during fabrication, including tempering and PWHT, as shown by the second equation below.

$$LMP = T \times (20 + \log t) \qquad \text{Final } LMP = T_i \times [20 + (\log t_i + t_{eqi})] \tag{1}$$

$$t_{eqi} = 10\wedge\{T_i / T_{eqi} * [20 + \log(t_i)] - 20\} \tag{2}$$

where

T is the temperature in kelvins;

t is the time in hours; and

t_{eqi} is the equivalent soaking time at temperature T_{eqi} having the same tempering effect as holding at temperature T_i for time t_i.

NOTE Hollomon-Jaffe parameters can be used in place of LMP parameters, as they use the same concept and formula structure, but have different constants. LMP is also referred to as the "tempering parameter."

3.1.5
manufacturer
The firm or organization receiving the purchase order to manufacture the pressure vessel, or materials.

3.1.6
maximum PWHT
Specified heat treatment (aggregate temperature and time) of test coupons to simulate the effect of the maximum heat treatment exposures on the vessel alloy. Prior to heat treatment, the coupons shall be representative of the as-supplied material (i.e. with the same austenitizing and tempering heat treatment). By definition, maximum PWHT includes all fabrication heat treatments above 900 °F (482 °C) [e.g. Intermediate Stress Relieving (ISR), all PWHT cycles, a PWHT cycle for possible shop repairs, and a minimum of one extra PWHT for possible future use by the purchaser]. Typically, the ISR and PWHT cycles are aggregated into one single equivalent heat treatment which

approximates the sum total effects of time and temperature. Methods to account for the aggregate effects on mechanical properties are discussed in the note below. Dehydrogenation heat treatments (DHT) do not need to be included as they are at too low of a temperature to alter material properties.

NOTE To determine the equivalent time at one temperature (within the PWHT range) of heat steps outside the PWHT range, the Larson-Miller Parameter formula (or Hollomon-Jaffe Parameter) may be used; results to be agreed upon by the purchaser and manufacturer. At the time of any future repairs, it is the purchaser's responsibility to determine any changes in properties that may have occurred from high temperature service, and the affects that any repair welding and PWHT will have on the vessel.

3.1.7
minimum PWHT
Specified heat treatment (aggregate temperature and time) of test specimens to simulate the effect of the minimum heat treatment exposures on the vessel alloy. Prior to heat treatment, the coupons shall be representative of the as-supplied material (i.e. with the same austenitizing and tempering heat treatment). By definition, the minimum PWHT includes only the minimum of all fabrication heat treatments above 900 °F (482 °C) [e.g. intermediate stress relieving (ISR) if any, and one PWHT cycle]. Typically, the ISR and PWHT cycles are aggregated into one single equivalent heat treatment which simulates all different heating listed above and the methods to simulate this are discussed in the note below.

NOTE To determine the equivalent time at one temperature (within the PWHT range) of heat steps outside the PWHT range, the Larson-Miller Parameter (or Hollomon-Jaffe Parameter) may be used; results to be agreed upon by the purchaser and manufacturer.

3.2 Abbreviations

For the purposes of this recommended practice, the following abbreviations apply.

DHT	dehydrogenation heat treatment
FN	Ferrite Number
HAZ	heat-affected zone
HBW	Brinell hardness with tungsten carbide indenter
HV	Vickers hardness
ISR	intermediate stress relief
MDMT	minimum design metal temperature
MT	magnetic particle testing
MTR	material test report
NDE	nondestructive examination
PQR	procedure qualification record
PT	penetrant testing
PWHT	postweld heat treatment
RT	radiographic testing
UT	ultrasonic testing
WPS	welding procedure specification

4 Design

4.1 Design and manufacture shall conform to the ASME *BPVC Section VIII, Division 1 or Division 2*, and *Code Cases*, as applicable. The latest edition effective through the date of the purchase agreement shall be used.

4.2 The manufacturer's design report (*Manufacturer's Data Book*), which includes ASME Code strength calculations, and when applicable local stress analysis for extra loads, and other special design analyses, should show compliance with the purchaser's design specification and other technical documents.

4.3 This RP does not cover design issues other than those listed as follows.

a) The minimum design thickness shall not take any credit for the corrosion allowance or weld overlay or clad thickness, or a combination thereof.

b) Weld seam layouts shall provide that all welds are accessible for NDE such as RT, UT, MT, and PT, both during fabrication and in-service. The use of external attachments that cover weld seams should be avoided and shall require the purchaser's approval.

c) Nozzle necks shall have transition to the vessel body as shown in the ASME Section VIII, Division 2, Table 4.2.13. With the purchaser's approval, nozzles with nominal size 4 in. (100 mm) and less may be fabricated in accordance with the ASME Section VIII, Division 2, Table 4.2.10, Detail 3 through Detail 6, with integral reinforcement.

d) Where possible, nozzle welds should be located without intersecting circumferential or longitudinal welds, unless otherwise approved by the purchaser (if approved, the purchaser should specify an additional NDE and NDE sequence).

5 Base Metal Requirements

5.1 Material Specifications

5.1.1 Pressure boundary base metals shall be in accordance with the applicable ASME specifications indicated in Table 1. Tubing is outside the scope of this document.

Table 1—Base Metal Specifications

Steel	Plate	Forgings	Pipe
$1^1/_4$Cr-$^1/_2$Mo	SA-387 Grade 11, Class 1 or Class 2	SA-182 Grade F11, Class 2 or Class 3 SA-336 Grade F11, Class 2 or Class 3	SA-335, Grade P11 SA-369, Grade FP11

5.1.2 Unless approved in advance by the purchaser, different base metals should not be mixed in the same vessel (such as using $2^1/_4$Cr-1Mo nozzles in a $1^1/_4$Cr-$^1/_2$Mo shell or head). There are some designs which use austenitic stainless steels as part of the outlet nozzles, which extend to outside the skirts and involve a dissimilar metal weld outside of the skirt. These cases require purchaser approval (also see 7.1.5).

5.1.3 External attachments (such as lugs, clips etc.) welded directly to the pressure boundary shall be of the same nominal material chemical composition (without the added limits as specified in 5.3) as the pressure boundary material.

5.2 Steel Making Practice

In addition to the steel making practice outlined in the applicable specifications, the steels shall be vacuum degassed and all plate, piping, and forging materials shall be made to fine grain practice in accordance with the application material specification (such as ASME SA-20 for plates). Pipe with wall thickness less than 2 in. (50 mm) and ASME SA-182 flanges do not require vacuum degassing.

5.3 Chemical Composition Limits

5.3.1 For $1^1/_4$Cr-$^1/_2$Mo steel, all plate and forging materials shall meet the following additional chemical requirements by heat analysis.

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

where:

P, Sb, Sn, and As are in ppm.

Additionally:

— C is 0.15 wt % max;

— P is 0.010 wt % max;

— S is 0.007 wt % max;

— Cu is 0.20 wt % max; and

— Ni is 0.30 wt % max.

5.3.2 For piping (including long-seam welded piping), pipe flanges, and pipe fittings, the P and S limits shall be as follows (or as agreed to by the purchaser):

— P is 0.012 wt % max; and

— S is 0.012 wt % max.

5.4 Heat Treatment

5.4.1 Heat treatment of pressure-boundary components, regardless of product form, shall be either:

a) Normalizing and tempering (N&T), or

b) Accelerated cooling from austenitizing by air blasting or liquid quenching, followed by tempering.

NOTE Components receiving liquid quenching are also referred to as “quenched and tempered” (Q&T).

5.4.2 For equal to or greater than 2 in. (50 mm) thickness, Q&T is typically required to meet the properties specified in this RP.

5.4.3 Tempering temperature may be below, at, or above the PWHT temperature.

5.5 Mechanical Properties

5.5.1 Location of Test Specimens

Test specimens for establishing the tensile and impact properties shall be removed from the following locations (where T is the maximum thickness of the material at the time of heat treatment):

a) Plate—from each plate, at the $^1/_2T$ location, (and at the $^1/_4T$ location in accordance with ASME SA-20 if required by Code). $^1/_2T$ is acceptable per Code for SA-387 material by specifying Supplementary Requirement S53.

Specimens shall be oriented transverse to the rolling direction in accordance with SA-20. Distance from plate edges shall be $1T$ minimum. If a hot tensile test is specified by the purchaser (it is not required by this RP), $^1/_2T$ specimens should be used.

b) Forging—from each heat, at the $^1/_2T$ of the prolongation or of a separate test block (sample location from side edges shall be per Code). Specimens shall be oriented transverse to the major working direction. A separate test block, if used, shall meet Code and shall be made from the same heat and should receive substantially the same reduction and type of hot working as the production forgings that it represents and should be of the same nominal thickness as the production forgings. The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forgings.

c) Pipe-from each heat and lot of pipe, at $^1/_2T$. Specimens shall be oriented transverse to the major working direction in accordance with ASME SA-530.

5.5.2 Tensile Test Requirements

Tensile testing of plates and forging materials shall comply with the applicable code(s) and the following additional requirements:

a) test coupon shall be heat treated to represent the maximum postweld heat treatment as specified in 3.1.6;

b) tensile properties at room temperature shall meet the requirements of the applicable code(s).

5.5.3 Impact Testing Requirements

Charpy V-notch (CVN) impact testing shall be performed for all $1^1/_4$Cr-$^1/_2$Mo steel material (by heat) used for pressure-retaining components except bolting. CVN impact tests shall comply with the applicable code(s) and the following additional requirements.

a) Test coupons from forgings shall be oriented transverse to the major direction of metal flow.

b) Test coupons heat treated to represent both the maximum and minimum post weld heat treatments that the equipment are expected to receive during fabrication per 3.1.6 and 3.1.7 shall be tested and meet the following requirements. The minimum CVN impact values at 0 °F (–18 °C) shall be 40 ft-lbs (54 Joules) average of three specimens and 20 ft-lbs (27 Joules) minimum for a single specimen. In addition, if the MDMT is less than 0 °F (–18 C), ASME Code requirements for impact testing must also be met. If the impact tests at this MDMT of less than 0 °F (–18 °C) meet the 40/20 ft-lbs (54/27 Joules) criteria, retesting at 0 °F (–18 °C) is not needed.

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 (i.e. the chemical requirements of the ASME material specification) to be welded.

6.1.2 The chemical composition shall also meet the following limits to improve resistance to embrittlement. These limits apply to the heat analysis.

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

where:

P, Sb, Sn, and As are in ppm.

Additionally:

— C is 0.15 wt % max;

— Cu is 0.20 wt % max; and

— Ni is 0.30 wt % max.

6.1.3 Welding electrodes and fluxes shall produce low hydrogen weld deposits with a maximum of 0.27 fl oz (8 ml) of diffusible hydrogen for every 3.5 oz (100 g) of weld metal, per AWS A4.3. (These acceptable consumables are often designated with suffixes of H4 or H8). They shall be baked, stored, and used in accordance with the consumable manufacturer's instructions (holding in electrode oven, length of time out of oven, etc.).

6.2 Mechanical Requirements

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.

6.2.2 Impact Properties

Prior to the start of fabrication, each lot of electrodes, heat of filler wire, and combination of batch of flux and heat of wire, shall be impact tested and shall meet the requirements of 5.5.3.

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, prepared by machining, grinding, or blast cleaning.

7.1.2 Welded joints, including non-pressure attachments to the vessel body shall:

a) be full penetration joints. With approval by purchaser, this can be waived for external attachment welds, but any pockets which are formed shall be vented;

b) be located so that full ultrasonic examination of welds can be made after fabrication and after the equipment has been in-service. In cases where this is not practical, the manufacturer should propose alternate NDE methods to verify weld quality for the purchaser's approval;

c) be made sufficiently smooth to facilitate NDE (MT, PT, UT, or RT), as applicable.

7.1.3 All welding shall be completed prior to final PWHT except welding of attachments to the internal corrosion resistant weld overlay or cladding, or to external stainless steel weld buildups, when permitted by the purchaser. For these attachment welds, a PQR or mockup test, or both, shall be performed to verify that this does not produce a HAZ in the base metal, unless waived by the purchaser.

7.1.4 Weld repairs to base metal, weld joints, and weld overlay shall be performed using a repair welding procedure qualified in accordance with 7.2 and shall meet all the same requirements as the normal fabrication welds.

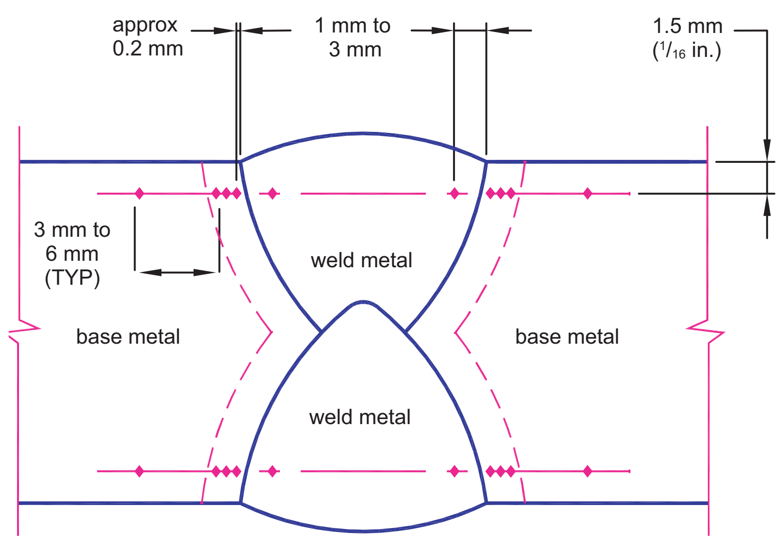
7.1.5 No pressure-retaining dissimilar metal welds of ferritic to austenitic alloys shall be allowed, especially at stress riser sites such as the nozzle-to-shell, nozzle-to-head or nozzle-to-flange welds, except if allowed on a case-by-case basis by the purchaser. Dissimilar metal welds should also be avoided at nozzle to pipe connections with constraint mismatch and at thickness transitions. In some cases, purchasers have allowed dissimilar metal welds in the outlet nozzles (typically in pipe-to-pipe or pipe-to-elbow welds) which extend to outside the skirts (with the weld typically located outside of the skirt). There are cases where a dissimilar metal pipe-to-pipe weld is preferred over dissimilar metal flanges, depending on the process temperature and line sizes.

7.2 Welding Procedure Qualification

Welding procedures shall be qualified in accordance with ASME Section IX, with the following additional requirements.

7.2.1 Base metal for welding procedure qualification tests shall be made from the same ASME base metal specification (same P-number and Group number) and similar in chemistry as specified for the vessel, but either plate or forging may be used. The welding consumable combination used (electrodes, wire and flux, whichever ones are applicable) shall be of the same type and brand as those to be used in production welding.

7.2.2 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 locations similar to those shown in Figure 1. The HAZ readings shall include locations as close as possible [approximately 8 mils (0.2 mm)] to the weld fusion line. If previously-qualified WPS/PQRs are proposed, the purchaser shall decide if the hardness test locations are sufficient. For other weld geometries, refer to NACE MR 0103. The hardness shall not exceed 235 HV10.



NOTE HV10 measurement for HAZ requires 0.04 in. (1 mm) minimum spacing between indentations. In some cases, it is acceptable that hardness measurement location is off the line in order to satisfy the minimum spacing requirements.

Figure 1—Location of Vickers Hardness Indentations

7.2.3 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.

7.2.4 Charpy V-notch impact testing shall be performed on weld metal and HAZ of the heat-treated test plate in the minimum and maximum PWHT conditions. These impact tests should be performed for each welding procedure and should meet the impact test temperature and acceptance requirements in 5.5.3.

7.2.5 WPSs and PQRs shall be submitted to the purchaser for review and acceptance prior to fabrication.

7.3 Preheat and Dehydrogenation Heat Treatment (DHT)

7.3.1 Preheat

7.3.1.1 All base metals shall be heated to a minimum of 300 °F (150 °C) during all welding, rolling, forming, pressing operations, thermal cutting, and gouging operations (except during weld overlay, see 7.5.4). 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 edge of the weld.

7.3.1.2 The preheat temperature shall be maintained until PWHT or DHT is performed in accordance with 7.3.2.

7.3.2 Dehydrogenation Heat Treatment (DHT)

7.3.2.1 The DHT shall be performed at a minimum metal temperature of 570 °F (300 °C) for a minimum duration of one hour. The purpose of DHT is to drive out hydrogen to minimize the risk of hydrogen cracking and to minimize problems due to low as-welded toughness.

7.3.2.2 ISR is not required. If the purchaser decides to require an ISR, the temperature and hold-time should be 1100 °F (593 °C) for a two-hour minimum.

7.4 Production Testing of Base Metal Welds

7.4.1 Chemical Composition of Production Welds

7.4.1.1 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 suitable accuracy and precision.

7.4.1.2 The chromium and molybdenum content of the weld deposits shall be within the ranges specified in ASME Section II, Part C for the specified electrodes.

7.4.2 Hardness of Weld Deposit and Adjacent Base Metal

7.4.2.1 After final PWHT (see 7.6), hardness determinations shall be made for each pressure-retaining weld (including each nozzle and attachment weld) using a portable hardness tester. The hardness testing instrument and procedure shall be submitted to purchaser for approval.

7.4.2.2 Each hardness test result shall be the average of three impressions at each test location. The test locations shall include weld metal and base metals adjacent to the fusion line on both sides. All individual hardness values should be reported.

7.4.2.3 Hardness values shall not exceed 225 HBW.

7.4.2.4 Hardness tests shall be performed on each 10 ft (3 m) length of weld, or fraction thereof. This testing should be performed on the side exposed to the process environment when accessible. This requirement does not apply to weld overlays or welds that are covered with weld overlay on the side exposed to the process.

7.4.3 Weld Metal Production Impact Tests

Production test plates per the ASME Code, Section VIII, Division 2, paragraph 3.11.8 or ASME Code Section VIII, Division 1, Section UG-84(i), shall be subjected to the minimum and maximum PWHT and test results shall meet the requirements in 5.5.3, item b).

7.5 Weld Overlay or Integral Clad

Both austenitic stainless steel and ferritic stainless steel may be used for integral cladding of steel. Austenitic stainless steel is typically used for the corrosion resistant weld overlay and clad restoration welding. The following special requirements apply to austenitic stainless steel overlay.

7.5.1 Material Requirements

The filler materials shall be purchased to be capable of passing the required ferrite testing listed in 7.5.5.2. The ferrite content of austenitic stainless steel weld overlay shall be between 3 FN and 10 FN, prior to any PWHT. This includes any layers using Type 309L SS filler metals.

7.5.2 Disbonding Tests

Experience indicates that the risk of disbonding is low at the thicknesses and hydrogen charging levels at which $1^1{}_4$Cr-$^1/_2$Mo is used. If testing is specified by the purchaser (it is not required by this RP), API RP 934-A can be used as a resource document, and the purchaser should define testing requirements and acceptance criteria.

7.5.3 Weld Overlay Procedure Qualification

7.5.3.1 The selected weld overlay process and the number of layers (including single layers) shall be qualified for each weld procedure in accordance with ASME Code Section IX and API RP 582, Appendix B (except paragraph B1.1).

7.5.3.2 Weld 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 1 in. (25 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.

7.5.3.3 The weld procedure qualification test plates shall be subjected to the maximum PWHT condition.

7.5.3.4 The chemical composition of the weld overlay shall be checked by chemical analysis of samples taken at minimum specified thickness from the process side. It shall meet the specified composition of the weld overlay (which may vary from the filler metal specification if a higher-alloy filler metal was used to account for dilution). The chemical composition, determined by these samples, should be used to calculate the ferrite content following the 1992 diagram appearing in WRC Bulletin 519, and the ferrite content shall meet the limits given in 7.5.1.

7.5.4 Preheat and Interpass Temperature During Weld Overlay

Base metal shall be preheated to 200 °F (94 °C) for the first layer of weld overlay. The maximum interpass temperature shall be 480 °F (250 °C). No preheating is required for the second and any subsequent layers of weld overlay.

7.5.5 Production Testing of Weld Overlay

7.5.5.1 Chemical Composition of Weld Overlay

The chemical composition of the weld overlay shall be checked by laboratory chemical analysis of a sample taken at minimum specified thickness. This composition shall meet the specified composition of the overlay material (C, Cr, Ni, Mo, and Nb, as applicable). At least one analysis for each shell ring and head, and one for each welding process for nozzles, shall be required. Positive materials identification (PMI) testers may also be used at the required thickness, if approved by the purchaser. This sampling/testing will result in the overlay needing repairs.

7.5.5.2 Ferrite Content of Weld Overlay

7.5.5.2.1 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.

7.5.5.2.2 Calibration (to account for the steel backing material) in accordance with AWS A4.2, Appendix A.7, paragraph A.7.1, may be used.

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

a) on at least ten locations, selected at random, for each shell ring and head;

b) on two locations for each nozzle overlay (one at each end);

c) on one location on cladding or overlay restoration of each Category A, Category B and Category D welds, if applicable.

7.5.5.2.4 The value of all ferrite readings at each location shall meet the requirements in 7.5.1. If readings are outside of the specification, the corrective action shall be determined to the agreement of the purchaser and the manufacturer.

7.6 Final Postweld Heat Treatment (PWHT)

7.6.1 PWHT shall comply with the minimum requirements of the applicable Code except that all $1^1/_4$Cr-$^1/_2$Mo weld joints shall be PWHT at 1250 °F ± 25 °F (675 °C ± 15 °C).

7.6.2 The fabricated vessel should be postweld 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 the ASME Code. The required band widths and thermocouple placements for local PWHT given in WRC 452 shall be required.

7.6.3 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.

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

8 Nondestructive Testing (NDE)

8.1 General

8.1.1 NDE personnel shall be qualified in accordance with ASNT SNT-TC-1A. For ASME Section VIII, Division 2 vessels, NDE personnel shall be qualified per paragraph 7.3 of Section VIII, Division 2. Personnel interpreting and reporting results should also be qualified to the same practice.

8.1.2 Where references to ASME Section VIII, Division 2, inspection requirements are listed, they shall be applied to Division 1 or Division 2 vessels.

8.2 NDE Prior to Fabrication

8.2.1 Ultrasonic Testing (UT)

8.2.1.1 Bare and clad base metal plates shall be ultrasonically examined with 100 % scanning before forming in accordance with ASME Section V and ASME SA-578, Level C, *Supplementary Requirement S1*.

8.2.1.2 Forgings for shell rings, nozzles, and manways shall be ultrasonically examined with 100 % scanning in accordance with ASME Section VIII, Division 2, paragraph 3.3.4.

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

8.2.2.1 On all forgings, the entire surfaces and all prepared welding edges shall be examined by MT in accordance with ASME Section VIII, Division 2, paragraph 7.5.6 or by PT in accordance with ASME Section VIII, Division 2, paragraph 7.5.7. Examination should be after finish machining but before welding.

8.2.2.2 Surfaces of all formed plates to be welded for shell rings and heads, including welding edges and surfaces to be weld overlayed, shall be examined by MT or PT after forming, as noted in 8.2.2.1. Examination should be after finish machining but before welding.

8.2.2.3 Where nozzle welds intersect circumferential and longitudinal welds (if approved in accordance with paragraph 4.3.d), all weld preparation surfaces (beveled edges) should receive PT or MT inspection as a minimum.

8.3 NDE During Fabrication

8.3.1 MT shall be performed after completion of all welds excluding stainless weld overlay. This includes pressure-retaining base metal welds, weld build-up deposits, root passes, and attachment welds. MT shall also be performed after any gouging or grinding operation including back gouging of root passes. MT should be in accordance with ASME Section VIII, Division 2, paragraph 7.5.6.

8.3.2 Temporary attachments should be minimized. All areas where temporary attachments have been removed shall be examined by MT or PT in accordance with ASME Section VIII, Division 2, paragraph 7.5.6, or paragraph 7.5.7, 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 or UT before final PWHT. RT shall be in accordance with ASME Section VIII, Division 2, paragraph 7.5.3 or UW-51 of ASME Section VIII, Division 1, as applicable. UT used in lieu of RT shall meet the requirements of ASME Section VIII, Division 2, paragraph 7.5.5.

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

8.4.2 Weld Overlay

Spot UT shall be done over four test strip patterns on the shell and one strip across the head. The shell strips shall be equally spaced, approximately 3.2 in. (80 mm) wide along the full length of the vessel shell. The head strip shall also be approximately 3.2 in. (80 mm) wide. UT should be in accordance with ASME SA-578, Level C.

8.5 NDE After Final PWHT

8.5.1 Base Metal Welds

8.5.1.1 Pressure-retaining base metal welds, including nozzles, shall be fully examined by UT in accordance with ASME Section VIII, Division 2, paragraph 7.5.4.

8.5.1.2 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

Entire surfaces of austenitic stainless steel weld overlay (full surface coverage), and attachment welds to the overlay, shall be examined by PT in accordance with ASME Section VIII, Division 2, paragraph 7.5.7.

8.6 Positive Material Identification

Positive material identification (PMI) shall be performed in accordance with the purchaser PMI specification.

9 Hydrostatic Testing

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

9.2 Test water should not contain more than 50 ppm of chlorides.

9.3 During the hydrostatic testing, the vessel metal temperature shall be at 60 °F (15 °C) or warmer, unless otherwise approved by purchaser.

NOTE This temperature is substantially warmer than 30 °F (17 °C) above the impact testing temperature of 0 °F (-18 °C).), and hence meets the ASME Code for both Division 1 and Division 2 vessels. For Division 2 vessels, even though paragraph 8.2.4 of the Code states that the hydrotest temperature must be 30 °F (17 °C) above the MDMT, ASME Code Case 2718 states that 30 °F (17 °C) above the impact testing temperature may be used whenever the impact testing temperature is lower than the MDMT.

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. Heat drying or other evaporative means, or both, shall not be used due to possible chloride contamination of stainless overlayed or clad vessels.

10.2 Vessel openings shall be sealed with a steel cover and gasket, and the vessel shall be filled with dry nitrogen gas at a suggested pressure of 5 psig (34.5 kPa), or a desiccant system or a vapor phase inhibitor shall be used. If nitrogen is applied, the nitrogen pressure should be maintained during transportation, erection and pre-commissioning. The vessel should be marked and a conspicuous warning tag shall be attached at each manway stating, “THIS VESSEL IS FILLED WITH NITROGEN—DO NOT ENTER.”

10.3 For preservation during transportation, all exposed machined surfaces, such as flange faces, bolting, and stainless steel surfaces, shall be protected by applying 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 should be available for examination by the purchaser at the time of inspection (except for the test results related to the fabricated vessel, which are not yet available):

a) MTRs showing all chemical composition and mechanical test results,

b) heat treatment data showing hold time and temperature for PWHT and DHT,

c) X-bars,

d) welding procedure specifications with applicable procedure qualification records,

e) NDE reports,

f) hardness test results,

g) the PMI report, and

h) production impact test results.

Items a) through h) should be submitted to the purchaser at the completion of the project.

12 Summary Material Examination and NDE Requirements

See Table 2 for a summary of API RP 934-C material examination and NDE requirements. This matrix is for reference use only to help direct the user to where each topic is discussed. The requirements in the main section of this RP take precedence. All Code requirements must also be met.

Table 2—Summary of API RP 934-C Material Examination and NDE Requirements

Materials and Locations for Testing or Inspection	Material Examination Requirements										
	Tensile Testing	Impact Testing	PMI	Chemical Composition	Ferrite	RT	UT	MT	PT	Hardness	Other
Base Material and Weld Metal Testing—Prior to Fabrication											
Plates (including SS clad plates)	5.5.2	5.5.3	8.6	5.3.1			8.2.1.1				
Forgings	5.5.2	5.5.3	8.6	5.3.1			8.2.1.2	8.2.2.1 [a]	8.2.2.1 [a]		
Pipe and Fittings		5.5.3.1	8.6	5.3.2							
Cr-Mo Filler Metal	6.2.1	6.2.2	8.6	6.1.2							6.1.3
Weld Qualification Test Plates											
Base Metal Weld	7.2.3	7.2.4								7.2.2	7.2.1
Weld Overlay [b]				7.5.3.4	7.5.1 7.5.3.4						
Production Pressure Welds											
Edges Prepared for Welding								8.2.2.1 [a] 8.2.2.2 [a]	8.2.2.1 [a] 8.2.2.2 [a]		
Back-gouged Surfaces, Prior to Back Welding								8.3.1			
Before PWHT			7.4.1 8.6	7.4.1		8.4.1.1 [c]	8.4.1.2 [c] 8.4.1.3 [d]	8.3.1			
After PWHT							8.5.1.1	8.5.1.2 [e]	8.5.1.2 [e]	7.4.2	

[a] Alternative to use MT or PT.

[b] Disbonding tests are not typically required. If desired by purchaser, the purchaser should define testing requirements and acceptance criteria (7.5.2).

[c] UT may be used in lieu of RT when the UT procedure fulfills the requirements of ASME Section VIII, Division 2, Paragraph 7.5.5.

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

[e] PT may be substituted for MT whenever MT is impractical.

[f] MT or PT is required for plate or forging surface to be weld overlayed; on plates, this NDE shall be after forming.

[g] All stainless-steel weld overlay, and attachments to the overlay.

[h] Areas where temporary attachments have been removed.

Table 2—Summary of API RP 934-C Material Examination and NDE Requirements (Continued)

Materials and Locations for Testing or Inspection	Material Examination Requirements										
	Tensile Testing	Impact Testing	PMI	Chemical Composition	Ferrite	RT	UT	MT	PT	Hardness	Other
After Hydrotest											
Production Weld Overlay											
Before Overlay Welding								8.2.2.1 [a, f] 8.2.2.2 [a, f]	8.2.2.1 [a, f] 8.2.2.2 [a, f]		
Before PWHT			8.6	7.5.5.1	7.5.5.2		8.4.2				
After PWHT									8.5.2 [g]		
Production Test Plates											
Base Metal Welds		7.4.3									
Miscellaneous											
Locations of Temporary Attachments								8.3.2 [a, h]	8.3.2 [a, h]		
Vessel to Skirt Welds Prior to PWHT						8.4.1.1	8.4.1.3 [d]				

[a] Alternative to use MT or PT.

[b] Disbonding tests are not typically required. If desired by purchaser, the purchaser should define testing requirements and acceptance criteria (7.5.2).

[c] UT may be used in lieu of RT when the UT procedure fulfills the requirements of ASME Section VIII, Division 2, Paragraph 7.5.5.

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

[e] PT may be substituted for MT whenever MT is impractical.

[f] MT or PT is required for plate or forging surface to be weld overlayed; on plates, this NDE shall be after forming.

[g] All stainless-steel weld overlay, and attachments to the overlay.

[h] Areas where temporary attachments have been removed.

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