

Standard Recommended Practice

Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments

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Foreword

Most petroleum refining equipment and piping is constructed of carbon steel having a minimum specified tensile strength of up to 480 MPa (70,000 psi), and in almost every case, the equipment is fabricated by welding. The welds for refinery equipment and piping are made to conform to various codes, including the ASME⁽¹⁾ Boiler and Pressure Vessel Code, Section VIII,¹ the ASME/ANSI⁽²⁾ B31.3² Code for Pressure Piping, or API⁽³⁾ Standards 620³ and 650⁴ on tanks. According to these codes and standards, these carbon steels are classified as P-1, Group 1 or 2, and in this standard they are referred to as “P-1 steels.”

Petroleum refineries as well as gas- and oil-processing plants have used P-1 steels widely for wet hydrogen sulfide (H₂S) or “sour” services. They are the basic materials of construction for pressure vessels, heat exchangers, storage tanks, and piping. Decades of successful service have shown them to be generally resistant to a form of hydrogen stress cracking (HSC) called sulfide stress cracking (SSC). HSC has been found to occur in high-strength materials or zones of a hard or high-strength microstructure in an otherwise soft material. With commonly used fabrication methods, P-1 steels should be below the strength threshold for this cracking.

Some useful information is given in NACE Standard MR0175,⁵ although that standard does not apply to refineries. It is directed to sour oil and gas production equipment, where higher-strength steels are sometimes used in valve components, wellheads, and downhole tubulars. NACE Standard MR0175 limits the hardness of P-1 steels to a maximum of 22 Rockwell C (HRC). This limit has proved successful for P-1 steels in reducing the likelihood of SSC.

In the late 1960s, a number of SSC failures occurred in hard weld deposits in P-1 steel refinery equipment. The high hardnesses were found to be caused by submerged arc welding (SAW) with active fluxes and/or additions of alloying elements, both of which primarily resulted in increased hardenability of the weld deposit. High hardnesses were also found in gas metal arc welds with high manganese and silicon contents. To detect hard weld deposits caused by improper welding materials or procedures, the petroleum refining industry began requiring hardness testing of production weld deposits under certain conditions and applied a criterion of 200 Brinell (HB) maximum. These requirements were given in previous editions of this standard and in a similar API document discussed below.

The hardness of 200 HB is lower than 22 HRC (which is the equivalent of about 237 HB). Reasons for applying a lower limit were to compensate for nonhomogeneity of some weld deposits and normal variations in production hardness testing using a portable Brinell tester.

In the late 1980s, numerous cracks were discovered in P-1 steel equipment that met the 200 HB weld deposit hardness limit. Some of these cracks have been identified as another form of hydrogen damage, labeled as stress-oriented hydrogen-induced cracking (SOHIC).⁶ These cracks propagated primarily in the heat-affected zones (HAZs) of weldments and were found in both high- and low-hardness HAZs.

Also, cases of SSC were reported in HAZs of weldments that met the 200 HB weld deposit hardness limit. In these cases, the HAZ exhibited high hardnesses, often higher than 240 HB. However, HAZ hardness limits and testing were outside the scope of the previous editions of this standard, which covered only weld deposit hardness limits. In 1991, NACE Task Group T-8-7 agreed that this standard should be more comprehensive, covering the entire weldment and various in-service cracking mechanisms that can occur in corrosive petroleum environments.

⁽¹⁾ American Society of Mechanical Engineers (ASME), Three Park Avenue, New York, NY 10016-5990.

⁽²⁾ American National Standards Institute (ANSI), 11 West 42nd St., New York, NY 10036.

⁽³⁾ American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005.

Experience has shown that accurate HAZ hardness measurements cannot be obtained effectively on most shop and field production welds using portable hardness testing methods. Therefore, some companies in the refining industry are using one or more of the following practices to control HAZ hardnesses:

- Use of controlled base material chemistries with lower hardenability when welded;
- Use of postweld heat treatment (PWHT); or
- Use of welding procedures that have been qualified with HAZ hardness testing.

Each of these practices is addressed in this standard.

In some specific corrosive refinery process environments, cracking of weldments can occur because of residual stresses. Generally, residual stresses are reduced by PWHT. This type of cracking and the use of PWHT as a prevention method are also addressed in this standard. Table 1 provides an overview (“roadmap”) of the guidelines applicable to the various types of cracking.

This standard, issued by NACE International under the auspices of Specific Technology 34 on Petroleum Refining and the Gas Processing (formerly Group Committee T-8 on Refining Industry Corrosion), was prepared by NACE Task Group T-8-7, which is composed of corrosion consultants, corrosion engineers, and other specialists associated with the petroleum refining industry. It was originally prepared in 1972, reaffirmed in 1974, revised in 1987 and 1995. It was reaffirmed in 2000 by Specific Technology Group 34. API previously published a document, API RP 942,⁷ with similar objectives. The API document has been discontinued with the intention of recognizing this NACE standard as the industry consensus standard.

In NACE standard, the terms *shall*, *must*, *should* and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. *Should* is used that which is considered good and is recommended but is not absolutely mandatory. *May* is used to state that which is considered optional.

**NACE International
Standard
Recommended Practice**

**Methods and Controls to Prevent In-Service
Environmental Cracking of Carbon Steel
Weldments in Corrosive Petroleum Refining
Environments**

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Section 1: General

1.1 This standard establishes guidelines to prevent most forms of environmental cracking of weldments in carbon steel refinery equipment and piping. Weldments are defined to include the weld deposit, base metal HAZs, and adjacent base metal zones subject to residual stresses from welding.

1.2 This standard covers only carbon steels classified as P-1, Group 1 or 2. These classifications can be found in the ASME Boiler and Pressure Vessel Code, Section IX,⁸ ASME/ANSI B31.3 Code for Pressure Piping, or API Standards 620 and 650. It excludes steels over 480 MPa (70,000 psi) minimum specified tensile strength. Other materials may be vulnerable to cracking, but these materials are outside the scope of this standard.

1.3 The types of equipment covered by this standard include pressure vessels, heat exchangers, storage tanks, piping, valve bodies, and pump and compressor cases. All pressure-containing weldments or internal attachment weldments to the pressure boundary are included. In addition, weldments in some nonpressure-containing equipment, such as storage tanks, are included. External attachment weldments are sometimes included as discussed in Paragraph 6.4.4.

1.4 Both new fabrication and repair welds are within the scope of this standard. However, the practices recommended herein are intended to avoid *in-service* cracking, and are not intended to address cracking that can occur during fabrication, such as delayed hydrogen cracking. In most cases, however, these practices are also helpful in minimizing these fabrication problems.

1.5 Welding processes covered by this standard include shielded metal arc welding (SMAW); gas metal arc welding (GMAW), including flux-core arc welding (FCAW); gas tungsten arc welding (GTAW); and submerged arc welding (SAW). Almost all types of weld configurations are included. Some specific exceptions include hot taps or weld build-ups. Hardness limits and PWHT requirements for these welds should be reviewed on a case-by-case basis.

1.6 Corrosive refinery process environments covered by this standard can be divided into the two general services listed below. However, identification of the specific environments to which the guidelines set forth in this standard are to be applied to prevent various forms of in-service environmental cracking is the responsibility of the user. Figure 1 is a simplified schematic showing the interrelationships of the various cracking mechanisms discussed in this standard.

1.6.1 Services that could cause cracking due to hydrogen charging:

1.6.1.1 In these services, the environment or corrosion reactions result in diffusion of atomic hydrogen into the base metal and weldment. In high-strength or high-hardness areas, this hydrogen can result in HSC. In refining processes, the primary manifestation of HSC is SSC of hard weldments in process environments containing wet H₂S. However, other processes that promote aqueous corrosion of steel and promote hydrogen charging (such as hydrofluoric acid) can also cause HSC. Controlling both the weld deposit and HAZ hardness using the guidelines of Section 2 prevents HSC in most cases.

1.6.1.2 SOHIC can also occur in the services described above, but it does not require high strengths or high hardnesses. Hence, limiting weldment hardness does not prevent this form of cracking. Reducing weldment hardness and residual stress is believed to reduce the likelihood of this cracking, so the guidelines given in Sections 2 and 6 may still be helpful. However, additional steps, such as the use of special clean steels, water washing, corrosion inhibitors, or corrosion-resistant liners, may be needed for some services.⁹ An overview of the materials selection, fabrication, postweld heat treatment, and testing practices that have been applied to new pressure vessels for mitigating SOHIC is provided in NACE Publication 8X194.⁹

1.6.2 Services that could cause alkaline stress corrosion cracking (ASCC):

1.6.2.1 Figure 1 provides examples of services that can cause ASCC and Section 6 provides recommended practices to avoid this type of cracking. Severity of cracking is often dependent on temperature, concentration, level of residual tensile stresses, and other factors. Controlling weldment hardness does not prevent ASCC because high tensile stresses may still be present.

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1.7 For most refinery services, weld deposit hardness should be controlled as discussed in Paragraph 2.2. This practice primarily helps avoid the use of improper welding materials, welding procedures, or heat treatment. It also minimizes the risk of HSC from external wet atmospheric corrodents, process upsets, or from future changes in services.

1.7 In some cases, environmental cracking (both HSC and ASCC) has initiated from pre-existing weldment fabrication defects. Hence, it is desirable to minimize, inspect for, and remove defects, such as lack of fusion, delayed hydrogen cracking, or severe undercut, during original fabrication.

1.9 One possible environmentally induced cracking mechanism in carbon steel weldments that is not addressed in this standard is high-temperature hydrogen attack. API Publication 941¹⁰ gives recommendations on materials selection to avoid this problem. Other types of in-service cracking not addressed by this standard are primarily mechanical in nature. Examples are fatigue, creep, and brittle fracture.

**TABLE 1
“ROADMAP” for RP0472**

General Service/Possible Cracking Mechanism ^(A)	Weldment Component	Cracking Prevention and/or Hardness Control Method	Hardness Limit	Application Guidelines ^(B)	Test Method and Implementation Guidelines ^(B)
1. Wet H ₂ S service/hydrogen stress cracking (HSC) or sulfide stress cracking (SSC) concerns	Weld deposit	Hardness testing of production welds	200 HB	Paragraphs 1.6.1, 1.7, and 2.2	Section 3
	HAZ	Three options: 1. Base metal chemistry controls, 2. PWHT, or 3. HAZ hardness tests during welding procedure qualification	Not applicable ^(C) Not applicable ^(C) 248 HV ^(C) (70.5 HR 15N)	Paragraphs 1.6.1 and 2.3.1 Paragraphs 1.6.1 and 2.3.1.2 Paragraphs 1.6.1, 2.3.1.3, and 2.3.2	Paragraph 4.2 and Reference 9 Paragraph 4.3 Section 5
2. Alkaline stress corrosion cracking	Entire weldment	PWHT	Not applicable ^(C)	Paragraph 1.6.2 and Figure 1	Section 6

^(A) Specific services requiring controls, and the optimum control method, shall be defined by the user.

^(B) Many qualifiers and additional details are given in the referenced sections and paragraphs.

^(C) It is also desirable to control weld deposit hardness to 200 HB maximum (see Paragraphs 1.7 and 6.2).

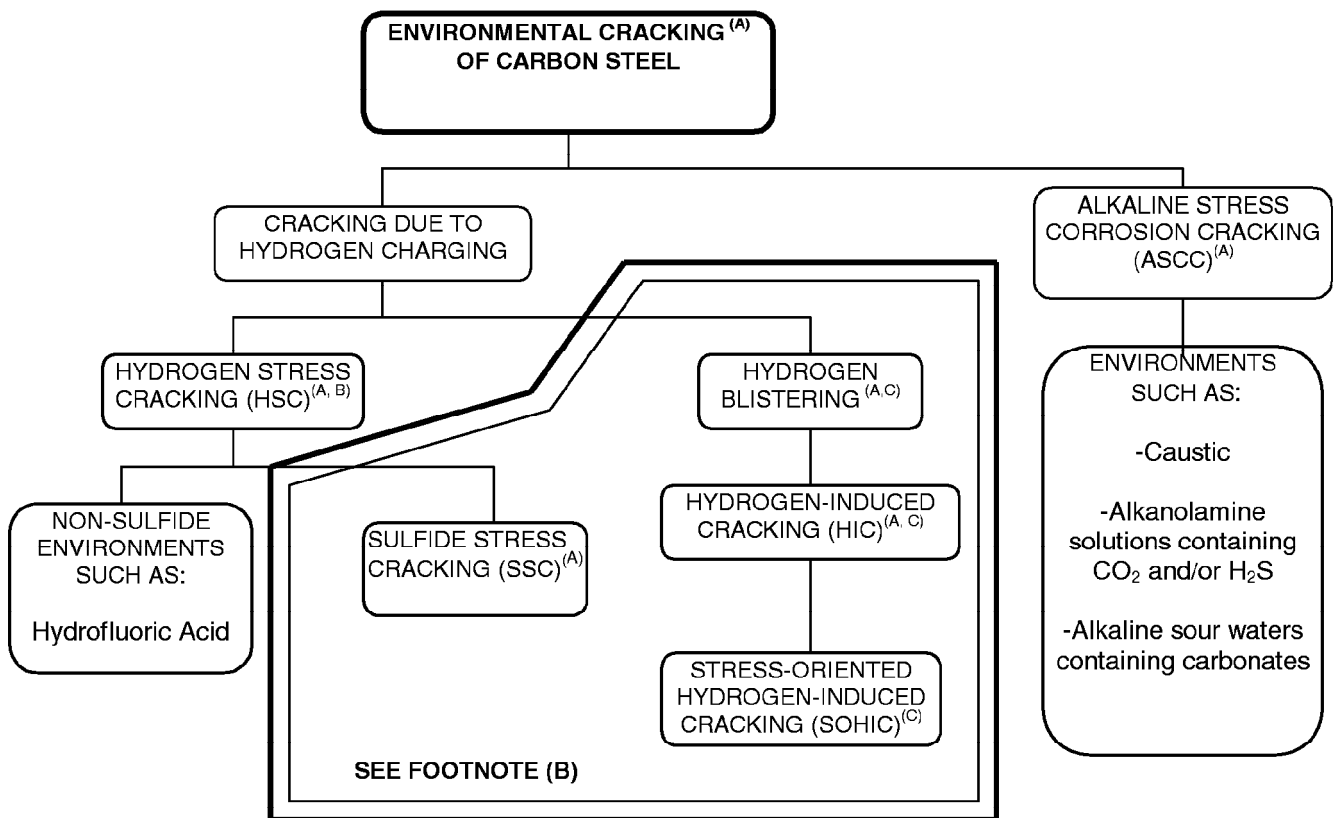


FIGURE 1
Interrelationships of the Various Cracking Mechanisms

(A) Refer to the NACE Glossary of Corrosion-Related Terms for definitions (including “stress corrosion cracking”).

(B) The forms of environmental cracking included within the double lines are commonly referred to as “wet H₂S cracking” when they occur in wet sulfide environments.

(C) This form of environmental cracking can also occur in non-sulfide environments such as hydrofluoric acid.

Section 2: Hardness Criteria and Guidelines

2.1 This section provides acceptable hardness limits for (a) production weld deposits and (b) laboratory hardness tests on weldments performed during welding procedure qualification. It also provides guidelines on filler metal selection to help meet the production weld deposit hardness criteria.

2.2 Production Weld Deposit Hardness Criteria and Filler Metal Selection Guidelines

2.2.1 For services in which control of the deposited weld metal hardness is considered necessary, the hardness of the completed weld deposit shall not exceed 200 HB.

2.2.2 Filler materials for the following welding processes shall conform to the listed specification from the ASME Boiler and Pressure Vessel Code, Section II, Part C:¹¹ SMAW, ASME SFA-5.1; GTAW and GMAW, ASME SFA-5.18; FCAW, ASME SFA-5.20; and SAW, ASME SFA-5.17.

2.2.3 Experience indicates that hardness values above 200 HB rarely occur in weld deposits with manual welding processes such as SMAW and GTAW using carbon steel consumables in accordance with ASME SFA-5.1 E60XX or E70XX, or ASME SFA-5.18 ER70S-X (except for any -6, -7, or -G materials). Hence, these weld deposits do not

require hardness testing unless otherwise specified by the user. This waiver may be applied even if a different consumable is used for the root pass.

2.2.4 High weld deposit hardnesses can occur with SAW when using a low- or medium-manganese wire in combination with an active flux.^{12,13,14} Also, some SAW welds with high manganese and silicon contents can have highly localized hard zones that are not softened significantly by postweld heat treatment (PWHT).¹⁵ Most welding consumable manufacturers recommend against the use of active fluxes for multipass welds. Hence, unless otherwise agreed, production SAW weld deposits shall meet the A-No. 1 chemical composition shown in Table QW-442 of the ASME Boiler and Pressure Vessel Code, Section IX.

2.2.5 Some GMAW and FCAW wire classifications allow high manganese levels. Therefore, production weld deposits made with these welding processes should also meet the A-No. 1 chemical composition shown in Table QW-442 of the ASME Boiler and Pressure Vessel Code, Section IX.

2.2.6 Testing guidelines are provided in Section 3.

2.3 HAZ Hardness Criteria and Application Guidelines

2.3.1 High-hardness microstructures in HAZs may be susceptible to cracking even with soft weld deposits in severely corrosive refinery services. For these services and equipment, as identified by the user, one or more of the following methods of obtaining acceptable HAZ hardnesses should be specified by the user:

2.3.1.1 Use and control of base material chemistries, preheat, and welding heat input such that a hard HAZ microstructure is not likely to be formed.

2.3.1.2 PWHT at a high enough temperature to ensure softening of the HAZ microstructure.

NOTE: Details on the use of the methods given in Paragraphs 2.3.1.1 and 2.3.1.2 are provided in Section 4 and in NACE Publication 8X194.

2.3.1.3 Preproduction HAZ hardness testing during the welding procedure qualification using Vickers (HV) or Rockwell Superficial Hardness (HR 15N) testing.

2.3.2 When preproduction welding procedure qualification HAZ hardness testing is used, the maximum allowable HAZ hardness shall be 248 HV (70.5 HR 15N).

2.3.2.1 Both laboratory testing and field experience with carbon and low-alloy steel weldments have shown that microstructures with hardness values less than 248 HV (70.5 HR 15N) have a low susceptibility to SSC.^{16,17,18}

2.3.2.2 The Brinell test method is considered unacceptable for HAZ hardness testing because it creates too large an indentation to obtain hardness values strictly from the HAZ and results in a bulk hardness value that is not representative of the peak HAZ hardness.

2.3.2.3 Guidelines for testing during welding procedure qualification and practices for ensuring that the test results are representative of production welds are given in Section 5.

Section 3: Weld Deposit Hardness Testing

3.1 The practices in this section should be applied to all services covered by the scope of this standard, except for the waiver given to some SMAW and GTAW welds in Paragraph 2.2.3, unless otherwise specified by the user. The practices may also be applied to other services for the reasons given in Paragraph 1.7.

3.2 When required, hardness testing on completed welds shall be done after any PWHT. Only *weld deposits* require testing unless otherwise specified by the user.

3.3 Weld deposits shall be tested on the side contacted by the process whenever possible. If access to the process side is impractical, such as on piping or small-diameter vessels, testing shall be done on the opposite side.

3.4 Hardness readings shall be taken with a portable Brinell hardness tester, in accordance with ASTM⁽⁴⁾ A 833. Additional test technique guidelines are given in Appendix A. Other hardness testing techniques may be employed if approved by the user.

⁽⁴⁾ American Society for Testing and Materials (ASTM) 100 Barr Harbor Drive, West Conshohocken, PA 19428.

3.5 For vessel or tank butt welds, a minimum of one location per weld seam shall be tested. Unless otherwise specified by the user, one test should be made for each 3 m (10 ft) of weld seam. In addition, one test shall be made on each nozzle flange-to-neck and nozzle neck-to-shell/head weld. Each welding procedure used shall be tested.

3.6 Testing of fillet weld deposits should be done when feasible. The number of tests and locations required shall be approved by the user with Paragraph 3.5 as a guide.

3.7 For piping welds, a percentage of butt welds shall be tested. A suggested minimum of 5% should be tested, unless otherwise specified by the user.

3.8 Weld deposits found to exceed the maximum hardness criteria given in Paragraph 2.2.1 are unacceptable and shall be reported to the user. Unless accepted by the user, hard welds shall be either removed and rewelded, or heat treated to reduce the hardness to an acceptable value. The specific approach to be used to correct the high-hardness condition shall be subject to the user's approval before any corrective action is taken. Regardless of the method of corrective action taken, the weld deposits shall be retested to ensure that the corrective action has resulted in acceptable hardness values. Also, additional welds should be tested for each high-hardness weld that is found, at a rate determined by the user.

Section 4: Materials and Fabrication Variables Affecting Weldment Hardness

4.1 Various references give general discussions on the effects of material composition, welding procedure, and PWHT on weld deposit and HAZ hardnesses. From this literature and field experience, the following methods of controlling weldment hardness have been determined.

4.2 Control of the base material chemistry of all production material for a given application can be an effective method of controlling the HAZ microstructure and hardness. This is generally done by controlling the carbon equivalent (CE), as determined by the formula given in Equation (1), total content of unspecified elements, and microalloying element additions. Examples of possible base material chemistry controls are provided in NACE Publication 8X194.

$$CE = \%C + \frac{\%Mn}{6} + \frac{(\%Ni + \%Cu)}{15} + \frac{(\%Cr + \%Mo + \%V)}{5} \quad (1)$$

4.3 PWHT almost always reduces weldment hardnesses to acceptable levels. PWHT concerns and issues are:

4.3.1 Required temperature ranges and hold times are given in various codes; however, a one-hour minimum hold time should be specified to ensure complete heat treatment.

4.3.2 A PWHT procedure should be developed prior to heat treating. It should include the type of heating process, the number and locations of thermocouples, supporting details, heat-up and cool-down rates, maximum allowable temperature differentials, soak time, and PWHT temperature range. The user may require submittal of the procedure for approval prior to the start of PWHT.

4.3.3 PWHT is not practical for some welds on valves, pumps, compressor casings, or compressor heads, especially after final machining. Other techniques of reducing HAZ hardness should be used (see Paragraph 2.3.1).

4.3.4 ASME Boiler and Pressure Vessel Code, Section VIII, allows PWHT to be performed at a lower than normally specified temperature, as long as it is held for a longer time (see Paragraph UCS-56 of Division 1). However, when PWHT is being performed to reduce HAZ hardness, these lower temperatures are not considered as effective.

4.3.5 P-1 steels in accordance with Paragraph 1.2 that have deliberate additions of microalloying elements may require additional preheat and higher PWHT temperatures to obtain acceptable HAZ hardnesses. These heat treatments needed to obtain acceptable HAZ hardnesses may adversely affect toughness values.⁹ There is a general consensus that this applies to steels with columbium plus vanadium contents greater than 0.03% or total content of unspecified elements greater than 0.5%. Welding procedures for such steels should be qualified in accordance with Section 5. Note: The definition of deliberate addition of a microalloying element for use with this standard is given in Paragraph 5.2.3.

4.4 Preheating and high heat inputs during welding are generally beneficial in reducing weldment hardness because they reduce the cooling rate of the weldment. Preheating may also be applied to thermal cutting and tack welding (if subsequent grinding will not be done). Guidelines for when to preheat and minimum preheat temperatures are given in applicable design codes, e.g., the nonmandatory Appendix R in ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. Additional information on the use of preheat and heat input to control weldment hardness (and susceptibility to delayed hydrogen cracking during fabrication) is available.

4.5 Small fillet welds on large sections are often prone to high HAZ hardnesses. This is because such welds often have low heat inputs and the large sections act as significant heat sinks, which result in high cooling

rates. One example is tray attachment welds in vessels. Hardness problems can be minimized by using the techniques discussed in Paragraphs 4.2, 4.3, or 4.4.

4.6 The highest hardness in weldments is generally in the HAZ of the last weld pass. Therefore, one-sided welds with no backwelding are of less concern than two-sided or backwelded welds, because the highest hardness zones are not in direct contact with the process. Problems on two-sided or backwelded welds can be minimized by using the techniques discussed in Paragraphs 4.2, 4.3, or 4.4, or by using a temper bead technique. With the temper bead technique, the cap pass should be applied so that the edges of the weld beads come within 3.0 mm (0.12 in.) of the base material, but do not touch the base material. If this results in an unacceptable profile as determined by the user, the excess weld may be removed by grinding.

Section 5: Welding Procedure Qualification Hardness Testing for Weldments

5.1 ASME Boiler and Pressure Vessel Code, Section IX, requires qualification of welding procedures to ensure that room-temperature tensile strength and ductility of the weldment meet minimum values. Welding must be performed within the essential variables specified for the welding process used. The ASME Boiler and Pressure Vessel Code has no requirements for hardness testing during procedure qualification tests. The following practices for hardness testing during procedure qualification tests have been developed and apply primarily to weldments where PWHT or base material chemistry controls are not used. The user shall specify when this hardness testing is required and which of the following practices are required, after reviewing the intended service for the weldment.

5.2 When HAZ hardness testing is being used during welding procedure qualification, additional practices are needed to ensure that the hardness tests are representative of production weldments. Materials and welding conditions used for the procedure qualification tests should be equivalent to what will be used for the equipment or piping. This can be done by applying the following additional essential variables, as appropriate. Some of the following practices may conflict with the ASME Boiler and Pressure Vessel Code, Section IX, supplemental essential variables for applications with notch toughness testing requirements. For these cases, the other options of PWHT or base material chemistry controls (Paragraphs 2.3.1.1 or 2.3.1.2) should be used.

5.2.1 Production materials should be of the same ASME specification and class or grade as the material used for the qualification hardness testing.

5.2.2 Maximum CE should not exceed the corresponding values obtained on the test sample. All chemical requirements should be applied to ladle analyses, unless otherwise specified by the user.

5.2.3 Maximum contents for each deliberately added microalloying element (such as Cb, V, Ti, and B) should not exceed the corresponding value on the test sample. Deliberate additions are generally considered to be greater than 0.01% for each of Cb, V, and Ti, and greater than 0.0005% of B. All chemical requirements should be applied to ladle analyses, unless otherwise specified by the user.

5.2.4 For all welding processes, the heat input during production welding should not vary by more than +25/-10% from the heat input used on the test sample. Heat input shall be calculated using Equation (2):

$$HI = \frac{(V \times A \times 60)}{(TS)} \quad (2)$$

where:

HI = Heat Input (J/mm or J/in.)
 V = Voltage (V);
 A = Amperage (A); and
 TS = Travel Speed (mm/min or in./min).

5.2.4 As an alternative for SMAW, the maximum bead size and the minimum length of weld bead per unit length of electrode used in the welding of the test sample shall be the limits applied to production welding.

5.2.5 For SAW, the flux and wire, and for FCAW, the wire used for production welding shall be the same brand name and type as that used in the qualification tests.

5.2.6 For GMAW and FCAW, the wire size used for production welding should be the same as that used during qualification tests. For other welding processes, only one size variation between the electrode or filler metal size used for the qualification tests and for subsequent production welding should be permitted.

5.2.7 Preheat and interpass temperatures used during production welding should be greater than or equal to that used in the welding procedure qualification tests.

5.2.8 For welds that will not be preheated, the maximum thickness allowed on production materials should be equal to the test sample thickness.

5.2.9 Weld bead sequence of the cap pass can affect the hardness of the HAZ. If a temper bead technique is used during qualification, the production procedure should require that the cap pass be applied so that the edges of the weld beads come within 3.0 mm (0.12 in.) of the base material, but not touch the base material. If this results in an unacceptable profile as determined by the user, the excess weld may be removed by grinding.

5.2.10 For fillet weld qualification tests, position should be an essential variable; however, tests on welds made in the overhead position shall qualify all other fillet positions.

5.3 Figures 2 and 3 show typical hardness test locations for butt welds and fillet welds, respectively. The maximum allowable HAZ hardness shall be 248 HV (70.5 HR 15N) as given in Paragraph 2.3.2. Using these test methods, the maximum weld deposit hardness should be 248 HV (70.5 HR 15N), and the average weld deposit hardness should not exceed 210 HV (91.5 HR 15T). Note: 210 HV is equivalent to 200 HB.

5.4 Microhardness testing using Knoop or Vickers tests with loads ≤ 500 g may be considered; however, the effects of surface preparation, etching, mounting procedures, appropriate criteria, and other details should be reviewed and approved by the user before being used.

5.5 Guidance on these hardness test techniques is given in ASTM E 384²¹ and ASTM E 18.²²

5.6 Individual HAZ hardness readings exceeding the value permitted by this standard can be considered acceptable if the average of three readings taken within close proximity does not exceed the values permitted by this standard and no individual reading is greater than 10 HV (1 HR 15N) units above the acceptable value.

5.7 The fabricator shall add the hardness test results to the ASME Procedure Qualification Record (PQR). The results should include a sketch of the test locations and corresponding results. The weld procedure specification (WPS) should be revised to reflect the limits imposed by the essential variables applied from Paragraph 5.2. The user may require that both forms be submitted for approval prior to production welding.

Section 6: Prevention of Weldment Cracking by Control of Residual Stress

6.1 This section deals with the prevention of stress corrosion cracking of carbon steels in alkaline environments. ASCC generally has three requirements: a crack-inducing environment, a susceptible material, and a tensile stress. Residual stresses from welding and/or forming are the most common sources of the tensile stress necessary for cracking. Residual tensile stresses are usually highest in the HAZ, but can sometimes extend up to 50 mm (2 in.) away from the weld deposit. Hence, these are the most common locations of ASCC, with the cracks typically oriented parallel to the weld.

6.2 Weldment hardnesses usually have no effect on ASCC susceptibility. However, in services in which **both** ASCC and HSC are concerns, weldment hardness controls are applicable.

6.3 PWHT is an effective method of mitigating ASCC. This is because PWHT has two primary benefits: lowering weldment hardness (which helps resist HSC) and reducing residual stresses from welding. By reducing residual stresses, PWHT helps prevent ASCC.

6.4 PWHT procedures, including temperatures, times, heating and cooling rates, etc., are given in the ASME Boiler and Pressure Vessel Code. The guidelines for PWHT differ somewhat for avoiding ASCC versus HSC. Guidelines for the latter are given in Paragraph 4.3. When PWHT is being performed to avoid ASCC, the following guidelines apply:

6.4.1 ASME Boiler and Pressure Vessel Code, Section VIII, allows PWHT to be performed at lower than the normally specified temperature, as long as it is held for a longer time. However, when PWHT is being performed to avoid ASCC, these lower temperatures may not be used, because they may not be as effective in reducing residual stresses.

6.4.2 Experience has shown that heating bands wider than required by codes (roughly >25 cm [10 in.]) are sometimes necessary. This applies primarily to weldments in large-diameter piping (>25 cm [10 in.]).

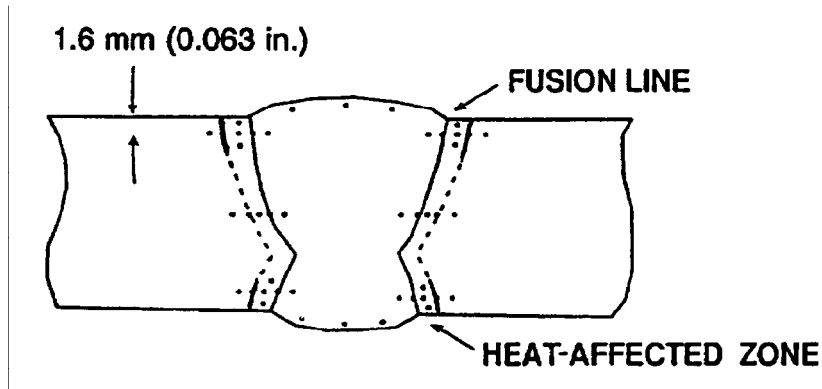


FIGURE 2
Typical Hardness Test Locations—Butt Weld

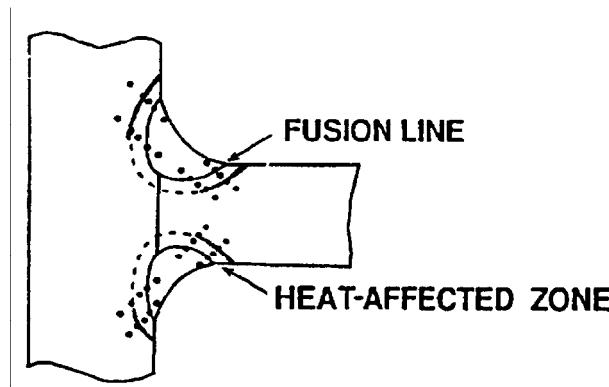


FIGURE 3
Typical Hardness Test Locations—Fillet Weld

NOTE: Figures 2 and 3 are schematic only. In both types of welds, hardness test results have typically been obtained from the points where the hardness traverses cross the weld fusion lines and from representative areas of the heat-affected zones.

6.4.3 Although some codes allow shorter hold times, a minimum of one hour should be used to ensure effective stress relieving.

6.4.4 When heat treatment is used to avoid ASCC, all welds and weld heat-affected areas require PWHT, including all pressure-containing welds, internal attachment welds, nozzle reinforcing pad welds, temporary fabrication attachment welds, arc strikes, etc. External attachment welds often generate residual stresses extending through the entire wall thickness, and if so, they should also

receive PWHT. Only if an evaluation shows that the residual stresses do not extend through-wall should PWHT be considered optional. Variables affecting the depth of residual stresses are welding heat input, base material thickness, and attachment weld size.

6.4.5 After PWHT, actions that reintroduce high residual stresses, such as straightening, should be avoided. If these actions have been done, a second PWHT should be performed when deemed necessary by the user.

6.5 Shot peening of the weldment surface contacted by the process may be considered by the user as an alternative to PWHT in reducing residual surface tensile stresses, but precautions should be taken to ensure it is done correctly. A concern is that shot peening produces a surface layer with compressive stresses, and this layer may eventually corrode away, exposing subsurface material that still has residual tensile stresses.

6.6 It is outside the scope of this standard to detail all the specific environments causing ASCC of P-1 steels. Various reference books and publications contain information on ASCC environments and preventive measures.^{23,24}

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Appendix A

Suggested Guidelines for Portable Brinell Hardness Testing of Welds

1. Grind the test area flush with the base metal. A smooth, relatively flat surface improves the accuracy of readings, and one method to achieve this is finish grinding with an 80 or finer grit sandpaper disc. Do not take readings on scaled or discolored areas.

2. Insert the test bar into the holder with the spacing button in the extreme forward position.

3. Ensure that the test block is flat on the test surface.

4. Make the impressions by striking the anvil nut squarely with a 1.4- to 2.3-kg (3.0- to 5.0-lb) hammer. Pull the hammer away so it does not rebound or restrike the anvil.

5. Measure the impression on the weld test site by placing the microscope so that the impression is approximately in the center of the scale. Adjust the eyepiece so the scale and the top of the impression are in sharp focus. Measure the diameter to the nearest half

division (0.05 mm); it should be between 3.0 to 4.0 mm (if not, discard the test and redo it). Rotate the eyepiece 90° and obtain a second reading. If the two readings vary by more than 0.10 mm (i.e., the impression is oblong), discard the test and redo it. If acceptable, average the two readings for the recorded result.

6. Repeat the procedure in step 5 to measure the impression on the test bar.

7. To do subsequent testing, move the spacing button one notch toward the rear. This ensures that the impressions on the test bar are properly spaced and avoids double impressions. Continue this practice for succeeding impressions until one-half of one side of the bar is covered with impressions. Then remove and reverse the bar, and again move the spacing button to the extreme front position.

8. Determine the Brinell hardness number by using the slide calculator supplied by the manufacturer or by using Equation (3):

$$H_w = H_b \times (D_b / D_w)^2 \quad (3)$$

where:

- H_w = Hardness of weld;
- H_b = Hardness stamped on the test bar;
- D_b = Diameter of impression in the test bar; and
- D_w = Diameter of impression in weld.

9. Subtract the determined weld hardness from the test bar hardness. The difference should be -10 to +50; if not, discard the reading and do a retest with a new test bar. The new test bar should have a hardness closer to the weld hardness to improve the reading accuracy.

10. All hardness impressions at one test location should have at least 6.4 mm (0.25 in.) between their nearest edges.

11. Hardness impressions can be made on only two adjacent sides of the test bars.

12. Replace the indenter ball when it is out-of-round.