

# **Recommended Practice for Materials and Fabrication of 1<sup>1</sup>/<sub>4</sub>CR-1<sup>1</sup>/<sub>2</sub>Mo Steel Pressure Vessels for Service Above 825 °F (440 °C)**

API RECOMMENDED PRACTICE 934-E  
FIRST EDITION, AUGUST 2010



AMERICAN PETROLEUM INSTITUTE



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**Downstream Segment**

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## Contents

	Page
<b>1</b>	<b>Scope</b> . . . . . <b>1</b>
<b>2</b>	<b>Normative References</b> . . . . . <b>1</b>
<b>3</b>	<b>Terms, Definitions, and Acronyms</b> . . . . . <b>3</b>
<b>3.1</b>	<b>Terms and Definitions</b> . . . . . <b>3</b>
<b>3.2</b>	<b>Acronyms</b> . . . . . <b>4</b>
<b>4</b>	<b>Design</b> . . . . . <b>4</b>
<b>5</b>	<b>Base Metal Requirements</b> . . . . . <b>5</b>
<b>5.1</b>	<b>Material Specification</b> . . . . . <b>5</b>
<b>5.2</b>	<b>Steel Making Practice</b> . . . . . <b>5</b>
<b>5.3</b>	<b>Chemical Composition Limits</b> . . . . . <b>5</b>
<b>5.4</b>	<b>Heat Treatment</b> . . . . . <b>6</b>
<b>5.5</b>	<b>Mechanical Properties</b> . . . . . <b>6</b>
<b>6</b>	<b>Welding Consumable Requirements</b> . . . . . <b>7</b>
<b>6.1</b>	<b>Material Requirements</b> . . . . . <b>7</b>
<b>6.2</b>	<b>Mechanical Requirements</b> . . . . . <b>7</b>
<b>7</b>	<b>Welding, Heat Treatment and Production Testing</b> . . . . . <b>7</b>
<b>7.1</b>	<b>General Welding Requirements</b> . . . . . <b>7</b>
<b>7.2</b>	<b>Welding Procedure Qualification</b> . . . . . <b>8</b>
<b>7.3</b>	<b>Preheat and Dehydrogenation Heat Treatment</b> . . . . . <b>8</b>
<b>7.4</b>	<b>Production Testing of Base Metal Welds</b> . . . . . <b>9</b>
<b>7.5</b>	<b>Weld Overlay or Integral Clad</b> . . . . . <b>10</b>
<b>7.6</b>	<b>Final PWHT</b> . . . . . <b>11</b>
<b>8</b>	<b>Nondestructive Examination (NDE)</b> . . . . . <b>12</b>
<b>8.1</b>	<b>General</b> . . . . . <b>12</b>
<b>8.2</b>	<b>NDE Prior to Fabrication</b> . . . . . <b>12</b>
<b>8.3</b>	<b>NDE During Fabrication</b> . . . . . <b>12</b>
<b>8.4</b>	<b>NDE After Fabrication and Prior to Final PWHT</b> . . . . . <b>12</b>
<b>8.5</b>	<b>NDE After Final PWHT</b> . . . . . <b>13</b>
<b>8.6</b>	<b>Positive Material Identification</b> . . . . . <b>13</b>
<b>9</b>	<b>Hydrostatic Testing</b> . . . . . <b>13</b>
<b>10</b>	<b>Preparations for Shipping</b> . . . . . <b>13</b>
<b>11</b>	<b>Documentation</b> . . . . . <b>14</b>
<b>Figure</b>	
<b>1</b>	<b>Location of Vickers Hardness Indentations</b> . . . . . <b>9</b>
<b>Table</b>	
<b>1</b>	<b>Base Metal Specifications</b> . . . . . <b>5</b>

## **Introduction**

This recommended practice (RP) applies to new pressure vessels in petroleum refining, petrochemical and chemical facilities in which fluids are processed at temperatures in the 825 °F to 1100 °F (440 °C to 595 °C) range. It is based on decades of industry operating experience and the results of recent experimentation and testing conducted by independent manufacturers, fabricators and users of pressure vessels for this service.

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



# Recommended Practice for Materials and Fabrication of 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo Steel Pressure Vessels for Service Above 825 °F (440 °C)

## 1 Scope

This recommended practice (RP) includes materials and fabrication requirements for new 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo steel and 1Cr-1<sup>1</sup>/<sub>2</sub>Mo pressure vessels and heat exchangers for high temperature service. It applies to vessels that are designed, fabricated, certified, and documented in accordance with ASME Code Section VIII, Division 1.

This document may also be used as a resource when planning to modify existing pressure vessels.

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

This RP is applicable to wall (shell) thicknesses from 1 in. (25 mm) 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<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo and 1Cr-1<sup>1</sup>/<sub>2</sub>Mo have been shown to have difficulty meeting the toughness requirements given in this document, but this does not preclude the use of this alloy if these properties can be met or if the equipment is designed with stresses below the threshold for brittle fracture. Although outside of the scope, this document can be used as a resource for vessels down to 0.5 in. (12.7 mm) shell thickness with changes defined by the purchaser.

This RP is not intended for use for equipment operating below 825 °F (440 °C). Refer to API 934-C for information on design for equipment operating at lower temperature ranges. Since hydrotreaters typically are designed to temperatures lower than 825 °F (440 °C), the guidelines in this RP do not apply to most hydrotreaters. Also, since coke drums typically fail due to fatigue and not due to reheat cracking; these RPs may not be appropriate for all aspects of coke drums.

## 2 Normative References

The following referenced documents are indispensable for 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 Recommended Practice 582, *Welding Guidelines for the Chemical, Oil, and Gas Industries*

API Recommended Practice 934-A, *Materials and Fabrication of 2<sup>1</sup>/<sub>4</sub>Cr-1Mo, 2<sup>1</sup>/<sub>4</sub>Cr-1Mo-1<sup>1</sup>/<sub>4</sub>V, 3Cr-1Mo, and 3Cr-1Mo-1<sup>1</sup>/<sub>4</sub>V Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service*

API Recommended Practice 934-C, *Materials and Fabrication of 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo Steel Heavy Wall Pressure Vessels for High Pressure Hydrogen Service Operating at or Below 825 °F (440 °C)*

API Recommended Practice 934-D, *Technical Report on the Materials and Fabrication Issues of 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo and 1Cr-1<sup>1</sup>/<sub>2</sub>Mo Steel Pressure Vessels*

API Publication 938-A, *An Experimental Study of Causes and Repair of Cracking of 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo Steel Equipment*

ASME *Boiler and Pressure Vessel Code* <sup>1</sup>, Section II—*Materials*; Part A—*Ferrous Material Specifications*; Part C, *Specification for Welding Rods, Electrodes and Filler Metals*; Part D—*Properties*

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<sup>1</sup> ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.

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*

ASME SA-182, *Specification for Forged or Rolled Alloy and Stainless 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*

ASME SA-264, *Standard Specification for Stainless Chromium-Nickel Steel-Clad Plate*

ASME SA-265, *Standard Specification for Nickel and Nickel-Base Alloy-Clad Steel Plate*

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 RP SNT-TC-1A <sup>2</sup>, *Personnel Qualification and Certification in Nondestructive Testing*

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

AWS A4.2 <sup>4</sup>, *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 Bulletin 342 <sup>5</sup>, *Stainless Steel Weld Metal: Prediction of Ferrite Content*

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<sup>2</sup> American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228, [www.asnt.org](http://www.asnt.org).

<sup>3</sup> ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, [www.astm.org](http://www.astm.org).

<sup>4</sup> American Welding Society, 550 NW LeJeune Road, Miami, Florida 33126, [www.aws.org](http://www.aws.org).

<sup>5</sup> The Welding Research Council, 3 Park Avenue, 27th Floor, New York, New York 10016-5902, [www.forengineers.org](http://www.forengineers.org).

## 3 Terms, Definitions, and Acronyms

### 3.1 Terms and Definitions

For the purposes of this RP, the following definitions apply:

#### 3.1.1

##### **ASME code**

*ASME Boiler and Pressure Vessel Code*, Section VIII, Division 1.

#### 3.1.2

##### **final PWHT**

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

#### 3.1.3

##### **fine grain practice**

A steelmaking practice where aluminum or other elements are added to the steel to provide resistance to grain growth during heat treatments. The steps and/or testing to achieve fine grain practice are defined in the ASME specifications for materials (e.g. ASME SA-20, paragraph 8).

#### 3.1.4

##### **hot forming**

Mechanical forming of vessel components above the final PWHT temperature.

#### 3.1.5

##### **Larson-Miller Parameter (LMP)**

Formula for evaluating heat treatments:

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

where

$T$  is the temperature in °Kelvin;

$t$  is time in hours.

#### 3.1.6

##### **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 formula may be used; results to be agreed upon by Purchaser and fabricator.

#### 3.1.7

##### **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 may be used; results to be agreed upon by Purchaser and fabricator.

### 3.1.8

#### **purchaser**

The firm or organization that has entered into the purchase order with the manufacturer, or their designated representative.

### 3.1.9

#### **reheat cracking**

Reheat cracking is creep cracking of welds or weld heat affected zones due carbide precipitation and the diffusion of certain elements (As, Cu, Sb, Sn, etc.) to grain boundaries resulting in loss of creep ductility and significantly lower than expected creep life. This phenomenon is also called in other publications “creep embrittlement cracking” or “stress relaxation cracking.”

## 3.2 Acronyms

For the purposes of this RP, 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
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 shall conform to the ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1. 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 RP is not intended to cover design issues other than those below.

- a) The design thickness shall not include any allowance for extra thickness provided as corrosion allowance or extra thickness provided as a corrosion resistance liner such as weld overlay or cladding.
- b) Weld seam layouts shall provide that all welds are accessible for fabrication and in-service NDE such as RT, UT, MT, and PT. Avoid the use of external attachments that cover weld seams.

- c) Nozzle necks should have transition to the vessel body as shown in Table 4.2.13 of the ASME Code, Section VIII, Div. 2. With Purchaser's approval, nozzles with nominal size 4 in. (100 mm) and less may be fabricated in accordance with Table 4.2.10, Details 3 through 7 of the ASME Code, Section VIII, Div. 2, with integral reinforcement.

## 5 Base Metal Requirements

### 5.1 Material Specification

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

**Table 1—Base Metal Specifications**

Steel	Plate	Forgings	Pipe
1 <sup>1</sup> / <sub>4</sub> Cr-1 <sup>1</sup> / <sub>2</sub> Mo	SA 387 Gr. 11, Cl. 1 or Cl. 2	SA 182 Gr. F11, Cl. 1, 2 & 3 SA 336 Gr. F11, Cl. 1, 2 & 3	SA 335 Gr. P11 SA 369 Gr. FP 11
1Cr-1 <sup>1</sup> / <sub>2</sub> Mo	SA 387 Gr. 12, Cl. 1 or Cl. 2	SA 182 Gr. F12, Cl. 1, 2 & 3 SA 336 Gr. F12	SA 335 Gr. P12 SA 369 Gr. FP 12

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

5.1.3 Nozzles shall be manufactured from forgings. For thicker nozzles, 2<sup>1</sup>/<sub>4</sub>Cr-1Mo may be used to ensure that toughness requirements are met. When using 2<sup>1</sup>/<sub>4</sub>Cr-1Mo, 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 shall be vacuum degassed.

### 5.3 Chemical Composition Limits

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

C = 0.15 wt % max

P = 0.012 wt % max

S = 0.007 wt % max

Cu = 0.20 wt % max

Ni = 0.30 wt % max

Nb = 0.004 wt % max

V = 0.025 wt % max

Ti = 0.02 wt % max

also: X-bar ≤ 15 ppm

where X – bar = (10P+5Sb+4Sn+As)/100 [with P, Sb, Sn, and As in ppm]

NOTE The J-factor is not applicable to these alloys, and an X-bar limit has been adopted as a means of restricting the concentration of elements that contribute to reheat cracking of the steel.

The chemistry restrictions described above along with other aspects of this RP are designed to provide the steel with resistance to the reheat cracking phenomenon described in API 938-A.

## 5.4 Heat Treatment

All product forms shall be annealed, normalized and tempered (N&T) or quenched and tempered (Q&T) to meet the required mechanical properties. For thickness > 2 in. (50 mm), Q&T may be required to meet fracture toughness specifications for the steel. Annealed steel and lower Class levels should be specified for applications involving high temperature service where the primary failure mechanism is creep rupture. For equipment exposed to cyclic service and where fatigue is an important factor the use of N&T or Q&T heat treatment and higher class levels may be more appropriate.

## 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:

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

NOTE If multiple plates are cut from one motherplate only one set of specimens from the motherplate is required.

- b) Forging—From each heat transverse to the major working direction in accordance with SA-182 or SA-336, and test specimens shall be taken at  $1/2T$  of the prolongation or of a separate test block. A separate test block, if used, shall be made from the same heat and shall receive substantially the same reduction and type of hot working as the production forgings that it represents and shall 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, transverse to the major working direction in accordance SA 530 except that test specimens shall be taken from  $1/2T$ .

### 5.5.2 Tensile Test Requirements

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

**5.5.2.2** Test coupon shall be heat treated to represent the maximum post-weld heat treatment per 3.1.6.

**5.5.2.3** 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  $1^{1/4}Cr-1/2Mo$  steel material used for pressure containing 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 minimum and maximum post-weld heat treatments per 3.1.7 and 3.1.6 shall be tested and meet the following requirements. The minimum CVN impact values shall be 40 ft-lbs (54 Joules) average of three specimens at 0 °F (−18 °C) and 20 ft-lbs (27 Joules) minimum for a single specimen at 0 °F (−18 °C). In addition, if the MDMT is < 0 °F (−18 °C), Code requirements for impact testing must also be met. If the toughness levels at the MDMT of < 0 °F (−18 °C) meet the toughness criteria levels (40/20 ft-lbs) listed above, retesting at 0 °F (−18 °C) is not needed.
- c) Lateral expansion and percent shear shall 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, 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 improve resistance to reheat cracking. The chemical composition restriction applies to the heat analysis.

$$X\text{-bar} = (10P + 5Sb + 4Sn + As) / 100 \leq 12$$

where

P, Sb, Sn, and As are in ppm

C is 0.15 % maximum

Cu is 0.20 % maximum

Ni is 0.30 % 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, per AWS A4.3, shall be used. They shall 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 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 lot of flux and heat of wire, shall 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 shall 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 shall:

- 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 shall propose alternate NDE methods to verify weld quality); and
- c) 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 corrosion resistant weld overlay or cladding. For these attachment welds, a PQR or mockup test shall be performed to verify that this does not produce a HAZ in the base metal unless waived by the Purchaser.

**7.1.4** All shop 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.

## **7.2 Welding Procedure Qualification**

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

**7.2.2** 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 electrodes, wire and flux combination shall be of the same type and similar in chemistry as those to be used in production welding.

**7.2.3** 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 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 250 HV10.

**7.2.4** 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.

**7.2.5** 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 shall be performed for each welding procedure and shall meet the impact test temperature and acceptance requirements in 5.5.3.

**7.2.6** All WPSs/PQRs shall be approved by the Purchaser prior to fabrication.

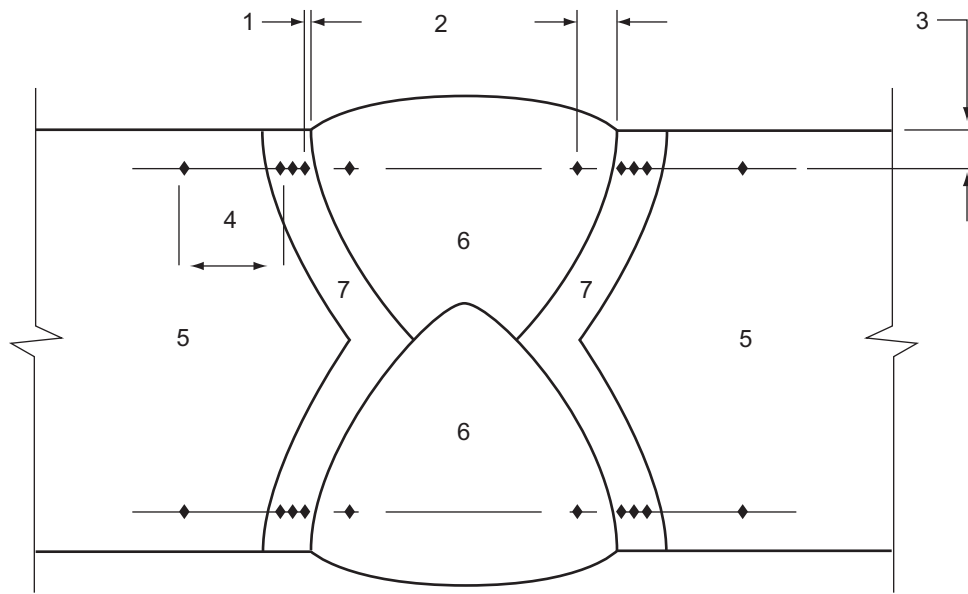
## **7.3 Preheat and Dehydrogenation Heat Treatment**

### **7.3.1 Preheat**

All base metals shall 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 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.

During welding, the preheat temperature shall be maintained until PWHT or dehydrogenation heat treatment (DHT) is performed in accordance with 7.3.2.



**Key**

1	approximately 8 mil (0.2 mm)	5	base metal
2	0.04 in. to 0.12 in. (1 mm to 3 mm) (TYP)	6	weld metal
3	1/16 in. (1.5 mm)	7	HAZ
4	0.12 in. to 0.24 in. (3mm to 6 mm) (TYP)		

**Figure 1—Location of Vickers Hardness Indentations****7.3.2 Dehydrogenation Heat Treatment (DHT)**

The DHT shall be performed at a minimum metal temperature of 570 °F (300 °C) for duration of one 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 equivalent 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 (heat affected zone hardness)**

**7.4.2.1** After final PWHT (see 7.6) hardness determinations shall be made for each pressure-retaining weld using a portable hardness tester.

**7.4.2.2** Each hardness test location 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. Hardness values of all three locations shall 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 shall 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 Impact Tests**

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

## **7.5 Weld Overlay or Integral Clad**

Austenitic stainless steel, ferritic stainless steel, or nickel alloy cladding may be used for the corrosion resistant weld overlay or for integral clad (refer to SA-264 and SA-265). The following special requirements shall apply.

### **7.5.1 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 except that the minimum ferrite content for Type 347 should be 5 FN (in accordance with API RP 582).

### **7.5.2 Disbonding Tests**

Experience indicates that the risk of disbonding is low at the thicknesses and hydrogen charging levels at which  $1\frac{1}{4}$ - $\frac{1}{2}$ Mo is used. If testing is considered, API 934-A can be consulted as a resource. The Purchaser shall define testing requirements and acceptance criteria (refer to ASTM G146).

### **7.5.3 Weld Overlay Procedure Qualification**

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

**7.5.3.2** 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 to be used in production.

**7.5.3.3** The 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 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 in the austenitic stainless weld overlay. The calculated ferrite content shall be between 3 FN and 10 FN except that the minimum ferrite content for Type 347 should be 5 FN (in accordance with API 582).

### **7.5.4 Preheat and Heat Treatments during Weld Overlay**

When the weld overlay is austenitic stainless steel or nickel alloy, the base metal shall be preheated to 200 °F (94 °C) for the first layer of weld overlay. The maximum interpass temperature shall be 350 °F (175 °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 required chemistry of the specified overlay material (C, Cr, Ni, Mo, and Nb). At least one analysis for each shell ring and head, and one for each manual welding process for nozzles, shall be required.

### 7.5.5.2 Ferrite Content of Austenitic Stainless 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 for the steel backing material in accordance with Appendix A7, Paragraph A7.1 of AWS A4.2 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) at least ten locations, selected at random, shall be checked for each shell ring and head;
- b) two locations for each nozzle overlay (one at each end); and
- c) one location on cladding or overlay restoration of each category A, B, and D welds if applicable.

**7.5.5.2.4** The value of all ferrite readings at each location shall meet the requirements of 7.5.1.

## 7.6 Final PWHT

**7.6.1** PWHT shall comply with the minimum requirements of the applicable code except that all 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo and 1Cr-1<sup>1</sup>/<sub>2</sub>Mo weld joints shall be PWHT at a minimum of 1225 °F (663 °C), and the recommended post-weld heat treat range is 1225 °F to 1275 °F (663 °C to 690 °C). Post-weld heat treatment temperatures above 1275 °F (690 °C) should be considered when the primary failure mechanism for the welds is creep, but these steels should not be post weld heat treated at temperatures above 1350 °F (732 °C). The use of higher post-weld heat treat temperatures helps prevent reheat cracking, but higher post weld heat treating may result in lower steel tensile strength. The post weld heat treatment used could affect the steel fracture toughness, and this should be taken into account because many refinery pressure vessels are pressurized at low temperatures during start-up and shut-down.

**7.6.2** 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 the ASME Code.

**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 Examination (NDE)**

### **8.1 General**

**8.1.1** All NDE personnel should be qualified in accordance with ASNT Recommended Practice No. SNT-TC- 1A. 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 should 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** All base metal plates should be ultrasonically examined before forming with 100 % scanning in accordance with ASME Section V and SA 578, Level C, Supplementary Requirement S1.

**8.2.1.2** All forgings for shell rings, nozzles and manways should be ultrasonically examined with 100 % scanning in accordance with Paragraph 3.3.4 of 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, should be examined by MT in accordance with Paragraph 7.5.6 or by PT in accordance with Paragraph 7.5.7 of ASME Section VIII, Division 2. Examination should be after finish machining but before welding.

**8.2.2.2** For formed plates to be welded for shell rings and heads, welding edges should be examined by MT or PT.

**8.2.2.3** If weld overlay is applied on the plate before forming, entire surface of all formed plates to be welded for shell rings and heads, including those for weld overlay, should be examined by MT or PT, as noted in 8.2.2.1.

### **8.3 NDE During Fabrication**

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

**8.3.2** Temporary attachments should be minimized. All areas where temporary attachments have been removed should be examined by MT or PT in accordance with Paragraph 7.5.6 or Paragraph 7.5.7 of ASME Section VIII, Division 2, 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 should be fully examined by RT in accordance with Paragraph 7.5.3 of ASME Section VIII, Division 2 or UW-51 of ASME Section VIII, Division 1 before final PWHT as applicable.

**8.4.1.2** UT may be applicable in lieu of RT when the UT procedure fulfills the requirements of Paragraph 7.5.5 of ASME Section VIII, Division 2.

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

## 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 strip approximately 3.2 in. (80 mm) wide across each head should be performed on weld overlay. 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** All pressure-retaining base metal welds, including nozzles, should be fully examined by UT in accordance with Paragraph 7.5.4 of ASME Section VIII, Division 2.

**8.5.1.2** All accessible welds should be examined by MT. An AC yoke method should 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 stainless steel weld overlay, and attachments to the overlay, should be examined by PT in accordance with Paragraph 7.5.7 of ASME Section VIII, Division 2.

## 8.6 Positive Material Identification

**8.6.1** Positive Material Identification (PMI) should be performed in accordance with the Purchaser PMI specification.

## 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 Preparations 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 and/or other evaporative means shall not be used due to possible chloride contamination of stainless overlay or clad vessels.

**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. A non-removal tag shall be attached with a warning that the vessel is filled with nitrogen.

**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 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 for base metal and weld metal;
- b) all 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) PMI report.



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