Materials and Fabrication of 1 1/4Cr-1/2Mo Steel Heavy Wall Pressure Vessels for High-pressure Hydrogen Service Operating at or Below 825 °F (441 °C)

API RECOMMENDED PRACTICE 934-C
FIRST EDITION, MAY 2008

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Introduction

This recommended practice applies to newly fabricated 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.

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 (441 °C)

1 Scope

This recommended practice presents 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 *BPVC*, 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, the heavy wall is defined as shell thickness 2 in. (50 mm) or greater but less or equal to 4 in. (100 mm). Integrally reinforced nozzles, flanges, tubesheets, bolted channel covers, etc. can be greater than 4 in. (100 mm). At shell or head thicknesses greater than 4 in. (100 mm), 1 $^1/_4$Cr-$^1/_2$Mo has been shown to have difficulty meeting the toughness requirements given in this document. Although outside of the scope of this document, it can be used as a resource for vessels down to 1 in. (25 mm) shell thickness with changes defined by the purchaser.

This recommended practice is not intended for use for equipment operating above 825 °F (441 °C) or in the creep range.

2 References

The following referenced documents are cited in the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

API RP 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 TR 938-A, *An Experimental Study of Causes and Repair of Cracking of 1 $^1/_4$Cr-$^1/_2$Mo Steel Equipment*

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

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

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

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-264, *Standard Specification for Stainless Chromium-Nickel Steel-Clad, 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-435, *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*

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*

ASTM[3] G-146, *Standard Practice for Evaluation of Disbonding of Bimetallic Stainless Alloy/Steel Plate for Use in High-Pressure, High-Temperature Refinery Hydrogen Service*

AWS[4] A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*

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

WRC[5] Bulletin 342, *Stainless Steel Weld Metal: Prediction of Ferrite Content*

3 Terms, Definitions, and Acronyms

3.1 Terms and Definitions

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

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.

[2] American Society for Nondestructive Testing, Inc., 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228, www.asnt.org.
[3] ASTM International, 100 Bar Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
[4] American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, www.aws.org.
[5] Welding Research Council, 3 Park Avenue, 27th Floor, New York, New York 10016, www.forengineers.com.

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

3.1.4
Larson-Miller parameter
Formula for evaluating heat treatments:

$$\text{LMP} = T \times (20 + \log t)$$

where

T is the temperature in °K;

t is time in hours.

3.1.5
maximum PWHT
Specified heat treatment of test specimens used to simulate all fabrication heat treatments including austenitizing, tempering, the final PWHT, a PWHT cycle for possible shop repairs, and a minimum of one extra PWHT for future use by the owner.

NOTE To determine the equivalent time at one temperature (within the PWHT range), the Larson-Miller parameter may be used; results to be agreed upon by purchaser and manufacturer.

3.1.6
minimum PWHT
Specified heat treatment of test specimens used to simulate the minimum heat treatments (austenitizing, tempering and one PWHT cycle).

NOTE To determine the equivalent time at one temperature (within the PWHT range), the Larson-Miller parameter formula may be used; results to be agreed upon by purchaser and manufacturer.

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

HBW Brinell hardness with tungsten carbide indenter

HV Vickers hardness

ISR intermediate stress relief

MDMT minimum design metal temperature

MT magnetic particle testing

NDE nondestructive examination

PQR procedure qualification record

PT penetrant testing

PWHT post-weld heat treatment

RT radiographic testing

UT ultrasonic testing

WPS welding procedure specification

4 Design

4.1 Design and manufacture should conform to the ASME *BPVC*, Section VIII, Division 1 or Division 2, as applicable. The latest edition including addenda effective through the date of the purchase agreement should 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 listed as follows.

a) The minimum design thickness should not take any credit for the corrosion allowance and/or weld overlay or clad thickness.

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

c) Nozzle necks should have transition to the vessel body as shown in the ASME *BPVC*, 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 *BPVC*, Section VIII, Division 2, Table 4.2.10, Detail 3 through Detail 7, with integral reinforcement.

5 Base Metal Requirements

5.1 Material Specification

5.1.1 Base metals should be in accordance with the applicable ASME specifications indicated in Table 1.

Table 1—Base Metal Specifications

Steel	Plate	Forgings	Pipe
1 $^{1}/_{4}$Cr-$^{1}/_{2}$Mo	SA 387 Gr. 11, Class 1 or Class 2	SA 182 Gr. F11, Class 2 or Class 3 SA 336 Gr. F11, Class 2 or Class 3	SA 335, Grade P11 SA 369, Grade FP11

5.1.2 All external attachments such as lugs, clips etc. welded directly to the pressure boundary should be of the same material as the pressure boundary material.

5.1.3 Nozzles should be manufactured from forgings. For thicker nozzles, 2 1/4Cr-1 Mo may be used to ensure that toughness requirements are met. When using 2 1/4Cr-1 Mo, appropriate weld procedures with higher preheat, PWHT temperatures, etc. should be used. Welding procedures should be approved by the purchaser.

5.2 Steel Making Practice

In addition to the steel making practice outlined in the applicable specifications, the steels should be vacuum degassed.

5.3 Chemical Composition Limits

For 1 1/4Cr-1/2Mo steel, all plate and forging materials should be made to fine grain practice and should meet the following additional chemical requirements by heat analysis.

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

where

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

Additionally

— C is 0.15 wt % max;

— P is 0.007 wt % max;

— S is 0.007 wt % max;

— Cu is 0.20 wt % max; and

— Ni is 0.30 wt % max.

5.4 Heat Treatment

All product forms should be normalized and tempered (N&T) or quenched and tempered (Q&T) to meet the required mechanical properties. For equal to or greater than 2 in. (50 mm) thickness, Q&T is typically required to meet the properties specified in this recommended practice.

5.5 Mechanical Properties

5.5.1 Location of Test Specimens

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

a) Plate—from each plate transverse to the rolling direction in accordance with ASME SA-20 at the standard test locations and at the $1/2T$ location. When permitted by the applicable product specification, coupons for all tests should be obtained from the $1/2T$ location only. If required, $1/2T$ specimens should be used for hot tensile test.

b) Forging—from each heat transverse to the major working direction in accordance with ASME SA-182 or ASME SA-336, and test specimens should be taken at $1/2T$ of the prolongation or of a separate test block. A separate test block, if used, should 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 should 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, transverse to the major working direction in accordance with ASME SA-530 except that test specimens should be taken from $^1/_2T$.

5.5.2 Tensile Test Requirements

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

a) test coupon should be heat treated to represent the maximum postweld heat treatment per 3.1.6;

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

5.5.3 Impact Testing Requirements

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

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

b) Test coupons heat treated to represent both the minimum and maximum post weld heat treatments that the equipment are expected to receive during fabrication per 3.1.5 and 3.1.6 should be tested and meet the following requirements. The minimum CVN impact values at 0 °F (–18 °C) should 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 < 0 °F (–18 °C), code requirements for impact testing must also be met. If the impact test at this MDMT of < 0 °F (< –18 °C) meet the 40/20 ft-lbs (54/27 Joules) criteria, retesting at 0 °F (–18 °C) is not needed.

c) Percentage shear fracture should meet 25 % minimum. Lateral expansion should also be reported for information.

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, should match the nominal chemical composition of the base metal to be welded.

6.1.2 The following chemical composition limits should be controlled. The chemical composition restriction applies to the heat analysis.

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

where

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

Additionally

— C is 0.15 wt % maximum,

— Cu is 0.20 wt % maximum, and

— Ni is 0.30 wt % maximum.

6.1.3 Low hydrogen welding consumables, including fluxes, having a maximum of 8 ml of diffusible hydrogen for every 100 g of weld metal, H8 per AWS A4.3, should be used. They should be baked, stored, and used in accordance with 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 should 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 lot of flux and heat of wire, should be screened by impact testing of weld deposit in accordance with 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 should consist of clean metal, prepared by machining, grinding, or blast cleaning.

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

a) have full penetration joint design;

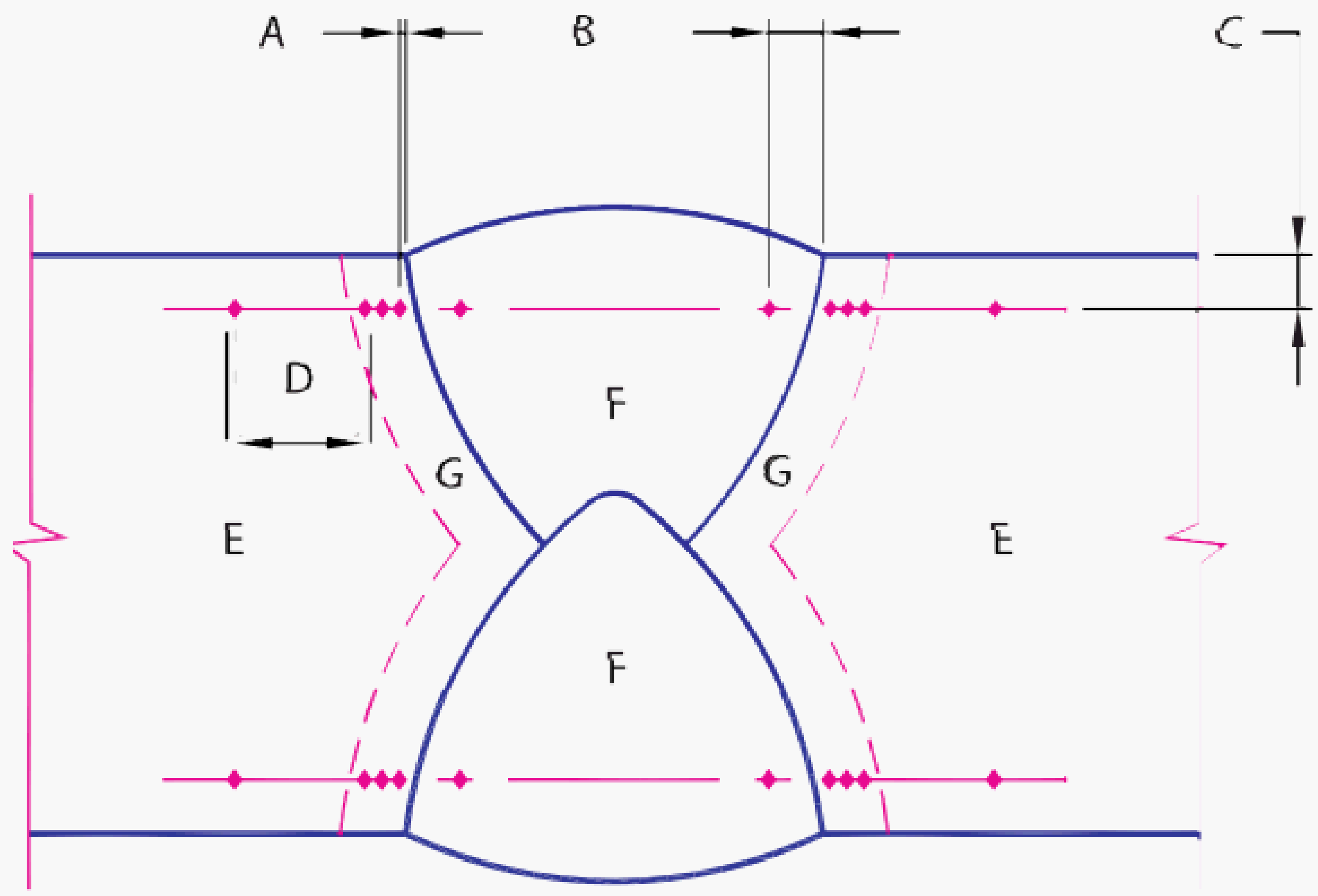
b) be located so that full ultrasonic examination of welds can be made after fabrication and after installation is complete (in cases where this is not practical, the manufacturer should propose alternate NDE methods to verify weld quality), and;

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

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

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

[redacted]



Key

A	Approx 8 mil (0.2 mm)	E	Base Metal
B	0.04 in. – 0.12 in. (1 mm – 3 mm) (TYP)	F	Weld Metal
C	$^{1}/_{16}$ in. (1.5 mm)	G	HAZ
D	0.12 in. – 0.24 in. (3 mm – 6 mm) (TYP)		

Figure 1—Location of Vickers Hardness Indentations

(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 should not exceed 235 HV10.

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

7.2.5 Charpy V-notch impact testing should 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.

7.2.6 All WPSs and PQRs should be approved by purchaser prior to fabrication.

7.3 Preheat and Dehydrogenation Heat Treatment (DHT)

7.3.1 Preheat

All base metals should be heated to a minimum of 300 °F (150 °C) during all welding, rolling, thermal cutting, and gouging operations (except during weld overlay, see 7.5.4). For butt welding and attachment welding, this preheat temperature should 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.

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

7.3.2 Dehydrogenation Heat Treatment (DHT)

The DHT should be performed at a minimum metal temperature of 570 °F (300 °C) for duration of one hour minimum.

ISR is not required. If the purchaser decides to require an ISR, the temperature and hold time should be 1100 °F (593 °C) for 2 hours minimum.

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.

7.4 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 should 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 should be within the ranges specified in ASME *BPVC*, 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 should be made for each pressure-retaining weld (including each nozzle and attachment welds) using a portable hardness tester.

7.4.2.2 Each hardness test result should be the average of three impressions at each test location. The test locations should 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 should not exceed 225 HBW.

7.4.2.4 Hardness tests should 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.

7.4.3 Weld Impact Tests

Production test plates subjected to the minimum and maximum PWHT should be tested and should meet the requirements of 5.5.3.

7.5 Weld Overlay or Integral Clad

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

7.5.1 Material Requirements

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

7.5.2 Disbonding Tests

Experience indicates that the risk of disbonding is low at the thicknesses and hydrogen charging levels at which 1 1/4Cr-1/2Mo is used. If testing is considered, API 934-A can be used as a resource document. 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 should be qualified in accordance with ASME *BPVC*, Section IX.

7.5.3.2 Procedure qualification tests should 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 should 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 should be the same type and brand to be used in production.

7.5.3.3 The qualification test plates should be subjected to the maximum PWHT condition.

7.5.3.4 The chemical composition of the weld overlay should be checked by chemical analysis of samples taken at [redacted]

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7.5.3 Weld Overlay Procedure Qualification

7.5.3.1 The selected weld overlay process and the number of layers should be qualified in accordance with ASME *BPVC*, Section IX.

7.5.3.2 Procedure qualification tests should 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 should 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 should be the same type and brand to be used in production.

7.5.3.3 The qualification test plates should be subjected to the maximum PWHT condition.

7.5.3.4 The chemical composition of the weld overlay should be checked by chemical analysis of samples taken at [redacted]