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# **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 STANDARD 934-C  
THIRD EDITION,  
BALLOT DRAFT

FOR COMMITTEE REVIEW ONLY

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## Introduction

This standard 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 or supplement this standard with additional proprietary requirements.

FOR COMMITTEE REVIEW ONLY

# 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)

## 1 Scope

This standard covers materials and fabrication requirements for new 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo steel heavy-wall pressure vessels and heat exchangers for high-temperature, high-pressure hydrogen service. It applies to pressure 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<sup>1</sup>/<sub>2</sub>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 standard, “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<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo plates and forgings have been shown to have difficulty meeting the toughness requirements given in this document. Thick 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo forgings, such as integrally reinforced nozzles, flanges, tube sheets, channel covers, etc., can especially have difficulty meeting specified properties. 2<sup>1</sup>/<sub>4</sub>Cr-1Mo vessel components 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 pressure vessels down to 1 in. (25 mm) or lower in shell thickness, with changes defined by the purchaser.

Multilayer pressure vessels are outside the scope of this document.

This standard is not intended for use for equipment operating above 825 °F (440 °C) or in the creep range. API Standard 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 the 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<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 Standard 934-E, *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)*

ASME <sup>1</sup> *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*

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

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

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

*WRC<sup>4</sup> 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*

### **3 Terms, Definitions, and Abbreviations**

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

<sup>3</sup> American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126, [www.aws.org](http://www.aws.org).

<sup>4</sup> Welding Research Council, 3 Park Avenue, 27th Floor, New York, New York 10016, [www.forengineers.com](http://www.forengineers.com).

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

##### **Cold forming**

The mechanical forming or rolling of steel vessel components at ambient temperature up to 900 °F (480 °C).

#### 3.1.3

##### **Final post-weld heat treatment (PWHT)**

The last PWHT after fabrication of the pressure vessel and prior to placing the pressure vessel in service.

#### 3.1.4

##### **hot forming**

The mechanical forming of steel vessel components immediately after soaking within a temperature range of 900 °F (480 °C) to the upper end of the PWHT temperature range.

#### 3.1.5

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

Parametric relationship between the aggregate elevated temperature exposures (heat treatment(s) temperatures), and times at temperature, 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. Additional details on LMP are under Section 5.

#### 3.1.6

##### **manufacturer**

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

#### 3.1.7

##### **maximum PWHT**

Specified heat treatment (aggregate temperature and time) of test coupons to simulate the maximum heat treatment exposures of the vessel alloy or vessel-portion alloy. Additional details on maximum PWHT are under Section 5.

#### 3.1.8

##### **minimum PWHT**

Specified heat treatment (aggregate temperature and time) of test coupons used to simulate the minimum heat treatment exposures of the vessel alloy. Additional details on minimum PWHT are under Section 5.

#### 3.1.9

##### **purchaser**

The operator-user that has entered into the pressure vessel purchase order with the manufacturer, or their designated representative.

#### 3.1.10

##### **warm forming**

The mechanical forming of steel vessel components immediately after soaking within a temperature range of 900 °F (480 °C) to the upper end of the PWHT temperature range.

### 3.2 Abbreviations



For the purposes of this standard, 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	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 or Division 2, and Code Cases*, as applicable.

**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 conform with the purchaser's design specification and other technical documents.

**4.3** This standard 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 pressure 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) Nozzle welds shall be located without intersecting circumferential or longitudinal welds, unless otherwise approved by purchaser (if approved, the purchaser shall specify an additional NDE and NDE sequence).

**4.4** Purchaser shall specify the use of dissimilar metal flanges or a dissimilar metal weld when mating to

pipng at the outlet nozzle that extends to the outside of the skirt. This is discussed further in section 6.1.2 and 8.1.5.

## 5 Heat Treatment

### 5.1 Maximum PWHT

Prior to heat treatment, coupons shall be representative of the as-supplied material (i.e., having the same austenitizing and tempering heat treatment). By definition, maximum PWHT includes all fabrication heat treatments above 900 °F (482 °C) [e.g. warm forming, intermediate stress relief (ISR), planned PWHT cycles, a PWHT cycle for possible shop repairs, and a minimum of one extra PWHT for possible future use by purchaser]. Typically, the ISR and PWHT cycles are aggregated into one single equivalent heat treatment that 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 temperatures too low to affect material properties.

**NOTE** To determine the equivalent time at one temperature (within the PWHT range) of heating steps that have temperatures outside the PWHT range, the Larson-Miller Parameter formula (or Hollomon-Jaffe Parameter) may be used (results are to be agreed upon by purchaser and manufacturer). During future repairs, it is the purchaser's responsibility to assess any changes in properties that may have occurred from high-temperature service and understand how the proposed repair welding and PWHT may impact the pressure vessel.

### 5.2 Minimum PWHT

Prior to heat treatment, coupons shall be representative of the as-supplied material (i.e. having the same austenitizing and tempering heat treatment). By definition, minimum PWHT includes only the minimum of fabrication heat treatments above 900 °F (482 °C), e.g., warm forming, intermediate stress relieving (ISR) if any, and one PWHT cycle. Typically, the ISR and PWHT cycles are aggregated into one single equivalent heat treatment that approximates the sum total effect of time and temperature. Methods to account for the aggregate effects on mechanical properties 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 formula (or Hollomon-Jaffe Parameter) may be used (results are to be agreed upon by the purchaser and manufacturer).

### 5.3 Larson-Miller parameter

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:

$$LMP = T \times (20 + \log t) \quad (1)$$

$$Final\ LMP = T_i \times [20 + \log(t_i + t_{eqi})] \quad (2)$$

$$t_{eqi} = 10^{\{T_i/T_{eqi} * [20 + \log(t_i)] - 20\}} \quad (3)$$

where

$T$  is the temperature in kelvins.

$t$  is the time in hours.

$t_{eqi}$  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.”

## 6 Base Metal Requirements

### 6.1 Material Specifications

6.1.1 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 <sup>1</sup> / <sub>4</sub> Cr-1 <sup>1</sup> / <sub>2</sub> Mo	SA-387 Grade 11, Class 1 or Class 2	SA-182 Grade F11, Class 2 SA-336 Grade F11, Class 2 or Class 3	SA-335, Grade P11 SA-369, Grade FP11

6.1.2 Unless approved in advance by the purchaser, different base metals should not be mixed in the same pressure vessel (such as using 2<sup>1</sup>/<sub>4</sub>Cr-1Mo nozzles in a 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo shell or head). There are some designs which use austenitic stainless steels as part of the outlet nozzles, which extend outside the skirts and involve a dissimilar metal weld outside of the skirt. These cases require purchaser approval (also see 8.1.5).

6.1.3 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 6.3) as the pressure boundary material.

### 6.2 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.

### 6.3 Chemical Composition Limits

6.3.1 For 1<sup>1</sup>/<sub>4</sub>Cr-1<sup>1</sup>/<sub>2</sub>Mo steel, all plate and forging materials shall meet the following additional chemical requirements by heat analysis.

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

where:

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

Additionally:

- C is 0.15 wt % max;
- P is 0.010 wt % max;
- S is 0.007 wt % max;
- Cu is 0.20 wt % max; and

— Ni is 0.30 wt % max.

**NOTE** While the J-factor is used to mitigate temper embrittlement in 2¼Cr-1Mo steels, it is not applicable to 1¼Cr-½Mo and 1Cr-½Mo steels, and an X-bar limit has been adopted as a means of restricting the concentration of elements that contribute to temper embrittlement, reheat cracking, and LCD cracking. The chemistry restrictions described above, along with other aspects of this standard, are designed to provide the steel with resistance to reheat and LCD cracking, balanced with the other desired properties. API Publication 938-A was used as a basis for these requirements, and the optimum limits have been compiled. The MPC-05 and MPC-07 formulas discussed in Publication 938-A are too complicated for steelmakers to develop strategies to consistently meet, and hence, it would be extremely impractical to add to purchasing requirements.

**6.3.2** 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.

## 6.4 Heat Treatment

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

- a) Normalizing and tempering (N&T):
- 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).

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

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

## 6.5 Mechanical Properties

### 6.5.1 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  $\frac{1}{2}T$  location, (and at the  $\frac{1}{4}T$  location in accordance with ASME SA-20 if required by Code).  $\frac{1}{2}T$  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 standard),  $\frac{1}{2}T$  specimens should be used.

- b) Forging—from each heat, at the  $\frac{1}{2}T$  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 shall 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.

### 6.5.2 Tensile Test Requirements

Tensile testing of plates and forging materials shall conform 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 5.1;  
b) tensile properties at room temperature shall meet the requirements of the applicable code(s).

### 6.5.3 Impact Testing Requirements

Charpy V-notch (CVN) impact testing shall be performed for all  $1\frac{1}{4}\text{Cr}-\frac{1}{2}\text{Mo}$  steel material (by heat) used for pressure-retaining components except bolting. CVN impact tests shall conform 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 5.1 and 5.2 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 shall 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. If impact test results do not meet specification only one re-test shall be permitted for each product form (i.e. according to SA-20 clause 16.2 for plate). Where it is suspected that the test methods and or samples were done incorrectly, and if approved by the purchaser, initial results can be voided and retesting can be performed. Repeating the heat treatment is also permitted (according to SA-20 for plates).

## 7 Welding Consumable Requirements

### 7.1 Material Requirements

7.1.1 Deposited weld metal, from each lot or batch of welding electrodes, 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.

7.1.2 The chemical composition of deposited weld metal samples shall also meet the following limits to improve resistance to embrittlement. These limits apply to the heat analysis.

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

where:

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

Additionally:

— C is 0.15 wt % max;

- Cu is 0.20 wt % max;
- Ni is 0.30 wt % max.
- B is 0.001 wt% max.

**7.1.3** 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.).

## **7.2 Mechanical Requirements**

### **7.2.1 Tensile Properties**

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

### **7.2.2 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 6.5.3.

## **8 Welding, Heat Treatment, and Production Testing**

### **8.1 General Welding Requirements**

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

**8.1.2** Welded joints, including non-pressure attachments to the pressure 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.

**8.1.3** Welding shall be completed prior to final PWHT. Welding of attachments to the internal corrosion resistant weld overlay or cladding, or to external stainless steel weld buildups, or subsequent layers of weld overlay may occur after PWHT when permitted by 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 purchaser. The location and dimensions of repairs shall be documented in accordance with Paragraph 12.

**8.1.4** Weld repairs to base metal, weld joints, and weld overlay shall be performed using a repair welding procedure qualified in accordance with 8.2 and shall meet all the same requirements as the normal fabrication welds.

**8.1.5** No pressure-retaining dissimilar metal welds of ferritic to austenitic alloys shall be allowed, especially at

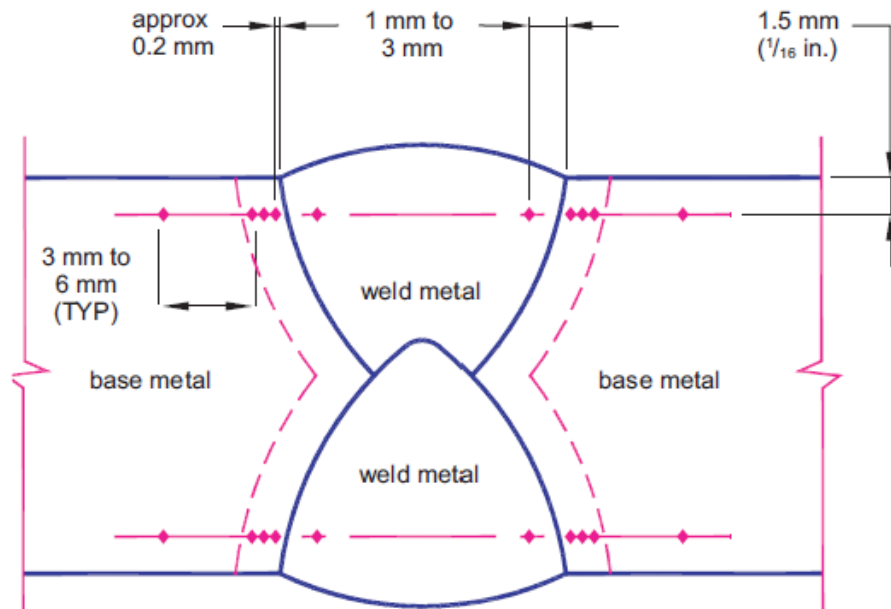
stress riser sites such as the nozzle-to-shell, nozzle-to-head or nozzle-to-flange welds, except on a case-by-case basis, approved by purchaser. Dissimilar metal welds should be avoided at nozzle-to-pipe connections with constraint mismatch and also at thickness transitions. In some cases, purchasers have allowed dissimilar metal welds in the outlet nozzles (typically in pipe-to-pipe or pipe-to-elbow welds) that are located outside of the skirts but preferably at locations where access allows for NDE. Depending on the process temperature and line size, there are cases in which a dissimilar metal pipe-to-pipe weld is preferred over dissimilar metal flanges.

## 8.2 Welding Procedure Qualification

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

**8.2.1** 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 pressure 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.

**8.2.2** Vickers hardness traverses of weld joints shall be made on weld samples 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, 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**

**8.2.3** 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.

**8.2.4** Charpy V-notch impact testing shall be performed on weld metal and HAZ of the heat-treated test plate

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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 6.5.3. Location of impact specimens shall also be as per ASME Sec VIII Div 2 Paragraph 3.11.8.

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

**NOTE** When qualifying new procedures, recording of a welding log is optional, but it is beneficial in the analysis of welding issues that may arise. The welding log may include variables for each weld bead such as current, voltage, welding travel speed, heat input, preheat, interpass temperature, filler metals heat/lot. Sketch of weld beads sequence and/or macro of cross section may also be prepared to qualitatively show weld geometry, weld bead dimensions and bead heights.

### **8.3 Preheat and Dehydrogenation Heat Treatment (DHT)**

#### **8.3.1 Preheat**

8.3.1.1 Base metal should be heated to a minimum of 400 °F (200 °C) during welding operations (except as modified for weld overlay; see 8.5.4). Lower preheat values can be proposed and submitted to the Purchaser for approval along with data from past experience but shall not be less than 300 °F (150 °C) prior to welding.

**NOTE** The 400 °F (205 °C) preheat for welding is based on the ASME Sec. VIII, Div. 2 non-mandatory Table 6.7 (see Paragraph 6.4.1.2 of the Code). Lower preheat values have been used successfully in the past by numerous manufacturers. Proposed lower preheat values can be proposed to the purchaser for approval along with data on past experience.

8.3.1.2 Base metal shall be heated to a minimum of 300F (150C) prior to, and during, thermal cutting and gouging operations.

8.3.1.3 Preheating at a minimum of 300F (150C) is also required for rolling, cold forming and pressing operations. Rolling, forming and pressing operations without preheating may be considered based on review of material toughness in the as supplied condition, edge preparation, ambient temperature and the manufacturer's experience with similar or more severe degree of forming.

8.3.1.4 The request to waive preheat shall be submitted by the manufacturer to the purchaser before starting fabrication along with details on prior relevant experience.

8.3.1.5 The preheat temperature shall be maintained until PWHT or DHT is performed in accordance with 8.3.2.

#### **8.3.2 Dehydrogenation Heat Treatment (DHT)**

8.3.2.1 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.

8.3.2.2 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.

### **8.4 Production Testing of Base Metal Welds**

#### **8.4.1 Chemical Composition of Production Welds**

8.4.1.1 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.

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



## 8.4.2 Hardness of Weld Deposit

8.4.2.1 After final PWHT (see 8.6), 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 (method, manufacturer and model) and procedure shall be submitted to purchaser for approval.

8.4.2.2 Each hardness test result shall be the average of three impressions at each test location. The test locations shall include weld metal only. Hardness values of all three locations should be reported.

8.4.2.3 Hardness values shall not exceed 225 HBW.

8.4.2.4 Hardness tests shall be performed on each 10 ft (3 m) length of weld, or fraction thereof. Where the side exposed to the process environment is weld overlaid, hardness testing of welds shall be performed on the non-overlaid side.

NOTE HAZ hardness tests measurements on vessel production weldments are typically an average of the HAZ, weld deposit, and base metal hardnesses, as the test indentation is generally larger than the HAZ width due to the limitations of the test method.

## 8.4.3 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 6.5.3, item b).

## 8.5 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.

### 8.5.1 Material Requirements

The filler materials shall be capable of passing the required ferrite testing listed in 8.5.5.2. 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.

### 8.5.2 Disbonding Tests

Experience indicates that the risk of disbonding is low at the thicknesses and hydrogen charging levels at which  $1\frac{1}{2}\% \text{ Cr-Mo}$  is used. If testing is specified by the purchaser (it is not required by this standard), API RP 934-A can be used as a resource document, and the purchaser should define testing requirements and acceptance criteria.

### 8.5.3 Weld Overlay Procedure Qualification

8.5.3.1 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 .

8.5.3.2 Weld procedure qualification tests shall be made on base metal of the same ASME specification as specified for the pressure 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 pressure 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.

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

8.5.3.4 The chemical composition of the weld overlay shall be checked by laboratory chemical analysis, or by using a portable analyzer of acceptable accuracy and precision when approved by purchaser. 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 8.5.1.

#### **8.5.4 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.

#### **8.5.5 Production Testing of Weld Overlay**

##### **8.5.5.1 Chemical Composition of Weld Overlay**

The chemical composition of weld overlays shall be checked by laboratory chemical analysis, or by using a portable PMI analyzer, of samples 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. This sampling/testing will result in the overlay needing repairs.

##### **8.5.5.2 Ferrite Content of Weld Overlay**

8.5.5.2.1 A magnetic instrument calibrated to AWS A4.2M/ISO 8249MOD shall be used to check the ferrite content of the production weld overlay prior to any PWHT.

8.5.5.2.2 Calibration (to account for the steel backing material) in accordance with AWS A4.2M/ISO 8249MOD may be used.

8.5.5.2.3 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.

8.5.5.2.4 The value of all ferrite readings at each location shall meet the requirements in 8.5.1. If readings are outside of the specification, the corrective action shall be determined to the agreement of the purchaser and the manufacturer.

#### **8.6 Final Post-weld Heat Treatment (PWHT)**

8.6.1 PWHT shall conform 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 weld joints shall be PWHT at 1250 °F ± 25 °F (675 °C ± 15 °C).

8.6.2 The fabricated pressure vessel should be postweld heat treated as a whole in an enclosed furnace whenever possible. When pressure vessel size does not allow a furnace PWHT as a whole, PWHT may be performed sectionally according to the ASME Section VIII, Division 2, Paragraph 6.4.3. Local PWHT shall follow the required heating, and gradient control band widths and thermocouple placements of WRC 452 unless otherwise approved by purchaser.

8.6.3 The PWHT temperature shall be strictly controlled. The temperature shall be measured using thermocouples attached to the inside and outside of the pressure vessel including portions of the pressure vessel outside of the furnace. Those sections of the pressure vessel outside the furnace shall be insulated such that the temperature gradient does not affect the mechanical integrity (e.g., physical condition, mechanical properties) of the pressure vessel

8.6.4 Continuous time-temperature records of all PWHT operations shall be documented. The records shall meet ASME Section VIII, Division 2, Paragraph 6.4.4.

## 9 Nondestructive Examination (NDE)

### 9.1 General

9.1.1 NDE personnel shall be qualified in accordance with ASNT SNT-TC-1A. For ASME Section VIII, Division 2 pressure 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.

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

### 9.2 NDE Prior to Fabrication

#### 9.2.1 Ultrasonic Testing (UT)

9.2.1.1 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*.

9.2.1.2 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.

#### 9.2.2 Magnetic Particle Testing (MT) or Dye Penetrant Testing (PT)

9.2.2.1 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.

9.2.2.2 Surfaces of all formed plates to be welded for shell rings and heads, including welding edges and surfaces to be weld overlaid, shall be examined by MT or PT after forming, as noted in 9.2.2.1. Examination should be after finish machining but before welding.

9.2.2.3 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.

### 9.3 NDE During Fabrication

9.3.1 MT shall be performed after completion of welds excluding stainless weld overlay. This includes

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

9.3.2 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.

## **9.4 NDE After Fabrication and Prior to Final PWHT**

### **9.4.1 Base Metal Welds**

9.4.1.1 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.

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

### **9.4.2 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 pressure 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.

## **9.5 NDE After Final PWHT**

### **9.5.1 Base Metal Welds**

9.5.1.1 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.

9.5.1.2 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.

### **9.5.2 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.

## **9.6 Positive Material Identification**

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

## **10 Hydrostatic Testing**

**10.1** 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 pressure vessel.

**10.2** Test water shall not contain more than 50 ppm of chlorides for stainless steel lined pressure vessels unless otherwise approved by purchaser.

**10.3** During the hydrostatic testing, the pressure 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 pressure vessels. For Division 2 pressure vessels, even though paragraph 8.2.4 of the Code states that the hydrotest temperature shall be 30 °F (17 °C) above the MDMT, ASME Code Case 2718 (Alternative Minimum Test Temperature for Hydrostatic Testing, Section VIII Division 2) also states that 30 °F (17 °C) above the impact testing temperature may be used whenever the impact testing temperature is lower than the MDMT.

**10.4** The pressure vessel shall be drained and thoroughly dried immediately after testing.

## 11 Preparation for Shipping

**11.1** Immediately after completion of final examination of the pressure vessel, the interior of the pressure 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 overlaid or clad vessels.

**11.2** Pressure vessel openings shall be sealed with a steel cover and gasket, and the pressure 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 pressure vessel should be marked and a conspicuous warning tag shall be attached at each manway stating, "THIS PRESSURE VESSEL IS FILLED WITH NITROGEN—DO NOT ENTER."

**11.3** 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.

## 12 Documentation

The following documentation should be available for Purchaser review at the following indicated fabrication stages. Final documentation shall be submitted to the purchaser at the completion of the project:

**12.1** For review prior to materials procurement

- a) Materials Purchase Specification
- b) Heat treatment calculations (i.e., basis for determining the minimum and maximum PWHT)

**12.2** For review and approval prior to fabrication

a) MTRs showing chemical composition and mechanical test result, and heat/batch/lot number. This applies to materials for all pressure containing parts, attachment materials welded to pressure containing parts and weld filler metals. This shall include:

- J-factors, (if applicable)
- X-bars (if applicable)
- impact test results (before and after step cooling if applicable)
- Step cooling results (if applicable)
- hot tensile test results (if applicable)

b) welding procedure specifications (WPS) with applicable procedure qualification records (PQR) including

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overlay disbonding testing.

- c) DHT procedure (if applicable)
- d) ISR procedure (if applicable)
- e) Furnace PWHT procedure and local PWHT procedure (if applicable)
- f) NDE (Including scan plans), PMI and hardness test procedures
- g) Inspection and test plan that:
  - o Is organized by fabrication and testing sequence
  - o Includes material procurement, inspection, and testing
  - o Includes any loose pressure boundary components (e.g. reactor dump caps, top reactor manway inlet spools etc.)
  - o Includes internals installation at Manufacturer's facility, if applicable
  - o Includes the location where each activity is taking place if other than the Manufacturer's shop

### 12.3 For review and approval during fabrication

- a) PMI results
- b) hardness test results
- c) NDE results
- d) Chemistry and ferrite examination reports for weld overlay and/or back cladding
- e) heat treatment charts, showing hold times and temperatures for PWHT, ISR, and DHT
- f) production test plate results
- g) Material traceability record connecting each component and weld to an MTR
- h) Repair procedure for each case of a major repair
- i) Weld and base metal repair map with sufficient detail to locate the repair, show the size of the grind out and indicate whether the repair was completed from the inside or outside surface

## 13 Summary Material Examination and NDE Requirements

See Table 2 for a summary of API Standard 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 standard take precedence. All Code requirements shall also be met.

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

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Materials and Locations for Testing or Inspection	Material Examination Requirements										
	Tensile Testing	Impact Testing	PMI	Chemical Composition	Ferrite	RT	UT	MT	PT	Hardness	Other
<b>Base Material and Weld Metal Testing—Prior to Fabrication</b>											
Plates (including SS clad plates)	6.5.2	6.5.3	9.6	6.3.1			9.2.1.1				
Forgings	6.5.2	6.5.3	9.6	6.3.1			9.2.1.2	9.2.2.1 <sup>a</sup>	9.2.2.1 <sup>a</sup>		
Pipe and Fittings		6.5.3.1	9.6	6.3.2							
Cr-Mo Filler Metal	7.2.1	7.2.2	9.6	7.1.2							7.1.3
<b>Weld Qualification Test Plates</b>											
Base Metal Weld	8.2.3	8.2.4								8.2.2	8.2.1
Weld Overlay <sup>b</sup>				8.5.3.4	8.5.1 8.5.3.4						
<b>Production Pressure Welds</b>											
Edges Prepared for Welding								9.2.2.1 <sup>a</sup> 9.2.2.2 <sup>a</sup>	9.2.2.1 <sup>a</sup> 9.2.2.2 <sup>a</sup>		
Back-gouged Surfaces, Prior to Back Welding								9.3.1			
Before PWHT			9.6	8.4.1		9.4.1.1 <sup>c</sup>	9.4.1.1 <sup>c</sup> 9.4.1.2 <sup>d</sup>	9.3.1			
After PWHT							8.5.1.1	9.5.1.2 <sup>e</sup>	9.5.1.2 <sup>e</sup>	8.4.2	
After Hydrotest											
<b>Production Weld Overlay</b>											
Before Overlay Welding								9.2.2.1 <sup>a,f</sup> 9.2.2.2 <sup>a,f</sup>	9.2.2.1 <sup>a,f</sup> 9.2.2.2 <sup>a,f</sup>		
Before PWHT			9.6	8.5.5.1	8.5.5.2		9.4.2				
After PWHT									9.5.2 <sup>g</sup>		
<b>Production Test Plates</b>											
Base Metal Welds		8.4.3									
<b>Miscellaneous</b>											
Locations of Temporary Attachments								9.3.2 <sup>a, h</sup>	9.3.2 <sup>a, h</sup>		
Vessel to Skirt Welds						9.4.1.1	9.4.1.2 <sup>d</sup>				

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Prior to PWHT												
<p>a Alternative to use MT or PT.</p> <p>b Disbonding tests are not typically required. If desired by purchaser, the purchaser should define testing requirements and acceptance criteria (7.5.2).</p> <p>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.</p> <p>d When RT is not practical for nozzle and skirt attachment welds, UT may be applied in lieu of RT.</p> <p>e PT may be substituted for MT whenever MT is impractical.</p> <p>f MT or PT is required for plate or forging surface to be weld overlaid; on plates, this NDE shall be after forming.</p> <p>g All stainless-steel weld overlay, and attachments to the overlay.</p> <p>h Areas where temporary attachments have been removed.</p>												

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