



American Welding Society
LEARNING

Study Guide: API 1104 Twenty-First Edition

STUDY GUIDE
for
API Standard 1104:
Welding of Pipelines
and Related Facilities
21st Edition

CWI
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Study Guide

for

API Standard 1104 Welding of Pipelines and Related Facilities

TWENTY-FIRST EDITION

**Published by
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Education Department**

Abstract

This study guide contains information on the use of API Standard [1104](#), Twenty-First Edition, which will assist the student in learning how to use the standard as well as in preparing for code-related examinations. Material is provided for each of the 13 sections of the standard and Annexes A and B. Exercise questions and answers are provided for each section and annex, and additional practice tests are included at the end.



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Study Guide for API Standard 1104, Twenty-First Edition

Foreword

AWS Education Services has published this Study Guide for [API 1104](#) to assist quality professionals—inspectors and supervisors—and quality-conscious engineers and managers in reading, understanding, and learning to apply the American Petroleum Institute’s (API) Standard [1104](#), Welding of Pipelines and Related Facilities, Twenty-First Edition. This Study Guide was written specifically for the 21st Edition with Errata 4 and Addendum 2. For other errata or addenda, page numbers may be different.

The API Standard [1104](#) applies to the welding of piping used in the compression, pumping, and transmission of petroleum products, fuel gases, carbon dioxide, and nitrogen. The standard’s purpose is to present methods for the production and inspection of high-quality welds through the use of qualified personnel using approved procedures, materials, and equipment. It applies to new construction and in-service welding and is voluntary.

This [API 1104](#) Study Guide consists of an introduction, 15 sections, each covering the corresponding section or annex of the standard along with exercise questions for each section, and several groups of practice questions with an answer key.

Answering the practice questions serves as a valuable review of the section contents. These questions also illustrate the types of questions you’re likely to encounter on the AWS CWI exam.

In addition to explanations of each section of [API 1104](#), in some cases, this Study Guide also provides a commentary or examples to further explain the provision.

As you read this book, open the standard to the corresponding page.

Remembering excerpts from the standard is neither necessary nor desirable. You need not memorize the standard; just learn how to use it.

The American Welding Society appreciates feedback from participants in its education programs. Please send comments or questions to:

American Welding Society
Education Department, 2nd Floor
8669 NW 36th Street #130
Miami, Florida 33166-6672

or contact the AWS Education Services Department by email at aws.seminars@aws.org. Additional information on AWS products and services may be found on our website at www.aws.org.

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INTRODUCTION: HOW TO USE API 1104

Definition of Documents

All codes, standards, and specifications are conceptually similar, but each has a specific application and purpose. [API 1104](#) is a good example of the concept, so learning to use this standard will help you learn to use others as well.

A CODE is a body of laws arranged systematically for easy reference and use. Because a code has legal status, it is, by definition, mandatory, and it uses words such as shall, will, and must to express requirements and to verify that those requirements are being met. Examples of codes include the [AWS D1.1](#) Structural Welding Code — Steel, the AASHTO/AWS D1.5 Bridge Welding Code, and the [ASME B31.1](#) Power Piping Code.

A STANDARD is established for use as a rule or basis of comparison in measuring quality, quantity, content, relative value, etc. API Standard [1104](#), Welding of Pipelines and Related Facilities, is an example. So are the AWS A3.0, Standard Welding Terms and Definitions and [AWS QC1](#) Standard for AWS Certification of Welding Inspectors.

A SPECIFICATION is a detailed description of the parts of a whole; a statement or enumeration of particulars, as to actual or required size, quality, performance, terms, etc. Thus, a specification describes all pertinent technical information for a material, product, system, or service, and indicates how to determine that the requirements have been met. Examples include the AWS Filler Metal Specifications A5.1 through A5.36.

A RECOMMENDED PRACTICE is a description of generally accepted industrial methods and techniques. One of the most common examples is ASNT's Recommended Practice No. SNT-TC-1A, ASNT's guideline to personnel qualification and certification in nondestructive examination.

Less Than or Greater Than?

In many codes and standards, including [API 1104](#), the rules vary depending on the size of a part, the intended service, and the manufacturing requirements. Often these rules are differentiated symbolically. Most people know that = means "equal to" but the symbols for "less than" and "greater than" can cause confusion. Here's an easy way to keep them straight:

"<" is the symbol for "less than" and it points to the left. Example: $5 < 9$ indicates that five is less than nine.

">" is the symbol for "greater than" and it points to the right. Example: $9 > 5$ indicates that nine is greater than five.

"≤" is the symbol for "less than or equal to."

"≥" is the symbol for "greater than or equal to."

Other Definitions

Section 3 Terms, Definitions, Acronyms, and Abbreviations presents a list of welding terms and their definitions that adds on to and, in some cases, supersedes those listed in AWS 3.0 Standard Welding Terms and Definitions. Many of the terms defined in Section 3 are specific to [API 1104](#).

The Meaning of Quality

Quality is generally understood to mean measurable conformance to specifications. To establish product quality, purchasers invoke or mandate certain codes, standards, and/or specifications that state the requirements to which the product must conform. Thus, quality professionals must be able to read, understand, and apply the provisions of the governing documents cited in a contract, job specification or purchase order.

For test-taking purposes, to find requirements in a code or standard more quickly, you should attach an index tab to the first page of each section and to significant tables and figures that you will use frequently. In addition, it may be helpful to briefly describe the contents of the section on that tab. [API 1104](#) has 13 sections and two annexes that are included in the scope of the AWS CWI exam. See Study Guide Figure A below.

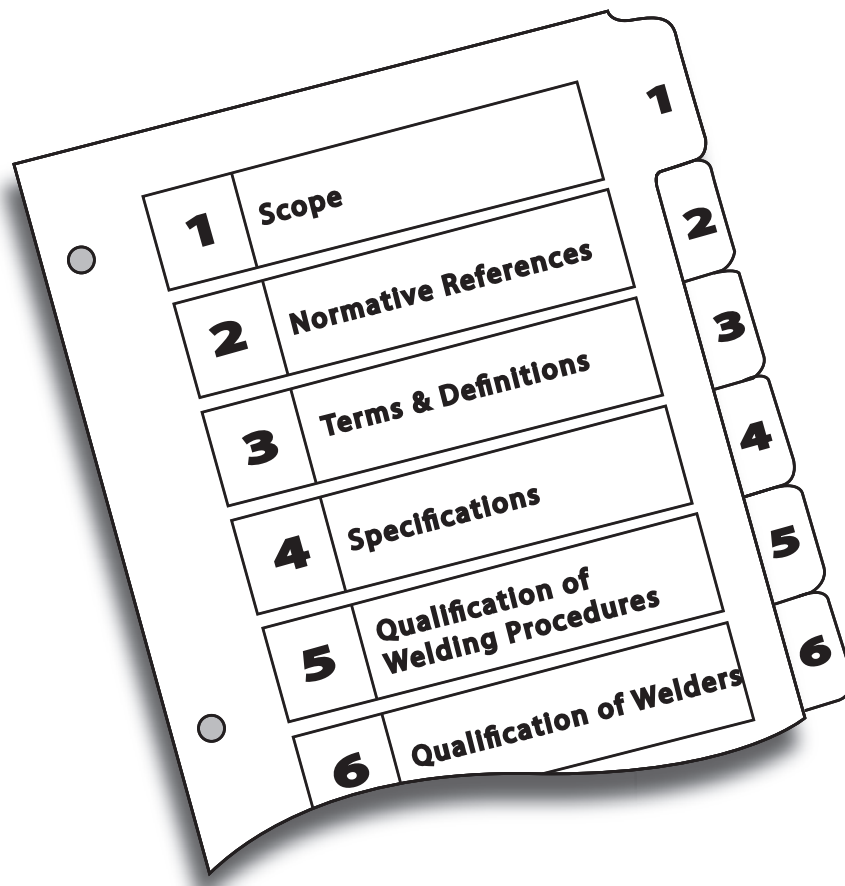


Figure A: Section ID Tabs

Many codes and standards make extensive use of notes, which may be footnotes in tables or figures or general notes incorporated into the text, to explain something or to cover special cases or particular circumstances. Every time you read the provisions of a code or standard, be thorough and pay close attention to any notes.

Carefully review the tables and figures, being attentive to superscripts and their corresponding footnotes, which can modify the application of the information in the table or figure. In many cases, the answer to a given code or standard inquiry will either be modified by the footnote or contained completely within the footnote. If the question does not invoke the conditions of the footnote, the footnote does not apply.

You will see three types of footnotes. They are:

- (a) Global or general footnotes—These appear in the title of a figure, list, or table and they influence all provisions from that figure, list, or table. Sometimes general footnotes are located in the footer of a table or figure and are labeled as “NOTE(S).”
- (b) Regional footnotes—These appear in the column header or at the end of a row title in a table or at the top of a subsection and influence only that column or row of the table or that specific subsection of text.
- (c) Local or specific footnotes—These apply only to the specific item being footnoted.

For example, turn to page 15 in [API 1104](#). Note the small superscript letters that follow certain filler metal Group Numbers in Table 1. Each superscript refers to a local footnote, which changes some aspect of the table’s provisions for that specific filler metal in the table.

As you work with a code or standard, be aware of applicable Errata Sheets. Errata are published to correct printing errors. If any exist, mark the changes in the code or standard. Subsequent printings of that code or standard will usually incorporate those corrections.

Typically, codes and standards are revised according to a regular schedule. API generally updates its standards every five years, though up to two additional years may be added to a review cycle. See the Foreword of [API 1104](#) for information on ascertaining the status of the Twenty-First Edition.

Finding Provisions

Codes and standards typically use the multiple decimal numbering system. See Study Guide Figure B below. The first “1” in “1.1.1.2.2” is the chapter or section in which the provision is found. The second “1” is the subsection within Section 1. However, for simplicity, in this Study Guide, any indented reference further than the second (subsection) number will be referred to simply as a “paragraph.” For instance, Section 5 is where rules for qualifying welding procedures using manual or semiautomatic welding processes are found. Subsection 5.4 lists the essential variables but “paragraph” 5.4.2.2 addresses base materials.

1.
 - 1.1
 - 1.1.1- -----
 - 1.1.2- -----
 - 1.2
 - 1.2.1- -----
 - 1.2.2- -----
- 2.

Figure B Multiple Decimal Numbering System

A provision is the specific text contained within a numbered section, subsection, or paragraph of a code or standard.

When you use a code or standard, identify the key term or phrase that best describes the issue or requirement of interest and then locate the provision that best addresses that issue or requirement.

Although you might find a particular provision by paging through the standard, a more systematic approach is to convert the information you seek into a question, then analyze the question to identify key words or phrases. In [API 1104](#), look for those key words or phrases in the table of contents to locate the applicable provisions by section or subsection number. Those numbers are called references. Then locate those references in the text.

Reference Exercise

For the radiographic test method, how long after processing of the developed film shall the images still be interpretable?

- Key Words:
- a) radiographic test method
 - b) processed, handled, and stored

Check Contents: Section 11 Procedures for NDT on page vi and
 Subsection 11.1 Radiographic Test Methods

Look it up: Find reference 11.1.10.4 Image Processing on page 61.

Provision: “When requested by the company, film or other imaging media shall be processed, handled, and stored so that the images are interpretable for at least three years after they are produced.”

API 1104 Contents

[API 1104](#) contains 13 sections and three annexes. They are:

1. Scope

2. Normative References
3. Terms, Definitions, Acronyms, and Abbreviations
4. Specifications
5. Qualification of Welding Procedures with Filler Metal Additions
6. Qualification of Welders
7. Design and Preparation of a Joint for Production Welding
8. Inspection and Testing of Production Welds
9. Acceptance Standards for NDT
10. Repair and Removal of Weld Defects
11. Procedures for NDT
12. Mechanized Welding with Filler Metal Additions
13. Automatic Welding Without Filler Metal Additions

Annex A Alternative Acceptance Standards for Girth Welds

Annex B In-service Welding

Annex C Requests for Interpretation and Request for Revision to the Document

This Study Guide follows the structure of [API 1104](#), except that Annex C will not be discussed. Otherwise, the sections and subsections in this Study Guide correspond to those in [API 1104](#).

The table of contents in [API 1104](#) is titled “Contents” and it begins on page v. It contains:

- (a) A list of provisions by section and subsection number and title, e.g., “3.1 Terms and Definitions.” The page on which a given section or subsection begins is to the right of that section or subsection’s title. For the annexes, only the number of the title page is listed.
- (b) A list of figures. A figure is a pictorial or schematic illustration. Figures are listed by number, title, and the page on which they appear in the text. The list of figures begins on page vii.
- (c) A list of tables. A table is a systematic arrangement of data, typically in rows and columns. Tables are listed by number, title, and the page on which they appear in the text. The list of tables begins on page viii.

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Section 1

Scope



Documents

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Section 1: Scope

API 1104 provides a list of eight permitted welding processes. They are listed below:

- (a) Shielded metal arc welding (SMAW).
- (b) Submerged arc welding (SAW).
- (c) Gas tungsten arc welding (GTAW).
- (d) Gas metal arc welding (GMAW).
- (e) Flux-cored arc welding (FCAW).
- (f) Plasma arc welding (PAW).
- (g) Oxyacetylene welding (OAW).
- (h) Flash butt welding (FW).

API 1104 also states that these processes may be applied using manual, semiautomatic, mechanized, or automatic welding techniques or a combination of these techniques. All of these techniques, except manual welding, are defined in Section 3. Study Guide Table 1.1 indicates which techniques are applicable to the permitted welding processes.

API 1104 covers procedures for various NDT methods and the acceptance standards to be applied to production welds. The NDT methods are listed below, along with their AWS abbreviations:

- (a) Radiographic testing (RT).
- (b) Magnetic particle testing (MT).
- (c) Liquid penetrant testing (PT).
- (d) Ultrasonic testing (UT).
- (e) Visual testing (VT).

The numerical values stated in API 1104 are given in either U.S. Customary units or metric (SI) units. The U.S. Customary values typically appear first, followed by the SI units in parentheses, but the SI units are approximations of the corresponding U.S. customary units. API 1104 emphasizes that you must use one system or the other and not combine them.

<i>Process</i>	<i>Manual</i>	<i>Semi-automatic</i>	<i>Mechanized</i>	<i>Automatic</i>
<i>Shielded metal arc welding (SMAW)</i>	X			
<i>Submerged arc welding (SAW)</i>		X	X	
<i>Gas tungsten arc welding (GTAW)</i>	X	X	X	X
<i>Gas metal arc welding (GMAW)</i>		X	X	X
<i>Flux-cored arc welding (FCAW)</i>		X	X	X
<i>Plasma arc welding (PAW)</i>	X		X	X
<i>Oxyacetylene welding (OAW)</i>	X			
<i>Flash butt welding (FW)</i>				X

Table 1.1

Processes and Techniques

Exercise Questions

Section 1 Scope

1.1 What topic(s) does **API 1104** cover?

- A. Gas welding of butt welds
- B. Arc welding of fillet and socket welds
- C. Welding of carbon and low-alloy steel piping
- D. Welding of petroleum pipelines
- E. All of the above

1.2 Which testing method(s) is(are) specified in **API 1104**?

- A. Nick break tests
- B. Only bend tests for butt welds
- C. Radiographic testing only
- D. Ultrasonic testing only
- E. Both radiographic and ultrasonic testing

1.3 Which welding process(es) is(are) addressed in **API 1104**?

- A. Flash butt
- B. Submerged arc
- C. Oxyacetylene
- D. Gas metal arc
- E. All of the above

1.4 **API 1104** permits the use of both US customary units and metric (SI) units.

- A. True, as long as each system is used independent of the other
- B. False
- C. True, as long as the inspector places the US customary value in parentheses
- D. True, as long as the metric values are used in conjunction with the US Customary values
- E. The inspector should use codes published in either SI or US Customary units.

1.5 Welds may be produced by:

- A. Fixed welding only
- B. Position or roll welding only
- C. Position welding, roll welding, or a combination of both
- D. Only position welding
- E. Only roll welding

1.6 **API 1104** covers:

- A. New construction
- B. In-service welding
- C. Structural tubular applications
- D. Cyclical applications
- E. Both A & B

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Section 2

Normative References



Documents
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Section 2: Normative References

This section lists the standards, codes, and specifications incorporated by reference throughout the standard. The footnotes provide contact information for the organizations that publish these documents. The address for the American Welding Society, however, is incorrect. The correct address is:

8669 NW 36th Street #130
Miami, Florida 33166-6672

Exercise Questions

Section 2 Normative References

2.1 Which of the referenced documents is used by Annex A for evaluating fracture toughness?

- A. [ASTM E164](#)
- B. API Specification [5L](#)
- C. AWS A5.28
- D. BS EN ISO 15653
- E. None of the above

2.2 Which organization writes most of the NDT specifications cited in [API 1104](#)?

- A. API
- B. ASNT
- C. ASTM
- D. AWS
- E. NACE

2.3 Which organization writes the filler metal specifications referenced in [API 1104](#)?

- A. AWS
- B. ASNT
- C. ASTM
- D. BSI
- E. NACE

2.4 Which organization writes a document on personnel certification in NDT methods that is cited by [API 1104](#)?

- A. API
- B. ASNT
- C. AWS
- D. BSI
- E. NACE

2.5 Which of the following is a specification that lists carbon steel rods for use with the GTAW process?

- A. AWS A5.1
- B. [ASTM E747](#)
- C. AWS A5.18
- D. ER70S-2
- E. AWS A5.29

2.6 Which of the following describes procedures for UT of weldments?

- A. AWS A5.28
- B. [ASTM E164](#)
- C. ASNT SNT-TC-1A
- D. AWS A5.1
- E. BS EN ISO 15653

2.7 Which of the following is a document that provides guidance for selection of metallic materials for oil field equipment when sulfide stress cracking is a concern?

- A. NACE MR0175
- B. E71T-1
- C. E6010
- D. [ASTM E747](#)
- E. AWS A5.18

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Section 3

Terms, Definitions,
Acronymns, and
Abbreviations



Documents

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Section 3: Terms, Definitions, Acronyms, and Abbreviations

For the purposes of this standard, the welding terms and definitions in AWS A3.0 Standard Welding Terms and Definitions apply with the additions and modifications listed in subsection 3.1. Terms defined in AWS A3.0 are not defined again here. Additional key terms not defined in Section 3 of the standard or AWS A3.0 are defined below:

butt weld. A nonstandard term for a groove weld in a butt joint.

classification (AWS). The AWS designation that lists rods, electrodes and filler metals according to their chemical composition and operating characteristics. Examples include, for SMAW—E7018, for GMAW—ER70S-6, and for GTAW—EWTh-2.

coupon test report. A form that can be used to record either procedure qualification or welder qualification test results or report on a weld coupon from a production weld. It is sometimes referred to as a “weld test report.”

crown surface. A nonstandard term for weld face, usually referring to the final bead placed on the outside of a pipe.

destructive testing. Mechanical testing that destroys a sample or part in the process of measuring a specific material property.

essential variable. A variable that has a significant effect on mechanical properties for procedure qualification or welder/operator skill for performance qualification. In general, if the value for an essential variable is changed to a value outside the range qualified, as defined by the code or standard in question, requalification of the procedure or welder/operator by testing is required. The essential variables for procedure and performance qualification are not the same within any given code or standard. Similarly, the essential variables for procedure or performance qualification are not usually the same from one code or standard to the next.

image quality indicator (IQI). A device used to confirm the resolution sensitivity of radiographic images. This is sometimes referred to as a penetrameter or “penny.” See Study Guide Figure 3.1 below.



Figure 3.1 — Wire-Type IQI

lineup clamp. An external or internal device used to bring two pipe segments into alignment for pre-weld tacking or for welding.

nick break test. A destructive test used to determine the soundness of weld metal by fracturing the specimen through the weld so the fractured surface of the weld metal can be visually examined for the presence of discontinuities.

pipe nipple. A short length or section of a pipe, usually used for qualifying a procedure or a welder.

shielding atmosphere. A gas envelope surrounding the weld area during welding to prevent or reduce the formation of oxides or other detrimental surface substances and facilitate their removal.

socket weld. A fillet weld joining two pipes or a pipe to a pipe fitting, where one pipe is inserted into the other pipe or into the fitting. See Study Guide Figure 3.2 below.

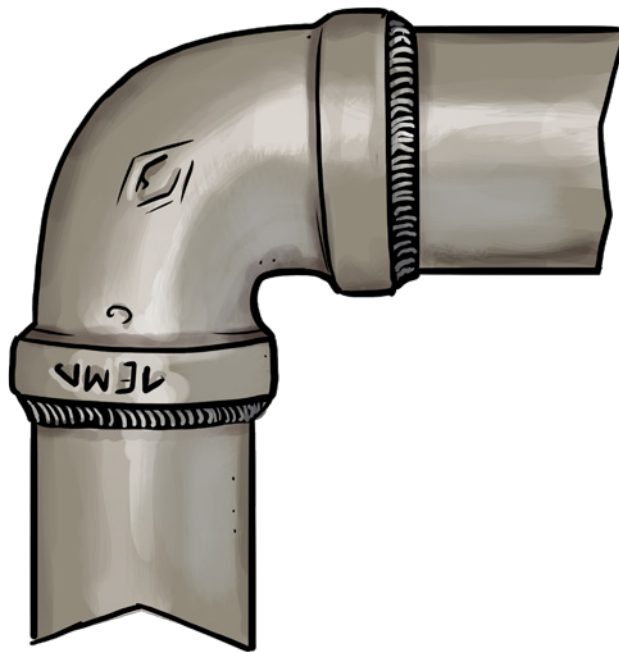


Figure 3.2—Socket Weld

soundness. Relative freedom from imperfections.

soundness testing. Testing done to verify a weldment is free from defects. [API 1104](#) permits the use of bend and nick break destructive tests, as well as radiographic and ultrasonic testing, which are both nondestructive tests.

specification (AWS). An AWS document that lists the rods, electrodes, or filler metals that can be used to weld a given category of base metals with a given category of welding processes. An example is AWS A5.1, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding.

specified minimum tensile strength (SMTS). The minimum ultimate tensile strength, specified by the pipe specification, for any given grade of pipe. For instance, [API 5L](#) Grade X52 pipe has a SMTS of 66,000 psi, meaning that a tension test of this pipe will result in an ultimate tensile strength no less than 66,000 psi.

specified minimum yield strength (SMYS). The minimum yield strength, specified by the pipe specification, for any given grade of pipe. For instance, API 5L Grade X52 pipe has a SMYS of 52,000 psi, meaning that a tension test of this pipe will result in a yield strength no less than 52,000 psi.

speed of travel. The rate of welding progression along the weld joint.

tensile strength test. A test in which the specimen is loaded in tension until failure occurs. This is also referred to as a tension test.

trepanning. A process, typically using a hole saw, in which a disc-shaped specimen containing a section of the weld is removed from a pipe weld. The disc is removed so the inspector can evaluate the weld quality and/or the degree of penetration. Trepanning is generally not permitted for production piping applications. See Study Guide Figure 3.3 below.

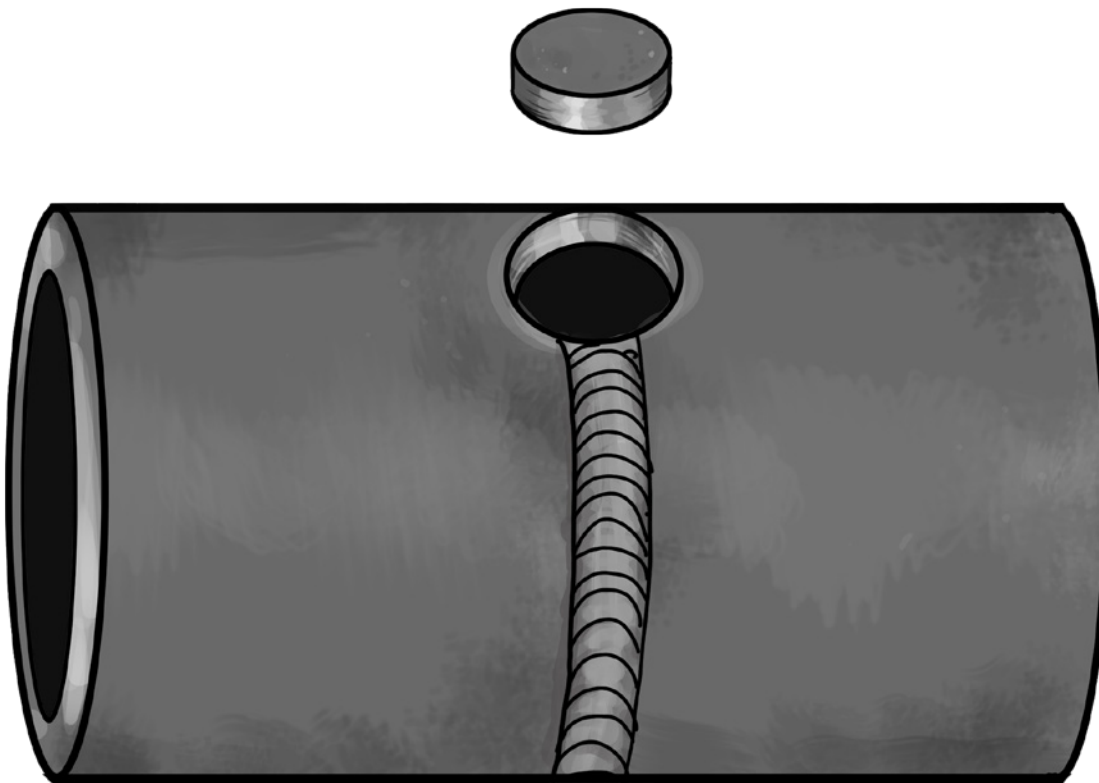


Figure 3.3—Trepanning

yield strength. The point at which a metal's response to the application of a tensile load changes from elastic to plastic.

In some cases, API 1104 uses different terms to refer to the same feature or characteristic. For instance, the terms “discontinuity,” “imperfection,” “flaw,” “irregularity,” and “anomaly” are used interchangeably in the text. However, only “imperfection” is defined in paragraph 3.1.11. All of these terms, however, have the same meaning. Similarly, the terms “position” welding and “fixed” welding are used interchangeably, although only “position welding” is defined in paragraph 3.1.17. In addition, the term “porosity” is defined in AWS A3.0 and is used in API 1104, but the term “voids,” is used as well; “voids” is not defined in API 1104 but has the same meaning as “porosity.” Root face is a standard term defined in AWS A3.0, but API 1104 also uses the nonstandard term “land” to refer to the root face of a weld joint.

Section 3 Terms, Definitions, Acronyms, and Abbreviations**3.1 The term that best describes a detectable irregularity in a weld is?**

- A. Defect
- B. Imperfection
- C. Indication
- D. Concavity
- E. Repair

3.2 API 1104 references which of the following standards for the definition of welding terms?

- A. API 5L
- B. ASNT's RP SNT-TC-1A
- C. AWS A3.0
- D. BS EN ISO 7910
- E. NACE MR0175

3.3 What welding process application technique uses equipment that controls only the filler metal feed with the advancement of the weld along the joint controlled by the welder?

- A. Repair welding
- B. Uphill welding
- C. Manual welding
- D. Semiautomatic welding
- E. Automatic welding

3.4 The welding position where the pipe is not rotating during welding is called:

- A. Automatic welding
- B. Position welding
- C. Roll welding
- D. Repair welding
- E. Semiautomatic welding

3.5 What does the term "roll welding" mean?

- A. Welding with an all-position welding electrode
- B. Welding is carried out with the pipe assembly rotated while the weld metal is deposited at or near the top dead center
- C. Welding with a semiautomatic process
- D. Welding with the pipe assembly stationary
- E. Welding without a welding procedure

3.6 The term that best describes welding without manual manipulation of the arc other than guiding or tracking and without any manual welding skill requirement is:

- A. Mechanized welding
- B. Semiautomatic welding
- C. Automatic welding
- D. Manual welding
- E. Orbital welding

3.7 What does the abbreviation "HAZ" mean?

- A. Heavily-alloyed zone
- B. Heat-altered zone
- C. Heat-affected zone
- D. High-amperage zone
- E. Both B & C

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Section 4

Specifications



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Section 4: Specifications

4.1 Equipment

This subsection calls for good judgment, sound engineering, suitable operating practices and attention to safety in the operation of welding equipment. Arc welding equipment shall be operated within the voltage and current ranges specified on the welding procedure specification. Gas welding equipment shall be operated with the flame characteristics and tip sizes given in the qualified WPS.

4.2 Materials

Paragraph 4.2.1 says that pipe and fittings must conform to API or any applicable ASME, ASTM, MSS, or ANSI specifications, but it then further states that materials that comply with the chemical and mechanical properties of any of these specifications are also acceptable, even if they are not manufactured in accordance with the specification. This suggests that the chemical and mechanical properties of any such material must be identified, preferably on the welding procedure specification, when used for an [API 1104](#) application.

Paragraph 4.2.2.1 states that filler metals must conform to one of the listed AWS filler metal specifications. Other filler metals may be used as long as the applicable welding procedures are qualified.

Table 1, in Section 5 on pages 15-16, divides filler metals into nine groups, based on electrode characteristics and the welding processes that use them. It is important to note that the Group Numbers that [API 1104](#) uses are different than the F-Numbers that AWS uses to group filler metals. For instance, the low-hydrogen SMAW electrodes are F-No. 4 electrodes as defined by AWS, but they are Group No. 3 electrodes in [API 1104](#). Table 1 lists:

- (a) Group Numbers for filler metals, electrodes, and fluxes.
- (b) AWS Specifications.
- (c) AWS Classifications for filler metals and electrodes.
- (d) AWS Classifications for fluxes.

Group Nos. 1, 2, and 3 electrodes are for SMAW. Group No. 4 electrodes and fluxes are for SAW. Group No. 5 electrodes are for GMAW, GTAW, and PAW. Group No. 6 electrodes are for OFW and Group Nos. 7, 8, and 9 are for FCAW.

Be attentive to the footnotes in Table 1, which modify the requirements for use of certain electrodes, filler metals, or fluxes and may give additional rules.

Paragraph 4.2.2.2 requires protection of filler metals and fluxes from deterioration and excessive changes in moisture, although no definition of “excessive” is provided. Obviously, if the flux coating on an SMAW electrode is damaged, it should not be used because it will not operate properly. Low-hydrogen SMAW electrodes (AWS classifications which end in 5, 6, or 8) must be stored in such a way that their coatings do not absorb excessive moisture from the atmosphere prior to use for welding.

Although it is not specifically required by [API 1104](#), there are recommended good manufacturing practices for the storage and use of low-hydrogen SMAW electrodes in applicable AWS filler metal specifications. These include (a) the storage of these electrodes in a heated, vented oven at a prescribed temperature after removal from their hermetically sealed containers, (b) limited exposure to the atmosphere and (c) recommended minimum baking times and temperatures after atmospheric exposure.

Paragraph 4.2.3.1 addresses the various types of shielding gases used for welding. Inert shielding gases do not react chemically with the weld pool; they work by simply shielding the weld pool from interacting with the gases in the atmosphere. An active gas, however, does interact with either the arc, the weld pool, or in some cases, both. Inert gases include argon and helium. Active gases include carbon dioxide and oxygen. In GMAW, sometimes mixtures of inert and active shielding gases are used. Gases must be relatively pure and dry and the shielding gas or gases to be used shall be qualified in accordance with the applicable essential variable rules for procedure qualification. [API 1104](#) does not reference AWS A5.32 for purity requirements for shielding gases.

Paragraph 4.2.3.2 addresses storage and handling of gases for welding. Gases shall not be field intermixed in their containers and gases of questionable purity or gases from damaged containers shall not be used.

Exercise Questions

Section 4 Specifications

4.1 API 1104 applies to the welding of pipe that conforms to which specifications?

- A. AWS A5.28
- B. BS EN ISO 1565
- C. API specifications
- D. ASTM specifications
- E. Both C & D

4.2 Filler metals and fluxes in opened containers shall be:

- A. Stored in any convenient container
- B. Protected from deterioration
- C. Kept in the original manufacturers' opened shipping container
- D. Stored in ambient air
- E. Secured in special plastic bags

4.3 What determines the tip size for gas welding equipment?

- A. Manufacturer's instructions
- B. Trial and error
- C. Qualified welding procedure specification
- D. Engineering drawing
- E. Pressure of the gas

4.4 Shielding gases used to shield the arc shall never be:

- A. Inert
- B. Mixed gases
- C. Field intermixed in their containers
- D. Kept in containers in which they are supplied
- E. Both A & B

4.5 Filler metals that are coated shall be protected from:

- A. Dust
- B. Strong magnetic fields
- C. Excessive ultraviolet rays
- D. Excessive changes in moisture
- E. None of the above

4.6 When is it permissible to use a filler metal not conforming to the specifications listed in API 1104?

- A. When approved by the company
- B. When approved by the API committee
- C. When the WPS involved with its use is qualified
- D. Only filler metals whose specifications are listed in Table 1 may be used
- E. Only filler metals approved by the engineer may be used

4.7 When is it permissible to use base materials that are not manufactured in accordance with the specifications listed in API 1104?

- A. When the material is approved by the engineer
- B. When the material has chemical and mechanical properties that comply with an ASTM or an API 5L specification
- C. It is not permissible to use a base material that does not have an approved specification number in accordance with Section 4
- D. When the WPS involving its use is qualified
- E. Both A & D

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Section 5

Qualification of Welding Procedures with Filler Metal Additions



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Section 5 Qualification of Welding Procedures with Filler Metal Additions

5.1 Procedure Qualification

AWS A3.0 defines a welding procedure as “the detailed methods and practices involved in the production of a weldment.” These methods and practices are communicated to the welder in the form of a document referred to as a welding procedure specification. Some codes and standards refer to a welding procedure specification as a “WPS,” but [API 1104](#) does not use that acronym. AWS A3.0 further defines a welding procedure specification as “a document providing the required welding variables for a specific application to assure repeatability by properly trained welders and welding operators.” The welding procedure specification should provide meaningful instructions to the welder for the successful completion of a production weldment.

These definitions set the stage for a detailed discussion of welding procedure qualification, which involves:

- (a) Qualifying a welding procedure by testing to prove that welds with suitable mechanical properties can be made by the procedure.
- (b) Documenting the results of the procedure qualification test.
- (c) Establishing conditions under which requalification of the welding procedure by testing is required.

Note that Section 5 covers only manual and semi-automatic welding using filler metal additions; mechanized welding with filler metal additions is addressed in Section 12, while automatic welding without filler metal additions is addressed in Section 13 of the standard.

5.2 Record

Subsection 5.2 requires the company to record the complete details of each procedure qualification and to keep that record as long as the welding procedure specification is in use. The record of the procedure qualification is the record of the pipe grade and wall thickness, as well as all of the other required welding variables used to weld the test coupon; this record also includes the results of the tests (tension, bends, and/or nick breaks) performed. Some codes refer to this document as a procedure qualification record or “PQR,” although [API 1104](#) does not use that term. [API 1104](#) provides sample forms for this purpose. Figure 2 on page 11 shows a Sample Coupon Test Report, which can be used to document the results of the procedure qualification test. When the form is used in this manner, the box on the left side of the form, in the middle of the page, labeled “Procedure,” should be checked. This form can be referred to as either a “Coupon Test Report” (“CTR”) or a “Weld Test Report” (“WTR”), although [API 1104](#) does not use these terms.

Figure 1 on page 10 is a Sample Welding Procedure Specification Form. The contents of this form are dictated by paragraph 5.3.2 of [API 1104](#).

5.3 Welding Procedure Specification and 5.4 Essential Variables

These subsections list the variables and the ranges thereof required to be specified on a welding procedure specification. Paragraph 5.3.2 describes the variables that must be listed on the welding procedure specification and paragraph 5.4.2 identifies which of those variables are essential variables and the ranges permitted on the welding procedure specification for each of those essential variables.

There are some variables that are listed in paragraph 5.3.2 that are not listed in paragraph 5.4.2. Paragraph 5.4.1 states of those variables, “Changes other than those given in 5.4.2 may be made in the

procedure without the need for requalification, provided the welding procedure specification is revised to show the changes.” In other words, the variables that are listed in 5.3.2 that are not listed in 5.4.2 are not essential variables and may be changed by a simple editorial revision of the welding procedure specification. However, in all cases, the welder must ALWAYS weld within the ranges of all of the variables specified on the welding procedure specification.

In the discussion that follows, each variable in 5.3.2 will be described, followed by a reference to the corresponding provision in paragraph 5.4.2 *if* it is an essential variable. If it is an essential variable, the range qualification rule from 5.4.2 will be explained. Variables listed in 5.3.2 but not listed in 5.4.2 will be so identified. Some codes and standards refer to these types of variables as “nonessential” variables, but [API 1104](#) does not use that term.

5.3.2.1 Process - States the welding process or processes to be used shall be identified and whether they are manual, semiautomatic, mechanized or automatic.

Paragraph 5.4.2.1 indicates that this is an essential variable.

5.3.2.2 Materials - The materials to which the procedure applies shall be identified by SMYS. The materials may be grouped; but to achieve a “group” qualification, the procedure shall be qualified on the highest SMYS material in that group, resulting in a qualification for that SMYS material and all pipe grades below it in that particular group. SMYS groupings are provided in paragraph 5.4.2.2 as follows:

- a) $SMYS \leq 42,000$ psi.
- b) $42,000 \text{ psi} < SMYS < 65,000$ psi.
- c) For pipe having an SMYS of 65,000 psi or greater, each pipe grade shall receive a separate qualification test.

For example, qualification on [API 5L](#) Grade X42 pipe would qualify for welding Grades X42, B, A, and X25 pipe. Furthermore, qualification on [API 5L](#) Grade X56 pipe would qualify for welding Grades X56, X52, and X46, but not Grade X60 because Grade X60 is a higher SMYS grade than that used for qualification. Qualification on [API 5L](#) Grade X70 would only qualify for welding Grade X70 pipe. However, a welding procedure specification for [API 5L](#) Grade X70 pipe could be used for welding Grade X70 to Grade X56 pipe (see paragraph 5.4.2.2).

Paragraph 5.4.2.2 indicates that a change in base material, group or SMYS, as applicable, is an essential variable.

5.3.2.3 Diameters and Wall Thicknesses - The welding procedure specification shall specify the range of outside diameters (ODs) and wall thicknesses that may be welded.

[API 1104](#) provides suggested groupings for outside diameters and wall thicknesses in paragraphs 6.2.2 d) and e), respectively. The OD groups are:

- (a) OD less than 2.375 inch.
- (b) ODs from 2.375 through 12.750 inch.
- (c) ODs greater than 12.750 inch.

The wall thickness groups are:

- (a) Wall thickness less than 0.188 (3/16) inch.
- (b) Wall thicknesses from 0.188 (3/16) inch through 0.750 (3/4) inch.
- (c) Wall thicknesses greater than 0.750 (3/4) inch.

Paragraph 5.4.2.5 indicates that a change from one specified wall thickness range to another is an essential variable. Outside diameter is not listed in paragraph 5.4.2, so it is not an essential variable.

5.3.2.4 Joint Design - The welding procedure specification must provide a sketch showing the angle of bevel, the size of the root face, the root opening, as well as the shape and size of fillet welds. If backing material is used, the type shall be identified.

Paragraph 5.4.2.3 states that a major change in joint design is an essential variable, but a minor change in the angle of bevel or the size of the root face is not. These definitions are vague, at best.

5.3.2.5 Filler Metal, Flux, and Number of Beads - The size (diameter) and AWS classification number of the filler metal and flux must be identified. In addition, the number and sequence of beads shall be listed.

This means that the welding procedure should be developed by welding a coupon using the smallest number of beads possible; then, as a result, the welding procedure generated can specify a weld schedule having that number of beads or greater.

Paragraph 5.4.2.6 states that a change from one filler metal Group Number in Table 1 to any other Group Number is an essential variable. It is important to restate here that [API 1104](#) uses a different grouping system for electrodes than the F-Numbers used by AWS and the rest of the welding world. [API 1104](#) uses Group Numbers, which are different than F-Numbers. So an SMAW procedure specification qualified by welding a coupon with an E6010 electrode could list E6010, E6011, E7010, and/or E7011 electrodes because these are all Group No. 1 electrodes. However, an SMAW procedure qualified by welding a coupon with an E7018 electrode could not list E6010 or E7010 or E8010 electrodes because E7018 electrodes are Group No. 3 electrodes while the E6010, E7010, and E8010 electrodes are Group No. 1 and No. 2 electrodes. For Group No. 1 through Group No. 3, any change in suffix designator is an essential variable. Also, for any filler metal with a G suffix only, a change in the manufacturer or trade name is an essential variable.

Furthermore, paragraph 5.4.2.6 states that, for welding pipe having an SMYS of 65,000 psi or higher, a change in the electrode classification is an essential variable. So, for welding a Grade X70 pipe with SMAW, a change in electrode classification from E8016 to E8018 requires requalification, even though the specified minimum ultimate tensile strength of the weld deposits made by these two low-hydrogen electrode classifications is the same.

Also, the general note at the bottom of Table 1 states that electrodes, filler metals and fluxes other than those listed can be used, but each would require a separate qualification. This includes commonly used higher-strength SMAW electrode classifications, such as E9015 or E10018.

Filler metal size (diameter) is not listed in paragraph 5.4.2 and, therefore, is not an essential variable.

5.3.2.6 Electrical Characteristics - The type of current used shall be identified. Specify either alternating current (AC) or direct current (DC). For DC, the polarity must be identified as well. Either reverse polarity [electrode positive or (EP)] or straight polarity [electrode negative or (EN)] must be listed. A range of voltage and current values must also be specified for each size and type of electrode or filler metal to be used. Typically, the amperage and voltage ranges should provide reasonable flexibility for the welders while being narrow enough to ensure production of an acceptable weld. The inspector should always verify that these ranges are consistent with the manufacturer's recommendations.

Paragraph 5.4.2.7 states that a change in current type or polarity is an essential variable. However, changes in the voltage and current ranges are not essential variables.

5.3.2.7 Flame Characteristics - For oxyacetylene welding, designate the type of flame being used. Three options exist. They are:

- (a) Carburizing (also referred to as a reducing flame), in which an excess of acetylene results in unburned acetylene at the tip of the flame that can deposit carbon on or “carburize” the surface of the base metal.
- (b) Oxidizing, in which an excess of oxygen results in unburned oxygen at the tip of the flame that can oxidize the surface of the base metal.
- (c) Neutral, in which there is no unburned acetylene or oxygen at the tip of the flame.

Also, the size of the orifice in the torch tip must be specified for each size of rod or wire. The inspector should always verify that tip sizes and gas pressures are within manufacturers’ recommendations.

This variable is not listed in paragraph 5.4.2 and, therefore, is not an essential variable.

5.3.2.8 Position - Designate whether the pipe is rolled or fixed during welding (roll or position welding).

Paragraph 5.4.2.4 states that a change from roll to fixed position, or vice versa, is an essential variable.

5.3.2.9 Direction of Welding - Designate whether welding is to be performed in the uphill or downhill direction. Sometimes this is referred to as the “progression” of welding.

Paragraph 5.4.2.9 states that a change in the direction of welding is an essential variable.

5.3.2.10 Time Between Passes - The maximum time between the end of the root bead and the start of the second bead (hot pass) must be specified as well as the maximum time between the completion of the second bead (hot pass) and the start of other beads.

Paragraph 5.4.2.8 states that an increase in the time between the end of the root bead and the start of the hot pass is an essential variable. If the welding procedure is qualified by welding a coupon in which the hot pass is begun 10 minutes after the completion of the root bead, the welding procedure specification should state, “Ten minutes, maximum, permitted between the end of the root bead and the start of the hot pass.” Obviously, it could state a length of time shorter than ten minutes may pass between the end of the root bead and the start of the hot pass, but it could NOT state a period of time longer than ten minutes. This is an ingenious way to control the interpass temperature for the hot pass, as generated by the root pass, during field welding.

The time between the completion of the hot pass and the start of other beads is not listed in paragraph 5.4.2, so this is not an essential variable and, although it is required to be listed on the procedure specification, it may be changed to any value by a simple editorial revision of the procedure specification without requalification by testing.

5.3.2.11 Type and Removal of Lineup Clamp - Specify whether a lineup clamp is required, and if so, what type (external or internal) is to be used and how much of the root bead must be deposited before the clamp is released. Typically, a prescribed amount of the joint must be welded before removing the clamp so that the partially welded joint is not subject to undue stress prior to completion of the weld.

This variable is not listed in paragraph 5.4.2 and, therefore, is not an essential variable.

5.3.2.12 Cleaning and/or Grinding - Describe whether hand tools or power tools are to be used when cleaning or grinding are necessary. This applies to pre-weld cleaning, interpass cleaning, and post-weld cleaning.

This variable is not listed in paragraph 5.4.2 and, therefore, is not an essential variable.

5.3.2.13 Preheat and Postweld Heat Treatment (PWHT) - For preheat, specify the minimum required temperature at the start of the weld, the minimum temperature below which preheat is required and the method of preheating required. For PWHT, specify the temperature range, the time at temperature, the method of heating, and the temperature control methods used to measure the temperature.

Paragraph 5.4.2.13 states that a decrease in the minimum preheat temperature is an essential variable. As a result, if a welding procedure is qualified by welding a test coupon at 70 °F, using this welding procedure specification when the temperature outside is 50 °F would require the welder to heat the joint to 70 °F before welding, regardless of pipe grade.

Paragraph 5.4.2.14 states that the addition of PWHT or a change in the range or values for the time, temperature, or technique specified in the welding procedure specification are all essential variables.

5.3.2.14 Shielding Gas and Flow Rate - The composition of the shielding gas and the range of flow rates permitted shall be specified.

Paragraph 5.4.2.10 states that a change in the nominal composition of the shielding gas is an essential variable. In addition, an increase or decrease in the flow rate of more than 20 % of the nominal value is also an essential variable.

5.3.2.15 Shielding Flux - The type of shielding flux must be specified. This variable only applies to submerged arc welding (SAW).

Paragraph 5.4.2.11 refers the reader to Table 1, footnote a for changes in shielding flux that constitute essential variables. Table 1, footnote a applies to Group No. 4 filler metals, which are those for SAW. This footnote states that any combination of electrode and flux can be used to qualify a welding procedure specification and that the combination is identified by its complete AWS classification, which, by definition in AWS Specifications A5.17, specifies both the flux and the electrode. Only substitutions that have the same AWS classification (for both flux and electrode) can be used without requalification.

So, if the welding procedure was qualified by welding a test coupon using a SAW consumable whose AWS classification was F7A0-EL12, any flux with the "F7A0" designation could be used with that welding procedure specification, whether it was made by the same manufacturer as that used on the test coupon or not. Conversely, the use of a flux whose AWS classification is different from that used during qualification would require requalification of the welding procedure by testing.

5.3.2.16 Speed of Travel - The range for speed of travel for each pass must be specified on the welding procedure specification, but this range is defined by the range(s) of travel speed(s) used on the test coupon used to qualify the welding procedure.

Paragraph 5.4.2.12 states that a change in the range for speed of travel is an essential variable. This means that if the test coupon was welded at 10 inches per minute, only 10 inches per minute can be specified on the welding procedure specification. Fabricators must realize that test coupons for qualifying welding procedures must be welded using a range of travel speeds to allow a range of travel speeds to be permitted on the welding procedure specification.

5.3.2.17 Method of Cooling After Welding - When controlled cooling from the welding operation is used, the welding procedure must specify the method used (e.g., water) and the maximum temperature at which the cooling is applied.

This variable is not listed in paragraph 5.4.2 and, therefore, is not an essential variable.

5.5 Welding of Test Joints - Butt Welds

For qualifying a welding procedure for making butt welds (sometimes referred to as girth or circumferential welds), a butt weld shall be made joining two pieces of pipe. Notice that a butt weld procedure is only qualified for making butt welds. For making fillet or branch connection welds, a separate welding procedure must be qualified.

5.6 Testing of Welded Joints - Butt Welds

Paragraph 5.6.1 gives directions for the preparation of the test coupons. The welded test joint is to be cut into sections, as shown in Figure 3 on page 18. Table 2 on page 19 gives the number of required specimens. Figure 3 and Table 2 should be used in tandem, along with 5.6.1, for procedure qualification testing requirements.

Figure 3 illustrates the locations from which test specimens shall be removed for procedure qualification testing. It contains four pipe illustrations, each representing a different range of pipe diameters. Think of each illustration as a clock face. For pipe diameters greater than 4.5 inches, the pipe is big enough that specimens can be removed from four locations approximately 90 degrees apart: at the two, four, eight, and 10 o'clock positions. At each location, arrows outside the pipes indicate the locations where the required specimens shall be taken. For pipes smaller in diameter than 4.5 inches, there is simply not enough room to remove samples from four locations 90 degrees apart, so the illustrations indicate that the specimens should be removed from the two and eight o'clock locations instead. In no case shall the specimens be removed from the area of the pipe containing the longitudinal (long seam) weld. Footnote a of Table 2 and paragraph 5.6.1 identify that for diameters less than 2.375 in. with wall thickness of 0.500 in. or less, two test welds are required to provide the required number of nick break and root bend specimens. The same note of Table 2 and Note 2 of Figure 3 specify that for pipe of 1.315 in. diameter and smaller, one full section tension specimen is tested.

Notice that footnote b of Table 2 states that no tension tests are required for pipe having a SMYS of 42,000 psi or less. For such low-strength pipe, it is not even necessary to determine the tensile strength of the tested coupon – only nick break tests and bend tests are needed.

One other feature to notice about Table 2 is that side bend tests are required in lieu of face and root bend tests when the wall thickness is greater than 0.500 inch. This is because heavier wall pipe can require significantly more force to bend the specimens in the face and root orientation. For thicker pipe, the use of side bend specimens 1/2 inch wide by the wall thickness thick (see Figure 9 on page 24) allows thicker pipe to be more easily tested in a field setting. All welding qualification codes have a thickness above which side bends are permitted in lieu of face and root bends. For ASME Section IX and AWS D1.1, that thickness is 3/8 inch. For API 1104, that thickness is 1/2 inch.

Subsection 5.6 discusses these specimens and tests in detail, describing the preparation of the specimens, the test methods, and the acceptance criteria for each. The discussion refers the reader to Figures 4 through 9 on pages 20 through 24.

Tensile strength test requirements are given in paragraph 5.6.2. Tension specimens are approximately 9 inches long by about 1 inch wide. They are required to be full-thickness specimens and they may be made to either one of the two configurations shown in Figure 4 on page 20. Note that weld reinforcement is not removed when testing a specimen prepared according to Figure 4 a). However, Figure 4 b) provides an option of removing a full-thickness specimen with a reduced width section, in which case the removal of weld reinforcement is optional.

The specimens shall be broken in any device capable of measuring the load at which failure occurs.

The tensile strength of the weld shall be no less than that specified for the base metal. If the specimen fails in the weld metal, then the fracture surface must also meet the requirements of paragraph 5.6.3.3, which is the criteria for evaluating the fractured surface of a nick break specimen. If the specimen fails in the pipe material and produces a tensile strength not less than 95 % of that specified for the pipe material, the test is acceptable.

Testing of nick break specimens is described in paragraph 5.6.3. The term “nick break” refers to the hacksaw notch or “nick” cut into each edge of each transverse specimen, such that the reduction of the overall cross section of the specimen helps facilitate the fracture. These specimens are to be approximately 9 inches long by about 1 inch wide and are shown in Figure 5 on page 21. The specimens may be broken by any convenient method, which may include pulling them apart using a tension-testing machine or hitting one end with a hammer while holding the other end firm.

Figure 6 on page 22 is a schematic of the exposed surface of such a specimen after breaking and it defines the directions in which discontinuity length, depth and separation are to be measured.

The exposed weld metal surfaces of a nick break specimen must show complete fusion and penetration. The maximum permitted pore size is 1/16 inch and the combined area of all acceptable pores shall not exceed 2 % (1/50th) of the fractured surface area. Slag inclusions shall not exceed 1/32 inch in depth and shall not exceed the lesser of 1/8 inch or one half the specified wall thickness. There shall be at least 1/2 inch separation between the edges of adjacent acceptable slag inclusions.

Root and face bend testing is described in paragraph 5.6.4. These specimens are approximately 9 inches long by roughly 1 inch wide and are shown in Figure 7 on page 22. They may be machine or oxygen cut. A maximum corner radius of 1/8 inch is permitted in order to help prevent corner cracks that could originate from the rough-cut corner rather than from flaws in the weld. In addition, the reinforcement on both the face and root surfaces is required to be removed flush with the surface of the specimen prior to bending in order to maintain smooth and consistent contact with the contour of the plunger. The bend test jig is shown in Figure 8 on page 23, which shows that the radius of the plunger is the same for all pipe grades.

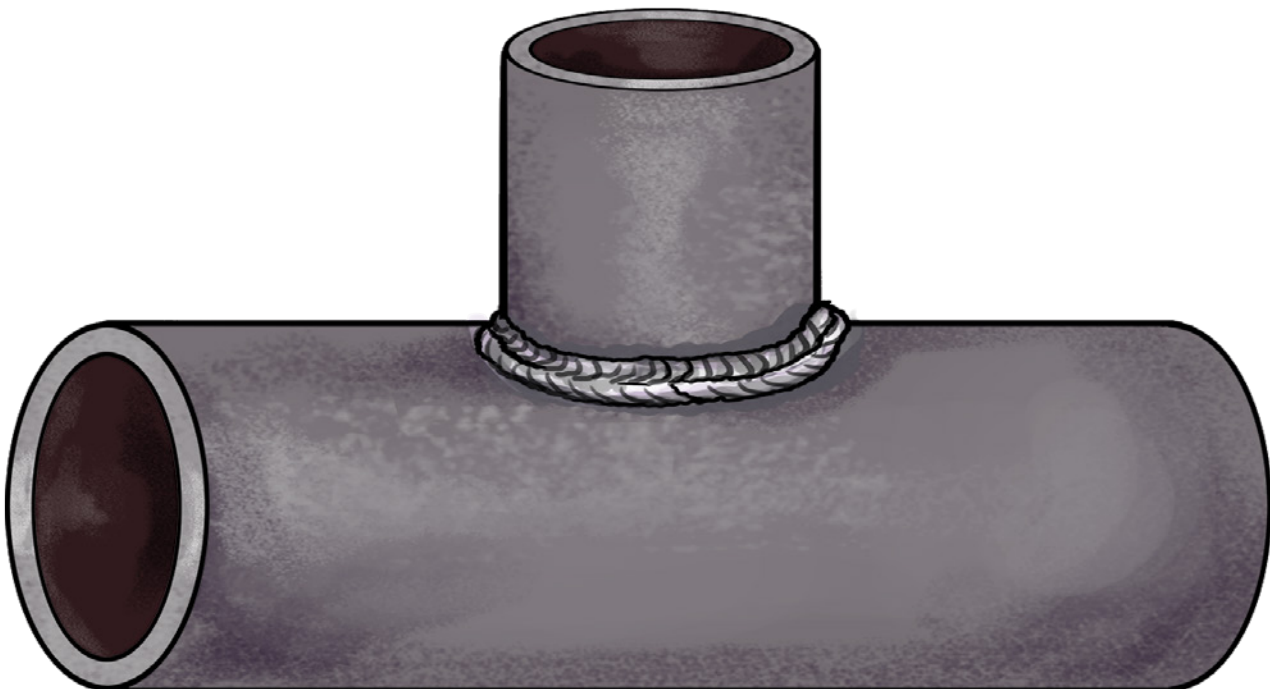


Figure 5.1 — Branch Connection Weld