Fabrication Considerations for Vanadium-Modified Cr-Mo Steel Heavy Wall Pressure Vessels

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Introduction

This document is intended as a best practice report to be used by manufacturers, in conjunction with API RP 934-A, when constructing new heavy wall pressure vessels with vanadium-modified Cr-Mo steels intended for service in petroleum refining, petrochemical, or chemical facilities. These materials are primarily used in high temperature, high pressure services which contain hydrogen.

The document provides typical practices to be followed during fabrication based upon experience and the knowledge gained from actual problems that have occurred during the fabrication of vanadium-modified Cr-Mo steels.

Background

The use of chrome-molybdenum steel vessels in hydrogen service can be traced back to the mid-1920s in Germany where they were used for reactors in high pressure hydrogenation plants. These vessels were fabricated from 2.25 % to 3.8 % chrome-molybdenum alloys operating in the pressure range of 28 to 70 MPa (4000 to 10,000 psi) [1]. These steels are now referred to as the “First Generation” technology and were in use until the mid-1960s. The steels have evolved with significant improvements in each generation that can be summarized as follows.

Second Generation (Mid-1960s to 1970s) was the birth of modern hydroprocessing reactors manufactured from heavy wall $2^{1}/_{4}$Cr-1Mo alloys with improved toughness (54 Joules at 10 °C [40 ft-lbs at 50 °F]), but with no particular temper embrittlement controls.

Third Generation (1970s to 1980s) added J-factor limit of 180 to control temper embrittlement and developed improved toughness to 54 Joules at –18 °C (40 ft-lbs at 0 °F). Also, began step cooling tests with varying criteria and precautions against weld overlay disbondment.

Fourth Generation (1980s to 1990s) improved temper embrittlement control by lowering J-factor limit to 100 and achieving better results after step cooling. This generation also had toughness improvements to 54 Joules at –32 °C (40 ft-lbs at –25 °F).

Fifth Generation (1990s to present) grades [2] of conventional 2¼Cr-1Mo steels have a 54-Joule (40 ft-lb) transition temperature typically lower than –40 °C (–40 °F), and even lower for conventional 3Cr-1Mo steels. Vanadium-modified Cr-Mo steels with $2^{1}/_{4}$ % and 3 % Cr were introduced for service with higher strength levels and increased hydrogen attack resistance. These grades achieved a 54 Joule (40 ft-lb) transition temperature typically around –29 °C (–20 °F). The vanadium-modified steels also offered enhanced creep rupture properties, lower temper embrittlement susceptibility, and a much lower susceptibility to hydrogen disbonding of weld overlay compared with conventional Cr-Mo steels.

As of 2019, more than 1100 hundred vanadium-modified reactors and separators have been fabricated by 21 experienced manufacturers around the world with more under construction [30].

Fabrication Considerations for Vanadium-Modified Cr-Mo Steel Heavy Wall Pressure Vessels

1 Scope

This best practice report complements API RP 934-A and specifies additional fabrication considerations that should be observed when constructing a new heavy wall pressure vessel using vanadium-modified Cr-Mo materials intended for hydrogen service at elevated temperature and pressure. It applies to vessels that are designed, fabricated, certified, and documented in accordance with ASME *Boiler and Pressure Vessel Code (BPVC)*, Section VIII, Division 2, including paragraph 3.4 of the ASME Code, Supplemental Requirements for Cr-Mo Steels and former ASME Code Case 2151, as applicable (or equivalent international codes).

Nominal material chemical compositions covered by this report are the vanadium-modified steels including 2$^{1}/_{4}$Cr-1Mo −2$^{1}/_{4}$V, 3Cr- 1Mo-$^{1}/_{4}$V-Ti-B, and 3Cr-1Mo-$^{1}/_{4}$V-Nb-Ca steels. The interior surfaces of these vessels may have an austenitic stainless steel cladding or weld overlay to provide additional corrosion resistance.

2 Normative References

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

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

API Recommended Practice 934-A, *Materials and Fabrication of 2$^{1}/_{4}$Cr-1Mo, 2$^{1}/_{4}$Cr-1Mo −2$^{1}/_{4}$V, 3Cr-1Mo, & 3Cr-1Mo-$^{1}/_{4}$V Steel Heavy-Wall Pressure Vessels for High-Temperature, High-Pressure Hydrogen Service*

API Recommended Practice 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*

ASME. *Boiler and Pressure Vessel Code,*[1] *Section II, Materials, Part A, Ferrous Material Specifications*

ASME .*Boiler and Pressure Vessel Code, Section II, Materials, Part C, Specifications for Welding Rods, Electrodes and Filler Metals*

ASME. *Boiler and Pressure Vessel Code, Section II, Materials, Part D, Properties*

ASME. *Boiler and Pressure Vessel Code, Section VIII, Div. 2 Rules for Construction of Pressure Vessels – Alternate Rules*

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-335, *Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service*

ASME SA-336, *Specification for Alloy Steel Forgings for Pressure and High-Temperature Parts*

ASME SA-369, *Specification for Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High Temperature Service*

ASME SA-387, *Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum*

[1] ASME International, 3 Park Avenue, New York, New York 10016-5990, www.asme.org.