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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 are 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 and piping are fabricated by welding. The welds for refinery equipment and piping are made to conform to various codes and standards, including the ASME[(1)] Boiler and Pressure Vessel Code, Section VIII,[1] the ASME/ANSI[(2)] B31.3[2] for process piping, or API[(3)] Standards 620[3] and 650[4] for tanks. According to these codes and standards, these carbon steels are classified as P-No. 1, Group 1 or 2, and in this standard they are referred to as "P-No. 1 steels."

Petroleum refineries as well as oil- and gas-processing plants have used P-No. 1 steels widely for wet hydrogen sulfide (H_2S) 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-No. 1 steels should be below the strength threshold for this cracking.

Some useful information is given in NACE Standard MR0103.[5] NACE Standard MR0103 provides guidance for materials in sour oil and gas environments in refinery services including limiting the hardness of P-No. 1 steels, reducing the likelihood of SSC. Additional useful information is given in NACE Standard MR0175/ISO[(4)] 15156,[6] a standard that provides guidance for materials in sour oil and gas environments in production services.

In the late 1960s, a number of SSC failures occurred in hard weld deposits in P-No. 1 steel refinery equipment and piping. 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 (HBW) maximum. These requirements were given in previous editions of this standard and in API RP 942.[7]

The current P-No 1 hardness limit of 200 HBW maximum is lower than the 22 HRC (237 HBW) hardness limit listed in NACE MR0175/ISO 15156. 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-No. 1 steel equipment that met the 200 HBW 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).[8] 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 HBW weld deposit hardness limit. In these cases, the HAZ exhibited high hardnesses, often higher than 240 HBW. However, HAZ hardness limits and testing were outside the scope of the previous editions of this standard, which covered only weld deposit hardness limits.

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(1) ASME International (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.
(4) International Organization for Standardization (ISO), 1 rue de Varembe, Case Postale 56, CH-1121, Geneve 20, Switzerland.

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 refining environments.

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.

This standard was originally prepared in 1972 by NACE Task Group T-8-7, which was composed of corrosion consultants, corrosion engineers, and other specialists associated with the petroleum refining industry. It was reaffirmed in 1974 and revised in 1987 and 1995. It was reaffirmed in 2000 by Specific Technology Group (STG) 34 on Petroleum Refining and Gas Processing, and revised in 2005 by NACE Task Group (TG) 326 on Weldments, Carbon Steel: Prevention of Environmental Cracking in Refining Environments. API previously published a standard, API RP 942, with similar objectives. The API standard has been discontinued with the intention of recognizing this NACE standard as the industry consensus standard. This standard is issued by NACE International under the auspices of STG 34 on Petroleum Refining and Gas Processing.

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 madatory requirements. *Should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

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Contents

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-No. 1, Group 1 or 2. These classifications can be found in the ASME Boiler and Pressure Vessel Code, Section IX,[9] ASME/ANSI B31.3 Code for process piping, or API Standards 620 and 650 for tanks. 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 6.4.6.

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. Useful information is provided by F.R. Coe, et. al.[10] 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); flux-cored 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 exceptions (i.e., weld configurations) 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 petroleum refining processes, the primary manifestation of HSC is SSC of hard weldments in process environments containing wet H_2S. Information regarding the definition of wet H_2S refinery services is given in NACE MR0103. 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.[11] An overview of the materials selection, fabrication, PWHT, and testing practices that have been applied to new pressure vessels for mitigating SOHIC is provided in NACE Publication 8X194.[11]

1.6.1.3 Cases of cracking of hard welds have occurred as a result of short-term upset, start-up, or transient conditions in nonstress-relieved P-No. 1 carbon steel refinery equipment and piping in which hydrogen sulfide is not normally present. While this standard covers only P-No. 1 materials, it should be noted that welds have also cracked in tanks and pressure vessels constructed of nonstress-relieved P-No. 10A and 10C carbon-manganese steels.

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, including caustic cracking, amine cracking, and carbonate cracking. Section 6 provides common practices used to avoid these types of ASCC. 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.