Materials and Fabrication of 2\textsuperscript{1/4}Cr-1Mo, 2\textsuperscript{1/4}Cr-1Mo-\textsuperscript{1/4}V, 3Cr-1Mo, and 3Cr-1Mo-\textsuperscript{1/4}V Steel Heavy Wall Pressure Vessels for High-temperature, High-pressure Hydrogen Service

API RECOMMENDED PRACTICE 934-A
THIRD EDITION, JANUARY 2019
Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API’s employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API’s employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to ensure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Classified areas may vary depending on the location, conditions, equipment, and substances involved in any given situation. Users of this Recommended Practice should consult with the appropriate authorities having jurisdiction.

Users of this Recommended Practice should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations to comply with authorities having jurisdiction.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

Where applicable, authorities having jurisdiction should be consulted.

Work sites and equipment operations may differ. Users are solely responsible for assessing their specific equipment and premises in determining the appropriateness of applying the Recommended Practice. At all times users should employ sound business, scientific, engineering, and judgment safety when using this Recommended Practice.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, NW, Washington, DC 20005.

Copyright © 2019 American Petroleum Institute
Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the standard.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the standard.

May: As used in a standard, “may” denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, “can” denotes a statement of possibility or capability.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.
Contents

1 Scope ................................................................................................................................. 1
2 Normative References. ......................................................................................................... 1
3 Terms, Definitions, and Acronyms ...................................................................................... 3
  3.1 Terms and Definitions ...................................................................................................... 3
  3.2 Acronyms .......................................................................................................................... 5
4 Design ................................................................................................................................ 6
5 Base Metal Requirements. .................................................................................................... 6
  5.1 Material Specifications ...................................................................................................... 6
  5.2 Steel-making Practice ...................................................................................................... 6
  5.3 Chemical Composition Limits ........................................................................................ 7
  5.4 Heat Treatment ................................................................................................................ 7
  5.5 Mechanical Properties .................................................................................................... 8
6 Welding Consumable Requirements. .................................................................................. 9
  6.1 Material Requirements .................................................................................................... 9
  6.2 Mechanical Properties .................................................................................................... 10
7 Welding, Heat Treatment, and Production Testing .............................................................. 12
  7.1 General Welding Requirements ...................................................................................... 12
  7.2 Welding Procedure Qualification. .................................................................................... 12
  7.3 Preheat and Heat Treatments During Base Metal Forming and Welding ..................... 13
  7.4 Production Testing of Base Metal Welds ......................................................................... 15
  7.5 Weld Overlay .................................................................................................................. 15
  7.6 Final Postweld Heat Treatment ....................................................................................... 18
8 Nondestructive Examinations ............................................................................................. 19
  8.1 General ............................................................................................................................. 19
  8.2 NDE Prior to Fabrication ............................................................................................... 19
  8.3 NDE During Fabrication .................................................................................................. 19
  8.4 NDE After Fabrication and Prior to Final PWHT .......................................................... 20
  8.5 NDE After Final PWHT ................................................................................................. 20
  8.6 Positive Material Identification. ..................................................................................... 20
9 Hydrostatic Testing ............................................................................................................... 20
10 Preparations for Shipping .................................................................................................. 21
11 Documentation ................................................................................................................... 21
12 Summary Material Examination and NDE Requirements. .............................................. 22

Annex A (informative) Guidance for Inspection for Transverse Reheat Cracking. ................. 24
Annex B (informative) Alternate Probe Setup with Offset for Detecting Transverse Defects .......... 34

Bibliography .......................................................................................................................... 47

Figures
1 Location of Vickers Hardness Indentations ................................................................. 13
A.1 Schematic Showing Reheat Cracking Locations .................................................... 26
A.2 B-scan for Detecting Transverse Defects with TOFD ........................................... 26
Contents

A.3 Alternate Probe Setup with Offset for Detecting Transverse Defects ........................................... 28
A.4 TOFD Sensitivity Demonstration Block ................................................................. 30
A.5 Characterization of Reheat Cracks Using Pulse-echo UT .................................................. 32
B.1 Example of a Gripping Device Devoted to Threaded-end Specimens ........................................ 36
B.2 Geometry of the Weld Joint to be Used for the Screening Test Coupon ................................. 38
B.3 Welding Sequence to be Used for the Screening Test .................................................... 39
B.4 Example of Strongbacks Used to Minimize Coupon Distortion ........................................... 39
B.5 Position of Pre-forms Inside the Welded Zone (Macrographic View) .................................... 40
B.6 Position of Pre-forms Inside the Welded Zone (Schematic View) ...................................... 40
B.7 Detailed Geometry of RHC Standard Specimen .......................................................... 41
B.8 Location of the Thermocouples on the RHC Standard Specimen ..................................... 42
B.9 Illustration of Heating Requirements on Test Specimens ................................................. 43

Tables
1 Base Metal Specifications ....................................................................................................... 7
2 Heat Treatment of Test Specimens ............................................................................... 8
3 Proposed Testing Conditions at 842 °F (450 °C) to Simulate Hydrogen Charging from
   Maximum Operating Conditions ......................................................................................... 16
4 Test Conditions Domains ............................................................................................... 17
5 PWHT Holding Temperature and Time ............................................................................ 19
6 Summary of API RP 934-A Material Examination and NDE Requirements ................. 22
A.1 TOFD Guideline for Identifying Transverse Reheat Cracks .............................................. 29
A.2 Manual Pulse-echo Shear Wave Guideline for Identifying Transverse Reheat Cracks .......... 31
B.1 Welding Parameters to be Used for Welding of Screening Test Coupons ...................... 38
B.2 Sample Test Certificate ................................................................................................. 45
Introduction

This recommended practice (RP) applies to new 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 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 and/or supplement this RP with additional proprietary requirements.
Materials and Fabrication of $2^{1/4}$Cr-1Mo, $2^{1/4}$Cr-1Mo-$^{1/4}$V, 3Cr-1Mo, and 3Cr-1Mo-$^{1/4}$V Steel Heavy Wall Pressure Vessels for High-temperature, High-pressure Hydrogen Service

1 Scope

This RP covers materials and fabrication requirements for new $2^{1/4}$Cr and 3Cr steel heavy wall pressure vessels for high-temperature, high-pressure hydrogen service. For this RP, "heavy wall" is defined as a shell thickness of 4 in. (100 mm) or greater, and high-temperature is considered to be operating temperatures of 650 °F (345 °C) and above. This RP applies to vessels that are designed, fabricated, certified, and documented in accordance with ASME Section VIII, Division 2, including Paragraph 3.4, Supplemental Requirements for Cr-Mo Steels, and ASME Code Case 2151, as applicable.

Although outside of its scope, this RP can be used as a resource for vessels with wall thicknesses below 4 in. (100 mm), and/or operating at temperatures of less than 650 °F (345 °C), with changes defined by the purchaser. This document may also be used as a resource when planning to modify an existing heavy wall pressure vessel.

ASME Section VIII, Division 3 is typically used for much higher-pressure applications (beyond the hydroprocessing range); however, a specific Code Case developed for these alloys is available under Division 3. Division 3 has much stricter design rules (e.g., fatigue and fracture mechanics analyses are required) and material testing requirements, and application of these rules is outside the scope of this document.

Materials covered by this RP are conventional steels including standard $2^{1/4}$Cr-1Mo and 3Cr-1Mo steels, and advanced steels which include $2^{1/4}$Cr-1Mo-$^{1/4}$V, 3Cr-1Mo-$^{1/4}$V-Ti-B, and 3Cr-1Mo-$^{1/4}$V-Nb-Ca steels. This document may be used as a reference document for the fabrication of vessels made of enhanced steels (steels with mechanical properties increased by special heat treatments such as ASME SA-542, Grade B, Class 4) at the purchaser's discretion. However, no attempt has been made to cover specific requirements for the enhanced steels, and they may be different than the requirements for vanadium grade steels.

The interior surfaces of these heavy wall pressure vessels may have an austenitic stainless steel weld overlay lining to provide additional corrosion resistance. A lining of stainless steel cladding using a roll-bonded or explosion-bonded layer on Cr-Mo base metal may be acceptable, but this is outside the scope of this document. Multilayer vessels are also outside the scope of this document.

Heat exchanger shells and channels which meet the conditions listed above are within the scope of this RP. They are included in the term "pressure vessel" for the purposes of this RP.

This is the third edition of RP 934-A. The legacy first edition was API RP 934, Materials and Fabrication Requirements for $2^{1/4}$Cr-1Mo & 3Cr-1Mo Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service, published December 2000. The second edition was issued in May 2008, and it was the first version referred to as “934-A.” RP 934-A, second edition, later incorporated Annex A and then Annex B, which were issued in February 2010 and March 2012 as Addendum 1 and Addendum 2, respectively.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes 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