ASME BPVC.IX-2025

SECTION IX

Welding, Brazing, and Fusing Qualifications

2025 ASME Boiler and Pressure Vessel Code

An International Code

Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators

ASME

SETTING THE STANDARD

AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition July 1, 2025

IX

QUALIFICATION STANDARD FOR WELDING, BRAZING, AND FUSING PROCEDURES; WELDERS; BRAZERS; AND WELDING, BRAZING, AND FUSING OPERATORS

ASME Boiler and Pressure Vessel Committee
on Welding, Brazing, and Fusing

The American Society of Mechanical Engineers
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Date of Issuance: July 1, 2025

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Library of Congress Catalog Card Number: 56-3934

Adopted by the Council of The American Society of Mechanical Engineers, 1914; latest edition 2025.

The American Society of Mechanical Engineers
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FOREWORD*

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)
(b) Committee on Materials (II)
(c) Committee on Construction of Nuclear Facility Components (III)
(d) Committee on Heating Boilers (IV)
(e) Committee on Nondestructive Examination (V)
(f) Committee on Pressure Vessels (VIII)
(g) Committee on Welding, Brazing, and Fusing (IX)
(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)
(i) Committee on Nuclear Inservice Inspection (XI)
(j) Committee on Transport Tanks (XII)
(k) Committee on Overpressure Protection (XIII)
(l) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating to pressure integrity. The rules govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. For nuclear items other than pressure-retaining components, the Committee also establishes rules of safety related to structural integrity. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. The Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity and, for nuclear items other than pressure-retaining components, structural integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of components addressed by the Code. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

The Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgment* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and overpressure protection.

responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of the Code. Requests for revisions, new rules, Code cases, or interpretations shall be addressed to the staff secretary in writing and shall give full particulars in order to receive consideration and action (see the Correspondence With the Committee page). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of the ASME Single Certification Mark.

When required by context in the Code, the singular shall be interpreted as the plural, and vice versa.

The words "shall," "should," and "may" are used in the Code as follows:

- *Shall* is used to denote a requirement.
- *Should* is used to denote a recommendation.
- *May* is used to denote permission, neither a requirement nor a recommendation.

STATEMENT OF POLICY ON THE USE OF THE ASME SINGLE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the ASME Single Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the ASME Single Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the ASME Single Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the ASME Single Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the ASME Single Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code." An ASME corporate logo shall not be used by any organization other than ASME.

The ASME Single Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the ASME Single Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the ASME Single Certification Mark.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the ASME Single Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the ASME Single Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

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General

ASME codes and standards are developed and maintained by committees with the intent to represent the consensus of concerned interests. Users of ASME codes and standards may correspond with the committees to propose revisions or cases, report errata, or request interpretations. Correspondence for this Section of the ASME Boiler and Pressure Vessel Code (BPVC) should be sent to the staff secretary noted on the Section's committee web page, accessible at https://go.asme.org/CSCommittees.

NOTE: See ASME BPVC Section II, Part D for guidelines on requesting approval of new materials. See Section II, Part C for guidelines on requesting approval of new welding and brazing materials ("consumables").

Revisions and Errata

The committee processes revisions to this Code on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Code. Approved revisions will be published in the next edition of the Code.

In addition, the committee may post errata and Special Notices at http://go.asme.org/BPVCerrata. Errata and Special Notices become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata and Special Notices.

This Code is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

Cases

(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Code

(4) to permit use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code.

(c) The committee will consider proposed cases concerning the following topics only:

(1) equipment to be marked with the ASME Single Certification Mark, or

(2) equipment to be constructed as a repair/replacement activity under the requirements of Section XI

(d) A proposed case shall be written as a question and reply in the same format as existing cases. The proposal shall also include the following information:

(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Code Section and the paragraph, figure, or table number to which the proposed case applies

(4) the editions of the Code to which the proposed case applies

(e) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Cases that have been approved will appear in the next edition or supplement of the Code Cases books, "Boilers and Pressure Vessels" or "Nuclear Components." Each Code Cases book is updated with seven Supplements.

Supplements will be sent or made available automatically to the purchasers of the Code Cases books until the next edition of the Code. Annulments of Code Cases become effective six months after the first announcement of the annulment in a Code Case Supplement or Edition of the appropriate Code Case book. The status of any case is available at http://go.asme.org/BPVCCDatabase. An index of the complete list of Boiler and Pressure Vessel Code Cases and Nuclear Code Cases is available at http://go.asme.org/BPVCC.

Interpretations

(a) Interpretations clarify existing Code requirements and are written as a question and reply. Interpretations do not introduce new requirements. If a revision to resolve conflicting or incorrect wording is required to support the interpretation, the committee will issue an intent interpretation in parallel with a revision to the Code.

(b) Upon request, the committee will render an interpretation of any requirement of the Code. An interpretation can be rendered only in response to a request submitted through the online Inquiry Submittal Form at http://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

(c) ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Code requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers may track the status of their requests at http://go.asme.org/Interpretations.

(d) ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

(e) Interpretations are published in the ASME Interpretations Database at http://go.asme.org/Interpretations as they are issued.

Committee Meetings

The ASME BPVC committees regularly hold meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the applicable committee. Information on future committee meetings can be found at http://go.asme.org/BCW.

INTRODUCTION

(25)

The following is provided as a brief introduction to Section IX, and cannot be considered as a substitute for the actual review of the document. However, this introduction is intended to give the reader a better understanding of the purpose and organization of Section IX.

Section IX of the ASME Boiler and Pressure Vessel Code relates to the qualification of welders, welding operators, brazers, brazing operators, and fusing operators, and the procedures employed in welding, brazing, or plastic fusing in accordance with the ASME Boiler and Pressure Vessel Code and the ASME B31 Code for Pressure Piping. As such, this is an active document subject to constant review, interpretation, and improvement to recognize new developments and research data. Section IX is a document referenced for the qualification of material joining processes by various construction codes such as Section I, III, IV, VIII, XII, etc. These particular construction codes apply to specific types of fabrication and may impose additional requirements or exemptions to Section IX qualifications. Qualification in accordance with Section IX is not a guarantee that procedures and performance qualifications will be acceptable to a particular construction code.

Section IX does not contain rules for production material joining, nor does it contain rules to cover all factors affecting production material joining properties under all circumstances. Where such factors are determined by the organization to affect material joining properties, the organization shall address those factors in the Procedure Specification to ensure that the required properties are achieved in the production material joining process.

The purpose of the Procedure Specification and the Procedure Qualification Record (PQR) is to ensure the material joining process proposed for construction is capable of producing joints having the required mechanical properties for the intended application. Personnel performing the material joining procedure qualification test shall be sufficiently skilled. The purpose of the procedure qualification test is to establish the mechanical properties of the joint produced by the material joining process and not the skill of the personnel using the material joining process. In addition, special consideration is given when toughness testing is required. The supplementary essential variables apply only when toughness testing is required by the referencing code, standard, or specification.

The purpose of Performance Qualification is to determine the ability of the person using a material joining process to produce a sound joint. In Operator Performance Qualification, the basic criterion is to determine the ability of the operator to properly operate the equipment to produce a sound joint.

In developing Section IX, each material joining process that is included was reviewed with regard to those factors (called variables) that have an effect upon the material joining operations as applied to procedure or performance criteria.

The user of Section IX should be aware of how Section IX is organized. It is divided into four Parts: general requirements, welding, brazing, and plastic fusing. Each Part addressing a material joining process is then divided into Articles. The Articles for each material joining process deal with the following:

(a) general requirements specifically applicable to the material joining process (Article I Welding, Article XI Brazing, and Article XXI Plastic Fusing)

(b) procedure qualifications (Article II Welding, Article XII Brazing, and Article XXII Plastic Fusing)

(c) performance qualifications (Article III Welding, Article XIII Brazing, and Article XXIII Plastic Fusing)

(d) data (Article IV Welding, Article XIV Brazing, and Article XXIV Plastic Fusing)

(e) standard welding procedure specifications (Article V Welding)

(f) material manufacturing using wire-additive welding (Article VI Welding)

These articles contain general references and guides that apply to procedure and performance qualifications such as positions, type and purpose of various mechanical tests, acceptance criteria, and the applicability of Section IX, which previously appeared in the Preamble of the 1980 Edition of Section IX (the Preamble has since been deleted). The general requirement articles reference the data articles for specific details of the testing equipment and removal of the mechanical test specimens.

PROCEDURE QUALIFICATIONS

Each material joining process that has been evaluated and adopted by Section IX is listed separately with the essential and nonessential variables as they apply to that particular process. In general, the Procedure Specifications are required to list all essential and nonessential variables for each process that is included under that particular procedure specification. When an essential variable must be changed beyond the range qualified and the change is not an editorial revision to correct an error, requalification of the procedure specification is required. If a change is made in a nonessential variable, the procedure need only be revised or amended to address the nonessential variable change. When toughness testing is required for Welding Procedure Specification (WPS) qualification by the referencing code, standard, or specification, the supplementary essential variables become additional essential variables, and a change in these variables requires requalification of the WPS.

In addition to covering various processes, there are also rules for procedure qualification of corrosion-resistant weld metal overlay and hard-facing weld metal overlay.

Beginning with the 2000 Addenda, the use of Standard Welding Procedure Specifications (SWPSs) was permitted. Article V provides the requirements and limitations that govern the use of these documents. The SWPSs approved for use are listed in Mandatory Appendix E.

In the 2004 Edition, rules for temper bead welding were added.

With the incorporation of the new Creep-Strength Enhanced Ferritic (CSEF) alloys in the 1986 Edition, using the existing P-Number groupings to specify PWHT parameters can lead to variations in heat treatments that may significantly degrade the mechanical properties of these alloys. CSEF alloys are a family of ferritic steels whose creep strength is enhanced by the creation of a precise condition of microstructure, specifically martensite or bainite, which is stabilized during tempering by controlled precipitation of temper-resistant carbides, carbo-nitrides, or other stable phases.

In the 2007 Edition of the Code, only P-No. 5B, Group 2 base metals met this definition and were approved for Code construction. Looking forward, a number of CSEF alloys are already in use in Code Cases and drawing near to incorporation. To facilitate addressing their special requirements, P-No. 15A through P-No. 15F have been established for CSEF alloys.

In the 2013 Edition, Part QG General Requirements and Part QF Plastic Fusing were added.

PERFORMANCE QUALIFICATIONS

These articles list separately the various requirements that apply to the performance qualifications. The performance qualifications are limited by essential variables.

QW-350, QW-360, QB-350, and QF-360 list the essential variables that are applicable for each specific process.

Generally, a welder or welding operator may be qualified by mechanical bending tests, or volumetric NDE of a test coupon, or volumetric NDE of the initial production weld. Brazers, brazing operators, and fusing operators may not be qualified by volumetric NDE.

WELDING, BRAZING, AND FUSING DATA

The data articles include the variables grouped into categories such as joints, base materials, filler materials, positions, preheat/postweld heat treatment, gas, electrical characteristics, and technique. They are referenced from other articles as they apply to each process.

These articles are frequently misused by selecting variables that do not apply to a particular process. Variables only apply as referenced for the applicable process in Article II or III for welding, Article XII or XIII for brazing, and Article XXII or XXIII for plastic fusing. The user of Section IX should not apply any variable that is not referenced for that process.

These articles also include assignments of welding and brazing P-Numbers to particular base materials and F-Numbers to filler materials. Article IV also includes A-Number tables for reference by the Code user.

Beginning with the 1994 Addenda, welding P-Numbers, brazing P-Numbers, and nonmandatory S-Numbers were consolidated into Table QW/QB-422. Both the QB-422 table (brazing P-Numbers) and Appendix C table (S-Numbers) were deleted. The new Table QW/QB-422 was divided into ferrous and nonferrous sections. Metals were listed in numerical order by material specification number to aid users in locating the appropriate grouping number.

In the 2009 Addenda, S-Number base metals listed in Table QW/QB-422 were reassigned as P-Numbers and the S-Number listings and references were deleted.

The QW-451 and QB-451 tables for procedure qualification thickness requirements and the QW-452 and QB-452 tables for performance qualification thickness are given and may be used only as referenced by other paragraphs. Generally, the appropriate essential variables reference these tables.

Revisions to the 1980 Edition of Section IX introduced new definitions for position and added a fillet-weld orientation sketch to complement the groove-weld orientation sketch. The new revision to position indicates that a welder qualifies in the 1G, 2G, 3G, etc., position and is then qualified to weld, in production, in the F, V, H, or O positions as appropriate. Table QW-461.9 is a revised table that summarizes these new qualifications.

The data articles also give sketches of coupon orientations, removal of test specimens, and test jig dimensions. These are referenced by Articles I, XI, and XXI.

QW-470 describes etching processes and reagents.

Within Part QG is a list of general definitions applicable to Section IX–adopted material joining processes. These may differ slightly from other welding documents.

Nonmandatory Forms for documenting procedure and performance qualifications are provided for the aid of those who do not wish to design their own forms. Any form(s) that address all applicable requirements of Section IX may be used.

SUMMARY OF CHANGES

Changes listed below are identified on the pages by a margin note, **(25)**, placed next to the affected area.

Page	*Location*	*Change*
xii	List of Sections	Title of Section XI, Division 1 revised
xiii	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
xvi	Personnel	Updated
xli	Introduction	(1) Third paragraph, "Performance Qualifications," and "Welding, Brazing, and Fusing Data" revised
		(2) Subparagraph (f) added
1	QG-100	Subparagraph (g) added
4	QG-106.4	Subparagraph (e) added
4	QG-108	Revised in its entirety
5	QG-109.2	(1) Definitions of *fusing (plastic fusing)*, *fusion interfacial pressure*, and *heat soak interfacial pressure* added
		(2) Term *fusing* revised to *fusion (plastic fusing)*, and definition revised
		(3) Definitions of *initial heating interfacial pressure*, *interfacial pressure*, *theoretical fusing pressure*, and *wire-additive welding* revised
17	QW-142	Title revised
17	QW-143	Title revised
18	QW-153.1	Subparagraph (c) revised
19	QW-163	Revised in its entirety
21	QW-185.3	Revised
24	QW-191.4	Revised in its entirety
25	QW-193.1	Last sentence and QW-193.1.1 through QW-193.1.3 revised
29	Appendix I	Deleted
32	QW-202.2	Subparagraphs (a) and (b) revised
32	QW-202.3	First paragraph revised
32	QW-202.4	Subparagraph (b)(1) revised
34	QW-215.4	Subparagraph (a) revised
40	Table QW-253	QW-410.92 added
41	Table QW-253.1	QW-410.92 added
42	Table QW-254	QW-410.92 added
44	Table QW-254.1	QW-410.92 added
45	Table QW-255	QW-410.92 added
47	Table QW-255.1	QW-410.92 added
48	Table QW-256	QW-410.92 added
50	Table QW-256.1	QW-410.92 added
51	Table QW-257	QW-410.92 added
53	Table QW-257.1	QW-410.92 added
58	Table QW-260	"Essential" and "Supplementary Essential" entries for QW-403.15 revised
63	Table QW-264.1	QW-410 rows revised in their entirety
64	Table QW-264.2	QW-410.92 added
69	QW-284	Revised
70	Table QW-288.1	"Brief of Variables" entry for QW-406.1 corrected by errata
76	QW-304	"P-No. 53" revised to "P-No. 54" twice
77	QW-305	"P-No. 53" revised to "P-No. 54" twice
79	QW-351	Revised in its entirety
80	QW-361.2	Subparagraphs (e) and (h) revised

Page	Location	Change
81	QW-381.1	Revised
81	QW-381.2	Introductory paragraphs and subpara. (c) revised
82	QW-382.1	Subparagraph (d) revised
82	QW-384	Revised
86	QW-403.6	Paragraph break inserted before “This variable...” by errata
86	QW-403.16	First paragraph revised
87	QW-403.29	Revised
87	QW-403.32	Revised
91	QW-407.2	First paragraph revised
92	QW-408.8	“P-No. 53” revised to “P-No. 54”
92	QW-408.9	Revised
92	QW-408.10	“P-No. 53” revised to “P-No. 54”
93	QW-408.26	Revised
95	QW-410.11	“P-No. 53” revised to “P-No. 54”
96	QW-410.52	Revised
96	QW-410.53	Revised
97	QW-410.67	Revised
98	QW-410.77	Revised
98	QW-410.91	Added
98	QW-410.92	Added
98	QW-410.93	Added
100	QW-421.1	In subpara. (a), third paragraph deleted
100	QW-421.3	Subparagraphs (a) and (c) deleted
100	QW-421.4	Revised
101	Table QW/QB-421.2	(1) Last row added (2) Second and third columns revised in their entirety
102	Table QW/QB-422	(1) Second column head revised (2) “Ferrous" and "Nonferrous" subheads deleted, and both tables combined (3) Rows added, deleted, revised, and corrected by errata (4) General Note deleted
193	QW-423.1	In-text table revised
194	Table QW-432	ERNiCr-8 row added
205	QW-433	Note (1) revised
210	Table QW-452.4	(1) Second entry in first column revised (2) Last row deleted
211	Table QW-453	Revised in its entirety
217	Table QW-461.9	For Plate — Groove and Pipe — Groove, first entry in last column revised
227	Figure QW-462.5(a)	Illustration and notes revised
246	Figure QW-466.1	In both U.S. Customary and SI tables, P-No. 49 revised to P-No. 81 and P-No. 54 added
256	Table QW-613	In third column, “(50*W*)” deleted by errata
257	Table QW-651	QW-410.92 added
261	QB-153.1	In subpara. (d), P-Numbers revised
271	QB-402.1	In last paragraph, cross-reference revised
271	QB-402.2	Revised in its entirety
272	Table QB-421	Added
298	Figure QB-466.3	General Note (c) revised
299	QF-131.1	Subparagraph (e) revised
300	QF-131.2	Subparagraphs (f) and (g) revised
300	QF-131.3	Subparagraph (e) revised
300	QF-132.1	Subparagraphs (b), (d), and (e) revised
300	QF-132.2	Subparagraph (c) revised

Page	*Location*	*Change*
300	QF-141.1	Subparagraphs (a)(1) and (a)(2) revised
302	QF-143.1.3	Subparagraph (a) revised
302	QF-143.2.1	Subparagraph (a) revised
305	QF-145.1.4	Revised
305	QF-145.2.1	Revised
307	QF-202.2.1	(1) Subparagraphs (a)(3)(-a) through (a)(3)(-d) and (b)(1) revised (2) Subparagraphs (a)(3)(-e) and (a)(3)(-f) added
309	Table QF-202.2.2	In second column, first two entries revised
309	QF-202.2.3	Subparagraph (c) revised
309	QF-221.1	Subparagraphs (f)(1), (f)(2), (h), (j), and (l) revised
310	QF-221.2	Subparagraphs (d), (f), and (g) revised
312	QF-222.1	Subparagraph (i) revised
313	Table QF-254	(1) “Brief of Variables” entry for QF-405.2 revised (2) QF-405.10 row added
314	Table QF-256	QF-405.2, QF-405.9, and QF-405.10 added
315	Table QF-257	(1) “Brief of Variables” entry for QF-405.2 revised (2) QF-405.10 added
318	Table QF-362	(1) In section (a), QF-406.7 and QF-406.8 added (2) In section (c), subheading and “Brief of Variables” entry for QF-406.7 revised
319	QF-405	(1) QF-405.1, QF-405.2, QF-405.5, and QF-405.9 revised (2) QF-405.10 added
320	QF-406.7	Revised
320	QF-406.8	Added
321	QF-450	Title revised
321	Table QF-452.3	Revised in its entirety
335	Form QF-482(a)	“Thermal Conditions (QF-405)” box revised
337	Form QF-482(c)	“Thermal Conditions (QF-405)” box revised
338	Form QF-483(a)	“Thermal Conditions (QF-405)” box revised
343	Form QF-483(c)	“Thermal Conditions (QF-405)” box revised
361	E-300	In table, edition years updated
370	J-100	First sentence revised
375	Nonmandatory Appendix M	Added

CROSS-REFERENCING IN THE ASME BPVC

Paragraphs within the ASME BPVC may include subparagraph breakdowns, i.e., nested lists. The following is a guide to the designation and cross-referencing of subparagraph breakdowns:

(a) Hierarchy of Subparagraph Breakdowns

(1) First-level breakdowns are designated as (a), (b), (c), etc.

(2) Second-level breakdowns are designated as (1), (2), (3), etc.

(3) Third-level breakdowns are designated as (-a), (-b), (-c), etc.

(4) Fourth-level breakdowns are designated as (-1), (-2), (-3), etc.

(5) Fifth-level breakdowns are designated as (+a), (+b), (+c), etc.

(6) Sixth-level breakdowns are designated as (+1), (+2), etc.

(b) Cross-References to Subparagraph Breakdowns. Cross-references within an alphanumerically designated paragraph (e.g., PG-1, UIG-56.1, NCD-3223) do not include the alphanumerical designator of that paragraph. The cross-references to subparagraph breakdowns follow the hierarchy of the designators under which the breakdown appears. The following examples show the format:

(1) If X.1(c)(1)(-a) is referenced in X.1(c)(1), it will be referenced as (-a).

(2) If X.1(c)(1)(-a) is referenced in X.1(c)(2), it will be referenced as (1)(-a).

(3) If X.1(c)(1)(-a) is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).

(4) If X.1(c)(1)(-a) is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).

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PART QG
GENERAL REQUIREMENTS

(25) QG-100 SCOPE

(a) This Section contains requirements for the qualification of welders, welding operators, brazers, brazing operators, plastic fusing operators, and the material-joining processes they use during welding, brazing, and fusing operations for the construction of components under the rules of the ASME Boiler and Pressure Vessel Code, the ASME B31 Codes for Pressure Piping, and other Codes, standards, and specifications that reference this Section. This Section is divided into four parts.

(1) Part QG contains general requirements for all material-joining processes.

(2) Part QW contains requirements for welding.

(3) Part QB contains requirements for brazing.

(4) Part QF contains requirements for plastic fusing.

(b) Whenever the referencing Code, standard, or specification imposes qualification requirements different than those given in this Section, the requirements of the referencing Code, standard, or specification shall take precedence over the requirements of this Section.

(c) Some of the more common terms relating to material-joining processes are defined in QG-109. Whenever the word "pipe" is used, "tube" shall also be applicable.

(d) New editions to Section IX may be used beginning with the date of issuance and become mandatory 6 months after the date of issuance.

(e) Code Cases are permissible and may be used, beginning with the date of approval by ASME. Only Code Cases that are specifically identified as being applicable to this Section may be used. At the time a Code Case is applied, only the latest revision may be used. Code Cases that have been incorporated into this Section or have been annulled shall not be used for new qualifications, unless permitted by the referencing Code. Qualifications using the provisions of a Code Case remain valid after the Code Case is annulled. The Code Case number shall be listed on the qualification record(s).

(f) Throughout this Section, references are made to various non-ASME documents. Unless a specific date is referenced, the latest edition of the reference document in effect at the time of performance or procedure qualification is to be used.

(g) This Section does not fully address tolerances. When dimensions, sizes, or other parameters are not specified as maximums, minimums, or with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when using standard practices based on engineering judgment.

QG-101 PROCEDURE SPECIFICATION

A procedure specification is a written document providing direction to the person applying the material-joining process. Details for the preparation and qualification of procedure specifications for welding (WPS), brazing (BPS), and fusing (FPS) are given in the respective Parts addressing those processes. Procedure specifications used by an *organization* (see QG-109.2) having responsibility for operational control of material-joining processes shall have been qualified by that organization, or shall be a standard procedure specification acceptable under the rules of the applicable Part for the joining process to be used. Procedure specifications shall be available for reference and review at the fabrication site.

Procedure specifications address the conditions (including ranges, if any) under which the material-joining process must be performed. These conditions are referred to in this Section as "variables." A procedure specification shall address, as a minimum, the specific essential and nonessential variables that are applicable to the material-joining process to be used in production. When the referencing code, standard, or specification requires toughness qualification of the material-joining procedure, the applicable supplementary essential variables shall also be addressed in the procedure specification.

QG-102 PROCEDURE QUALIFICATION RECORD

The purpose of qualifying the procedure specification is to demonstrate that the joining process proposed for construction is capable of producing joints having the required mechanical properties for the intended application. Qualification of the procedure specification demonstrates the mechanical properties of the joint made using a joining process, and not the skill of the person using the joining process.

The procedure qualification record (PQR) documents what occurred during the production of a procedure qualification test coupon and the results of testing that coupon.

As a minimum, the PQR shall document the essential procedure qualification test variables applied during production of the test joint, and the results of the required tests. When toughness testing is required by the referencing code, standard, or specification for qualification of the procedure, the applicable supplementary essential variables shall be recorded for each process. The organization shall certify the PQR by a signature or other means as described in the organization's quality program. The PQR shall be available for review. A procedure specification may be supported by one or more PQR(s), and one PQR may be used to support one or more procedure specification(s).

QG-103 PERFORMANCE QUALIFICATION

The purpose of qualifying the person who will use a joining process is to demonstrate that person's ability to produce a sound joint when using a procedure specification.

QG-104 PERFORMANCE QUALIFICATION RECORD

The performance qualification record documents what occurred during the production of a test coupon by a person using one or more joining processes following an organization's procedure specification. As a minimum, the record shall document

(a) the essential variables for each process used to produce the test coupon

(b) the ranges of variables qualified as required by the applicable part (see QW-301.4, QB-301.4, and QF-301.4)

(c) the results of the required testing and nondestructive examinations

(d) the identification of the procedure specification(s) followed during the test

The organization shall state on the record that the performance qualification test was conducted in accordance with the requirements of this Section, and certify the record by a signature or other means as described in the organization's quality program. Performance qualification records shall be available for review.

QG-105 VARIABLES

QG-105.1 Essential Variables (Procedure). Essential variables are conditions in which a change, as described in the specific variables, is considered to affect the mechanical properties (other than toughness) of the joint. Before using a procedure specification whose essential variables have been revised and fall outside their qualified range, the procedure specification must be requalified. Procedure qualification records may be changed when a procedure qualification test supporting the change has been completed, or when an editorial revision is necessary to correct an error, as permitted by the rules of the Part applicable to the material-joining process.

QG-105.2 Essential Variables (Performance). Essential variables are conditions in which a change, as described in the specific variable list, will affect the ability of the person to produce a sound joint.

QG-105.3 Supplementary Essential Variables. Supplementary essential variables are conditions in which a change will affect the toughness properties of the joint, heat-affected zone, or base material. Supplementary essential variables become additional essential variables in situations where the referencing code, standard, or specification requires toughness testing for procedure qualification. When procedure qualification does not require the addition of toughness testing, supplementary essential variables are not applicable. See QW-401.1.

QG-105.4 Nonessential Variables. Nonessential variables are conditions in which a change, as described in the specific variables, is not considered to affect the mechanical properties of the joint. These variables shall be addressed in the procedure specification, as required by QG-101.

A procedure specification may be editorially revised to change a nonessential variable to fall outside of its previously listed range, but does not require requalification of the procedure specification.

QG-105.5 Special Process Variables. Special process variables are conditions that apply only to special processes that are described in the Part that addresses those processes. When these special processes are used, only the applicable special process variables shall apply.

QG-105.6 Applicability. The applicable essential, supplementary essential, nonessential, and special process variables for a specific joining process are given in the Part addressing that joining process.

QG-106 ORGANIZATIONAL RESPONSIBILITY

Personnel performing supervisory activities specified in this Section shall

(a) be designated by the organization with responsibility for supervision, control, evaluation, and acceptance of qualification testing.

(b) have a satisfactory level of competence in accordance with the organization's quality program. As a minimum, they shall be qualified by education, experience, or training in the following areas:

(1) knowledge of the requirements of this Section for the qualification of procedures and/or joining personnel

(2) knowledge of the organization's quality program

(3) the scope, complexity, or special nature of the activities to which oversight is to be provided

(c) have a record, maintained by the organization, containing objective evidence of the qualifications, training, or experience.

QG-106.1 Procedure Qualifications. Each organization is responsible for conducting the tests required by this Section to qualify the procedures that are used in the construction of components under the rules of the Codes, standards, and specifications that reference this Section.

(a) The personnel who produce test joints for procedure qualification shall be under the full supervision and control of the qualifying organization during the production of these test joints.

(b) Production of qualification test joints under the supervision and control of another organization is not permitted, except as permitted in QG-106.4. However, it is permitted to subcontract any or all of the work necessary for preparing the materials to be joined, the subsequent work for preparing test specimens from the completed test joint, and the performance of nondestructive examination and mechanical tests, provided the organization accepts full responsibility for any such work.

(c) If the effective operational control of procedure qualifications for two or more companies of different names exists under the same corporate ownership, the companies involved shall describe in their quality programs the operational control of procedure qualifications. In this case, separate procedure qualifications are not required, provided all other requirements of this Section are met.

QG-106.2 Performance Qualifications. Each organization is responsible for the supervision and control of material joining performed by persons for whom they have operational responsibility and control. The organization shall conduct the tests required by this Section to qualify the performance of those persons with each joining process they will use for the construction of components under the rules of the Codes, standards, and specifications that reference this Section. This requirement ensures that the qualifying organization has determined that the personnel using its procedures are capable of achieving the minimum requirements specified for an acceptable joint. This responsibility cannot be delegated to another organization.

(a) The personnel who produce test joints for performance qualification shall be tested under the full supervision and control of the qualifying organization.

(b) The performance qualification test shall be performed following either a qualified procedure specification or a standard procedure specification acceptable under the rules of the applicable Part for the joining process. The Part addressing any specific joining process may exempt a portion of the procedure specification from being followed during production of the performance qualification test coupon.

(c) Production of test joints under the supervision and control of another organization is not permitted. It is permitted to subcontract any or all of the work necessary for preparing the materials to be joined in the test joint, and the subsequent work for preparing test specimens from the completed test joint, and the performance of nondestructive examination and mechanical tests, provided the organization accepts full responsibility for any such work.

(d) The performance qualification test may be terminated at any stage, whenever it becomes apparent to the supervisor conducting the tests that the person being tested does not have the required skill to produce satisfactory results.

(e) When a procedure qualification test coupon has been tested and found acceptable, the person who prepared the test coupon is also qualified for the joining process used, within the ranges specified for performance qualification for the applicable process(es).

(f) Persons who are successfully qualified shall be assigned an identifying number, letter, or symbol by the organization, which shall be used to identify their work.

(g) If effective operational control of performance qualifications for two or more companies of different names exists under the same corporate ownership, the companies involved shall describe in their quality programs the operational control of performance qualifications. In this case, requalification of persons working within the companies of such an organization are not required, provided all other requirements of this Section are met.

QG-106.3 Simultaneous Performance Qualifications. Organizations may participate in an association to collectively qualify the performance of one or more persons for material-joining processes simultaneously and may share performance qualification information with other participating organizations within the association. When simultaneous performance qualifications are conducted, each participating organization shall be represented by an employee with designated responsibility for performance qualifications.

(a) The essential variables of the procedure specifications to be followed during simultaneous performance qualifications shall be compared by the participating organizations, and shall be identical, except as otherwise provided in the Part addressing the specific joining method. The qualified thickness ranges need not be identical but shall include the test coupon thickness.

(b) Alternatively, the participating organizations shall agree to follow a single procedure specification that has been reviewed and accepted by each participating organization. Each participating organization shall have a supporting PQR or shall have accepted responsibility for using a standard procedure specification having a range of variables consistent with those to be followed during the performance qualification test, in accordance with the applicable Part for the joining method.

(c) Each participating organization's representative shall

(1) positively identify the person whose performance is to be tested

(2) verify the markings on the test coupon correspond to the person's identification

(3) verify that the positional orientation markings on the test coupon reflect the test position of the coupon as required to identify the location of test specimen removal

(4) perform a visual examination of each completed test coupon and each test specimen to determine its acceptability

(-a) When the test coupon(s) is prepared and the test specimens are mechanically tested by an independent laboratory, the laboratory's report may be used as the basis for accepting the test methods and their results.

(-b) When the test coupon(s) is examined by volumetric examination, the examining organization's report may be used as the basis for acceptance of the test methods, qualification and certification of the examiner, and the results of the examination.

(5) prepare and certify a performance qualification record for each person qualified

(d) When the qualified person changes employers between participating organizations, the employing organization shall verify the continuity of the person's qualifications has been maintained by previous employers since his qualification date, as required by the applicable Part for the joining method. Evidence of activities supporting performance qualification continuity may be obtained from any member of the association, even if the member was not a participant in the simultaneous welder qualifications.

(e) If a person has had their performance qualification revoked for specific reasons, the employing organization shall notify all other participating organizations that the person's qualification(s) has been revoked. The remaining participating organizations shall determine whether they will uphold or revoke the performance qualifications for that person in accordance with this Section.

(f) When a person's performance qualifications are collectively renewed in accordance with the applicable Part for the joining method, the testing procedures shall follow the rules of this paragraph.

(25) **QG-106.4 Simultaneous Procedure Qualifications.** When expressly permitted by the referencing code, standard, or specification, material-joining procedures may be simultaneously qualified by more than one organization, provided that each organization accepts full responsibility for any such qualifications and the following requirements are met:

(a) Each participating organization shall be represented by an individual with responsibility for qualification of joining procedures, as detailed in QG-106.

(b) A preliminary joining procedure specification acceptable to the representatives of each participating organization shall be prepared addressing the essential and nonessential variables and, when applicable, the supplementary essential variables and other requirements that are to be observed for each process to be used for joining the test coupon(s). If any variables are revised during the joining of a test coupon, the revised variables shall be agreed upon by the representatives of each participating organization.

(c) Joining of the test coupon(s) shall be conducted under the simultaneous supervision of the representatives of each participating organization.

(d) The PQR shall document that the qualification was conducted under the provisions of QG-106.4.

(e) The PQR shall be certified in accordance with QG-102 by each participating organization.

QG-107 OWNERSHIP TRANSFERS

Organizations may maintain effective operational control of PQRs, procedure specifications, and performance qualification records under different ownership than existed during the original procedure qualification. Multiple organizations under a common ownership may use PQRs, procedure specifications, and performance qualification records under that owner's name. The quality program of each organization shall describe the effective operational control and authority for technical direction of welding.

When an organization or some part thereof is acquired by a new owner(s), the PQRs, procedure specifications, and performance qualification records may remain valid for use by the new owner(s) without requalification; and the new owner(s) PQRs, procedure specifications, and performance qualification records become valid for use by the acquired organization, provided all of the following requirements have been met:

(a) The new owner(s) takes responsibility for the procedure specifications and performance qualification records.

(b) The procedure specifications identify the name of the new owner(s) prior to use.

(c) The quality program documents the original source of the PQRs, procedure specifications, and performance qualification records as being from the original qualifying organization.

QG-108 SPECIFICATIONS AND QUALIFICATIONS MADE TO PREVIOUS EDITIONS (25)

(a) Joining procedure specifications, procedure qualifications, and performance qualifications that were made in accordance with earlier Editions or Addenda of this Section may be used in any construction for which the current Edition has been specified. Such procedures and qualifications do not require amendment to include any changes required by later Editions of Section IX, except as required by QW-421.4. However, the qualification requirements of the referencing code,

standard, or specification shall also be met [see QG-100(b)].

(b) Existing procedure qualification records may be used to support new or revised joining procedure specifications written to later Editions or Addenda than those that were in effect at the time that those qualification records were developed. When this is done, the essential and, when applicable, supplementary essential variables identified in that Edition or Addenda shall have been documented in those existing qualification records. Such procedure specifications may then be used in accordance with (a).

(c) New procedure and performance qualifications shall be in accordance with the current Edition of Section IX.

QG-109 DEFINITIONS

QG-109.1 GENERAL

Definitions of the more common terms relating to material-joining processes are defined in QG-109.2. There are terms listed that are specific to ASME Section IX and are not presently defined in AWS A3.0. Several definitions have been modified slightly from AWS A3.0 so as to better define the context or intent as used in ASME Section IX.

(25) QG-109.2 DEFINITIONS

arc seam weld: a seam weld made by an arc welding process.

arc spot weld: a spot weld made by an arc welding process.

arc strike: any inadvertent discontinuity resulting from an arc, consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any metal object. The arc may be caused by arc welding electrodes, magnetic inspection prods, or frayed electrical cable.

arc welding: a group of welding processes wherein coalescence is produced by heating with an arc or arcs, with or without the application of pressure, and with or without the use of filler metal.

as-brazed: adj. pertaining to the condition of brazements after brazing, prior to any subsequent thermal, mechanical, or chemical treatments.

as-welded: adj. pertaining to the condition of weld metal, welded joints, and weldments after welding but prior to any subsequent thermal, mechanical, or chemical treatments.

backgouging: the removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.

backhand welding: a welding technique in which the welding torch or gun is directed opposite to the progress of welding.

backing: a material placed at the root of a weld joint for the purpose of supporting molten weld metal. The material may or may not fuse into the joint. See also *retainer*.

backing gas: a gas, such as argon, helium, nitrogen, or reactive gas, which is employed to exclude oxygen from the root side (opposite from the welding side) of weld joints.

base metal: the metal or alloy that is welded, brazed, or cut.

bead-up cycle: part of the butt-fusing process to ensure complete contact between the heater surface and the pipe ends. The bead-up cycle begins when initial contact of the pipe ends to the heater is made at butt-fusing pressure until an indication of melt is observed around the pipe circumference.

bond line (brazing and thermal spraying): the cross section of the interface between a braze or thermal spray deposit and the substrate.

bracketed qualification: a procedure qualification performed by preparing test coupons using combinations of high and low values of specified variables to establish the upper and lower range of qualification for those variables.

braze: a joint produced by heating an assembly to suitable temperatures and by using a filler metal having a liquidus above 840°F (450°C) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

brazer: one who performs a manual or semiautomatic brazing operation.

brazing: a group of metal joining processes which produces coalescence of materials by heating them to a suitable temperature, and by using a filler metal having a liquidus above 840°F (450°C) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary action.

brazing operator: one who operates machine or automatic brazing equipment.

brazing temperature: the temperature to which the base metal(s) is heated to enable the filler metal to wet the base metal(s) and form a brazed joint.

brazing temperature range: the temperature range within which brazing can be conducted.

brazing, automatic: brazing with equipment which performs the brazing operation without constant observation and adjustment by a brazing operator. The equipment may or may not perform the loading and unloading of the work.

brazing, block (BB): a brazing process that uses heat from heated blocks applied to the joint. This is an obsolete or seldom used process.

brazing, dip (DB): a brazing process in which the heat required is furnished by a molten chemical or metal bath. When a molten chemical bath is used, the bath may act as a flux; when a molten metal bath is used, the bath provides the filler metal.

brazing, furnace (FB): a brazing process in which the workpieces are placed in a furnace and heated to the brazing temperature.

brazing, induction (IB): a brazing process that uses heat from the resistance of the workpieces to induced electric current.

brazing, machine: brazing with equipment which performs the brazing operation under the constant observation and control of a brazing operator. The equipment may or may not perform the loading and unloading of the work.

brazing, manual: a brazing operation performed and controlled completely by hand. See also *automatic brazing* and *machine brazing*.

brazing, resistance (RB): a brazing process that uses heat from the resistance to electric current flow in a circuit of which the workpieces are a part.

brazing, semiautomatic: brazing with equipment which controls only the brazing filler metal feed. The advance of the brazing is manually controlled.

brazing, torch (TB): a brazing process that uses heat from a fuel gas flame.

build-up of base metal (restoration of base metal thickness): this is the application of a weld material to a base metal so as to restore the design thickness and/or structural integrity. This build-up may be with a chemistry different from the base metal chemistry which has been qualified via a standard butt-welded test coupon. Also, may be called base metal repair or buildup.

butt joint: a joint between two members aligned approximately in the same plane.

butt-fusing cycle: pressure–time diagram for a defined fusing temperature, representing the entire fusing operation.

butt-fusing pressure: the sum of the theoretical butt-fusing pressure plus the drag pressure. This is verified by the gauge pressure used by the fusing operator on the butt-fusing machine to join the pipe ends or by applied torque when torque verification is required by the fusing procedure specification (FPS).

butt fusion (BF): fusing accomplished by heating the ends of polyethylene pipes above their melting point using a contact heater, then removing the heater and applying pressure necessary to achieve coalescence of the molten polyethylene materials during the cooling phase. Some of the more common terms relating to BF are defined in ASTM F412.

buttering: the addition of material, by welding, on one or both faces of a joint, prior to the preparation of the joint for final welding, for the purpose of providing a suitable transition weld deposit for the subsequent completion of the joint.

clad or cladding: weld metal overlay or bonded corrosion-resistant material added to a metal surface.

clad brazing sheet: a metal sheet on which one or both sides are clad with brazing filler metal.

coalescence: the growing together or growth into one body of the materials being joined.

complete fusion: fusion which has occurred over the entire base material surfaces intended for welding, and between all layers and beads.

consumable insert: filler metal that is placed at the joint root before welding, and is intended to be completely fused into the root to become part of the weld.

contact tube: a device which transfers current to a continuous electrode.

control method (FSW): the manner of monitoring and controlling the position of the rotating tool with respect to the weld joint during the friction stir welding process.

control method, force (FSW): a control method that uses a force set point, such as plunge force or travel force, to control the tool position. Under the force control method, the plunge depth or travel speed can vary, within a specified range, during welding.

control method, position (FSW): a control method that uses a set plunge position relative to the plate surface to control the tool position. Under the position control method, the plunge force can vary, within a specified range, during welding.

control method, travel (FSW): a control method that uses a set travel speed to control the tool position. Under the travel control method, the travel force can vary, within a specified range, during welding.

control specimen: a section from the base material tested to determine its tensile strength for the purpose of comparing to the tensile strength of the fused joint.

cool time at butt-fusing pressure: the minimum time that the butt-fusing pressure shall be maintained between the pipe faces while the pipe joint cools. This is a function of the wall thickness.

corner joint: a joint between two members located approximately at right angles to each other in the form of an L.

coupon: see *test coupon*.

crack: a fracture-type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement.

creep strength enhanced ferritic alloys (CSEF's): a family of ferritic steels whose creep temperature strength is enhanced by the creation of a precise condition of microstructure, specifically martensite or bainite, which is stabilized during tempering by controlled precipitation of temper-resistant carbides, carbo-nitrides, or other stable and/or meta-stable phases.

data acquisition record: a detailed, permanent record of variables applicable to the fusing process, such as butt-fusion pressure, electrofusion voltage, and cycle cool-down times, along with the measured heater surface temperature, employee information, butt-fusing or electrofusion machine information, pipe information, date, and time for each joint made.

defect: a discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability. See also *discontinuity* and *flaw*.

direct current electrode negative (DCEN): the arrangement of direct current arc welding leads in which the electrode is the negative pole and the workpiece is the positive pole of the welding arc.

direct current electrode positive (DCEP): the arrangement of direct current arc welding leads in which the electrode is the positive pole and the workpiece is the negative pole of the welding arc.

discontinuity: an interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect. See also *defect* and *flaw*.

double-welded joint: a joint that is welded from both sides.

double-welded lap joint: a lap joint in which the overlapped edges of the members to be joined are welded along the edges of both members.

drag pressure: the pressure required to overcome the drag resistance and frictional resistance in the butt-fusing machine and keep the carriage moving at its slowest speed.

drag resistance: force-opposing movement of the movable clamp of the butt-fusing machine due to the weight of the pipe.

dwell: the time during which the energy source pauses at any point in each oscillation.

electrode, arc welding: a component of the welding circuit through which current is conducted.

electrode, bare: a filler metal electrode that has been produced as a wire, strip, or bar with no coating or covering other than that incidental to its manufacture or provided for purposes of preservation, feeding, or electrical contact.

electrode, carbon: a nonfiller material electrode used in arc welding and cutting, consisting of a carbon or graphite rod, which may be coated with copper or other materials.

electrode, composite: a generic term of multicomponent filler metal electrodes in various physical forms, such as stranded wires, tubes, and covered electrodes.

electrode, covered: a composite filler metal electrode consisting of a core of a bare electrode or metal-cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied. The covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization, and can serve as a source of metallic additions to the weld.

electrode, electroslag welding: a filler metal component of the welding circuit through which current is conducted between the electrode guiding member and the molten slag.

NOTE: Bare electrodes and composite electrodes as defined under arc welding electrode are used for electroslag welding. A consumable guide may also be used as part of the electroslag welding electrode system.

electrode, emissive: a filler metal electrode consisting of a core of a bare electrode or a composite electrode to which a very light coating has been applied to produce a stable arc.

electrode, flux-cored: a composite filler metal electrode consisting of a metal tube or other hollow configuration containing ingredients to provide such functions as shielding atmosphere, deoxidation, arc stabilization, and slag formation. Alloying materials may be included in the core. External shielding may or may not be used.

electrode, lightly coated: a filler metal electrode consisting of a metal wire with a light coating applied subsequent to the drawing operation, primarily for stabilizing the arc.

electrode, metal: a filler or nonfiller metal electrode used in arc welding and cutting that consists of a metal wire or rod that has been manufactured by any method and that is either bare or covered.

electrode, metal-cored: a composite filler metal electrode consisting of a metal tube or other hollow configuration containing alloying ingredients. Minor amounts of ingredients providing such functions as arc stabilization and fluxing of oxides may be included. External shielding gas may or may not be used.

electrode, resistance welding: the part of a resistance welding machine through which the welding current and, in most cases, force are applied directly to the workpiece. The electrode may be in the form of a rotating wheel, rotating roll, bar, cylinder, plate, clamp, chuck, or modification thereof.

electrode, stranded: a composite filler metal electrode consisting of stranded wires which may mechanically enclose materials to improve properties, stabilize the arc, or provide shielding.

electrode, tungsten: a nonfiller metal electrode used in arc welding, arc cutting, and plasma spraying, made principally of tungsten.

electrofusion (EF): fusing accomplished by heating polyethylene materials above their melting points using electric elements within a confined space, producing temperatures and pressures necessary to achieve coalescence of the molten polyethylene materials during the cooling phase. Some of the more common terms relating to EF are defined in ASTM F1290 and ASTM F412.

electrofusion manufacturer: the manufacturer of electrofusion fittings.

face feed: the application of filler metal to the face side of a joint.

filler metal: the metal or alloy to be added in making a welded, brazed, or soldered joint.

filler metal, brazing: the metal or alloy used as a filler metal in brazing, which has a liquidus above 840°F (450 °C) and below the solidus of the base metal.

filler metal, powder: filler metal in particle form.

filler metal, supplemental: in electroslag welding or in a welding process in which there is an arc between one or more consumable electrodes and the workpiece, a powder, solid, or composite material that is introduced into the weld other than the consumable electrode(s).

fillet weld: a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint.

flaw: an undesirable discontinuity. See also *defect*.

flux (welding or brazing): a material used to dissolve, prevent, or facilitate the removal of oxides or other undesirable surface substances. It may act to stabilize the arc, shield the molten pool, and may or may not evolve shielding gas by decomposition.

flux cover: metal bath dip brazing and dip soldering. A layer of molten flux over the molten filler metal bath.

flux, active (SAW): a flux from which the amount of elements deposited in the weld metal is dependent upon the welding parameters, primarily arc voltage.

flux, alloy (SAW): a flux which provides alloying elements in the weld metal deposit.

flux, neutral (SAW): a flux which will not cause a significant change in the weld metal composition when there is a large change in the arc voltage.

forehand welding: a welding technique in which the welding torch or gun is directed toward the progress of welding.

frequency: the completed number of cycles which the oscillating head makes in 1 min or other specified time increment.

frictional resistance in the butt-fusing machine: force-opposing movement due to friction in the mechanism of the fusing machine.

fuel gas: a gas such as acetylene, natural gas, hydrogen, propane, stabilized methylacetylene propadiene, and other fuels normally used with oxygen in one of the oxyfuel processes and for heating.

fused spray deposit (thermal spraying): a self-fluxing thermal spray deposit which is subsequently heated to coalescence within itself and with the substrate.

fusing (plastic fusing): the process of producing a fusion joint. Butt, manual butt, electrofusion, and sidewall are the fusing processes addressed in this Code.

fusing gauge pressure: the hydraulic gauge pressure to be observed by the fusing operator when butt fusing or sidewall fusing polyethylene (PE) piping. This is the sum of the theoretical fusing pressure plus the drag pressure.

fusing operator: person trained and qualified to carry out fusing of polyethylene (PE) pipes and/or fittings using a butt-fusing or sidewall-fusing procedure or electrofusion procedure with applicable equipment.

fusing procedure specification: a document providing in detail the required variables for the fusing process to ensure repeatability in the fusing procedure. This generic term includes fusing procedure specifications qualified by testing (FPS), as well as standard fusing procedure specifications (SFPS) or manufacturer qualified electrofusion procedure specifications (MEFPS).

fusion (fusion welding): the melting together of filler metal and base metal, or of base metal only, to produce a weld.

fusion (plastic fusing): the portion of the fusing process involving the coalescence of two plastic members by the combination of controlled heating and the application of pressure approximately normal to the interface between them; the joint produced by plastic fusing.

fusion face: a surface of the base metal that will be melted during welding.

fusion interfacial pressure: the interfacial pressure applied during the fusion phase of the fusing process.

fusion line: a non-standard term for weld interface.

gas backing: see *backing gas*.

globular transfer (arc welding): a type of metal transfer in which molten filler metal is transferred across the arc in large droplets.

groove weld: a weld made in a groove formed within a single member or in the groove between two members to be joined. The standard types of groove weld are as follows:

(a) square groove weld
(b) single-Vee groove weld
(c) single-bevel groove weld
(d) single-U groove weld
(e) single-J groove weld
(f) single-flare-bevel groove weld
(g) single-flare-Vee groove weld
(h) double-Vee groove weld
(i) double-bevel groove weld
(j) double-U groove weld
(k) double-J groove weld
(l) double-flare-bevel groove weld
(m) double-flare-Vee groove weld

header: pipe used as a central connection or a manifold for other piping runs.

heat soak cycle: the portion of the butt-fusing or sidewall-fusing procedure where heat is allowed to soak into the pipes or fittings after the bead-up cycle is complete. The heat soak cycle begins by reducing the pressure to that required to maintain contact with the heater surfaces without force. The pipe ends continue heating until the minimum heat soak time is completed for the pipe wall being joined and the minimum bead size is attained per the standard procedure.

heat soak time: the time required to complete the butt-fusing or sidewall-fusing heat soak cycle.

heater removal (dwell) time: period of time during butt fusing or sidewall fusing from the separation of the pipe or fitting from the heater surface, removal of the heater, and closure of the carriage to bring the molten pipe or fitting surfaces together.

heater temperature: measured temperature on the surface of the heater where the pipe or fitting cross section makes contact during butt fusing or sidewall fusing.

heat-affected zone: that portion of the base metal which has not been melted, but whose mechanical properties or microstructures have been altered by the heat of welding or cutting.

heat soak interfacial pressure: the interfacial pressure applied during the heat soak cycle of the fusing process.

initial heating interfacial pressure: the interfacial pressure applied during the bead-up cycle before the heat soak cycle of the fusing process.

instantaneous energy: as used for waveform controlled welding, the determination of total energy during a time period using the product of current and voltage measurements made at rapid intervals that capture brief changes in the welding waveform.

instantaneous power: as used for waveform controlled welding, the determination of average power using the product of current and voltage measurements made at rapid intervals that capture brief changes in the welding waveform.

integrated backing: base metal that is used to support or contain the weld puddle during its deposition and remains as part of the completed weldment.

interfacial pressure: the amount of force applied per unit area of fusion joint during each phase of the fusing process, including bead-up cycle, heat soak cycle, and fusion. This is used to calculate the fusing machine gauge pressure during each phase. The interfacial pressure is often expressed as a range [example: 60 psi to 90 psi (400 kPa to 600 kPa) for fusion interfacial pressure], and the common practice is to use the mid-range [example: 75 psi (500 kPa)] when making these calculations.

interpass temperature: for multiple-pass welds, the temperature in the previously deposited weld metal or adjacent base metal [typically within 1 in. (25 mm) of the weld deposit] immediately before the next pass is started.

joint: the junction of members or the edges of members which are to be joined or have been joined.

joint penetration: the distance the weld metal extends from the weld face into a joint, exclusive of weld reinforcement.

keyhole welding: a technique in which a concentrated heat source penetrates partially or completely through a workpiece, forming a hole (keyhole) at the leading edge of the weld pool. As the heat source progresses, the molten metal fills in behind the hole to form the weld bead.

lap joint: a joint between two overlapping members in parallel planes.

lap or overlap: the distance measured between the edges of two plates when overlapping to form the joint.

layer: a stratum of weld metal consisting of one or more beads. See Figures QG-109.2.1 and QG-109.2.2.

lower transformation temperature: the temperature at which austenite begins to form during heating.

macro-examination: the process of observing a specimen cross-section by the unaided eye, or at a specified low magnification, with or without the use of smoothing and etching.

Manufacturer Qualified Electrofusion Procedure Specification (MEFPS): an electrofusion fusing procedure specification developed by an electrofusion fitting manufacturer based on standard industry practice in accordance with the Plastics Pipe Institute (PPI) MAB-02 and ASTM F1290, for the electrofusion fitting manufacturer's specific electrofusion joint design, and qualified by the electrofusion fitting manufacturer in accordance with ASTM F1055 to define the ranges for the essential variables identified in QF-253. An MEFPS may be used for production fusing by organizations without further qualification.

material-joining processes: welding, brazing, or plastic-fusing processes, including wire-additive welding and processes used to deposit overlays or cladding.

melt bead size: the width of a bead formed at the interface between the heated pipe surface and the heater surface during the butt-fusing or sidewall-fusing heating cycle.

melt-in: a technique of welding in which the intensity of a concentrated heat source is so adjusted that a weld pass can be produced from filler metal added to the molten weld metal.

metal transfer mode (gas metal-arc welding): the manner in which molten metal travels from the end of a consumable electrode to the workpiece. See also *short-circuiting transfer (gas metal-arc welding)*; *pulsed power welding*; *globular transfer (arc welding)*; *pulsed spray welding*; and *spray transfer (arc welding)*.

nugget: the volume of weld metal formed in a spot, seam, or projection weld.

organization: as used in this Section, an organization is a manufacturer, contractor, assembler, installer, or other entity having responsibility for operational control of the material-joining methods used in the construction of components in accordance with the codes, standards, and specifications which reference this Section.

oscillation: for a machine or automatic process, an alternating motion relative to the direction of travel of welding, brazing, or thermal spray device. See also *weave bead*.

overlay: a non-standard term, used in Section IX, for surfacing. See also *hard-facing* and *corrosion-resistant overlay*.

overlay, corrosion-resistant weld metal: deposition of one or more layers of weld metal to the surface of a base material in an effort to improve the corrosion resistance properties of the surface. This would be applied at a level above the minimum design thickness as a nonstructural component of the overall wall thickness.

overlay, hard-facing weld metal: deposition of one or more layers of weld metal to the surface of a material in an effort to improve the wear resistance properties of the surface. This would be applied at a level above the minimum design thickness as a nonstructural component of the overall wall thickness.

pass: a single progression of a welding or surfacing operation along a joint, weld deposit, or substrate. The result of a pass is a weld bead or layer.

pass, cover: a final or cap pass(es) on the face of a weld.

pass, wash: pass to correct minor surface aberrations and/or prepare the surface for nondestructive testing.

peel test: a destructive method of testing that mechanically separates a lap joint by peeling.

peening: the mechanical working of metals using impact blows.

performance qualification: the demonstration of a welder's or welding operator's ability to produce welds meeting prescribed standards.

plastics:: those materials listed in Table QF-422.

plug weld: a weld made in a circular, or other geometrically shaped hole (like a slot weld) in one member of a lap or tee joint, joining that member to the other. The walls of the hole may or may not be parallel, and the hole may be partially or completely filled with weld metal. (A fillet-welded hole or spot weld should not be construed as conforming to this definition.)

polarity, reverse: the arrangement of direct current arc welding leads with the work as the negative pole and the electrode as the positive pole of the welding arc; a synonym for direct current electrode positive.

polarity, straight: the arrangement of direct current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc; a synonym for direct current electrode negative.

polyethylene (PE): a polyolefin composed of polymers of ethylene.

postbraze heat treatment: any heat treatment subsequent to brazing.

postheating: the application of heat to an assembly after welding, brazing, soldering, thermal spraying, or thermal cutting.

postweld heat treatment: any heat treatment subsequent to welding.

postweld hydrogen bakeout: holding a completed or partially completed weld at elevated temperature below 800°F (425°C) for the purpose of allowing hydrogen diffusion from the weld.

powder: see *filler metal, powder*.

preheat current: an impulse or series of impulses that occurs prior to and is separated from the welding current.

preheat maintenance: practice of maintaining the minimum specified preheat temperature, or some specified higher temperature for some required time interval after welding or thermal spraying is finished or until post weld heat treatment is initiated.

preheat temperature: the minimum temperature in the weld joint preparation immediately prior to the welding; or in the case of multiple pass welds, the minimum temperature in the section of the previously deposited weld metal, immediately prior to welding.

preheating: the application of heat to the base metal immediately before a welding or cutting operation to achieve a specified minimum preheat temperature.

pulsed power welding: an arc welding process variation in which the welding power source is programmed to cycle between low and high power levels.

quality program: a written program or procedure that includes, as a minimum, provisions for ensuring that welding, brazing, and fusing qualifications conform to the requirements of this Section.

rabbet joint: typical design is indicated in Figures QB-462.1(c), QB-462.4, QB-463.1(c), and QB-463.2(a).

retainer: nonconsumable material, metallic or nonmetallic, which is used to contain or shape molten weld metal. See also *backing*.

seal weld: any weld designed primarily to provide a specific degree of tightness against leakage.

seam weld: a continuous weld made between or upon overlapping members in which coalescence may start and occur on the faying surfaces, or may have proceeded from the surface of one member. The continuous weld may consist of a single weld bead or a series of overlapping spot welds. See also *resistance welding*.

short-circuiting transfer (gas metal-arc welding): metal transfer in which molten metal from a consumable electrode is deposited during repeated short circuits. See also *globular transfer* and *spray transfer*.

sidewall fusion (SWF): fusing accomplished by melting the concave surface of the base of a saddle fitting while simultaneously melting a matching pattern on the surface of the main pipe using a contact heater, then removing the heater and bringing the two melted surfaces together under pressure to achieve coalescence of the molten polyethylene materials during the cooling phase. Some of the more common terms relating to sidewall fusion are defined in ASTM F2620.

single-welded joint: a joint welded from one side only.

single-welded lap joint: a lap joint in which the overlapped edges of the members to be joined are welded along the edge of one member only.

slag inclusion: nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

specimen: see *test specimen*.

spot weld: a weld made between or upon overlapping members in which coalescence may start and occur on the faying surfaces or may proceed from the outer surface of one member. The weld cross section (plan view) is approximately circular.

spray transfer (arc welding): metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets.

spray-fuse: a thermal spraying technique in which the deposit is reheated to fuse the particles and form a metallurgical bond with the substrate.

Standard Fusing Procedure Specification (SFPS): a fusing procedure specification that contains acceptable polyethylene (PE) fusing variables based on standard industry practice and testing as defined in ASTM F2620. An SFPS may be used for production fusing by organizations without further qualification. Test results are described in Plastics Pipe Institute (PPI) Technical Reports TR-33 for butt fusing and TR-41 for sidewall fusing.

Standard Welding Procedure Specification (SWPS): a welding procedure specification, published by the American Welding Society, that is made available for production welding by companies or individuals without further qualification, and that may be used in Code applications in accordance with the restrictions and limitations of Article V.

stringer bead: a weld bead formed without appreciable weaving.

surface temper bead reinforcing layer: a subset of temper bead welding in which one or more layers of weld metal are applied on or above the surface layers of a component and are used to modify the properties of previously deposited weld metal or the heat-affected zone. Surface layer may cover a surface or only the perimeter of the weld.

surfacing: the application by welding, brazing, or thermal spraying of a layer(s) of material to a surface to obtain desired properties or dimensions, as opposed to making a joint.

tee joint (T): a joint between two members located approximately at right angles to each other in the form of a T.

temper bead welding: a weld bead placed at a specific location in or at the surface of a weld for the purpose of affecting the metallurgical properties of the heat-affected zone or previously deposited weld metal. The bead may be above, flush with, or below the surrounding base metal surface. If above the base metal surface, the beads may cover all or only part of the weld deposit and may or may not be removed following welding.

test coupon: a weld or braze assembly for procedure or performance qualification testing. The coupon may be any product from plate, pipe, tube, etc., and may be a fillet weld, overlay, deposited weld metal, etc.

test coupon, fusing: a fused plastic test joint that is made to qualify a fusing procedure or fusing operator.

test specimen: a sample of a test coupon for specific test. The specimen may be a bend test, tension test, toughness test, chemical analysis, macrotest, etc. A specimen may be a complete test coupon, for example, in radiographic testing or small diameter pipe tension testing.

theoretical fusing pressure: the pipe area multiplied by the fusion interfacial pressure and divided by the total effective piston area of the butt-fusing machine.

thermal cutting (TC): a group of cutting processes that severs or removes metal by localized melting, burning, or vaporizing of the workpieces.

throat, actual (of fillet): the shortest distance from the root of a fillet weld to its face.

throat, effective (of fillet): the minimum distance from the fillet face, minus any convexity, to the weld root. In the case of fillet welds combined with a groove weld, the weld root of the groove weld shall be used.

throat, theoretical (of fillet): the distance from the beginning of the joint root perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the cross-section of a fillet weld. This dimension is based on the assumption that the root opening is equal to zero.

trailing gas: a gas used to produce a protective atmosphere that extends beyond the weld pool in the direction opposite of travel.

undercut: a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

upper transformation temperature: the temperature at which transformation of the ferrite to austenite is completed during heating.

usability: a measure of the relative ease of application of a filler metal to make a sound weld or braze joint.

waveform controlled welding: A welding process modification of the voltage and/or current wave shape to control characteristics such as droplet shape, penetration, wetting, bead shape or transfer mode(s).

weave bead: for a manual or semiautomatic process, a weld bead formed using weaving. See also *oscillation*.

weaving: a welding technique in which the energy source is oscillated transversely as it progresses along the weld path.

weld: a localized coalescence of metals or nonmetals produced either by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone and with or without the use of filler material.

weld bead: a weld deposit resulting from a pass. See also *stringer bead* and *weave bead*.

weld face: the exposed surface of a weld on the side from which welding was done.

weld interface: the interface between the weld metal and base metal in a fusion weld.

weld metal: metal in a fusion weld consisting of that portion of the base metal and filler metal melted during welding.

weld reinforcement: weld metal on the face or root of a groove weld in excess of the metal necessary for the specified weld size.

weld size: for equal leg fillet welds: the leg lengths of the largest isosceles right triangle which can be inscribed within the fillet weld cross section.

weld size: for unequal leg fillet welds: the leg lengths of the largest right triangle which can be inscribed within the fillet weld cross section.

weld size: groove welds: the depth of chamfering plus any penetration beyond the chamfering, resulting in the strength carrying dimension of the weld.

weld, autogenous: a fusion weld made without filler metal.

welder: one who performs manual or semiautomatic welding.

welding operator: one who operates machine or automatic welding equipment.

welding, arc stud (SW): an arc welding process that uses an arc between a metal stud, or similar part, and the other workpiece. The process is used without filler metal, with or without shielding gas or flux, with or without partial shielding from a ceramic or graphite ferrule surrounding the stud, and with the application of pressure after the faying surfaces are sufficiently heated.

welding, automatic: welding with equipment which performs the welding operation without adjustment of the controls by a welding operator. The equipment may or may not perform the loading and unloading of the work. See also *machine welding*.

welding, consumable guide electroslag: an electroslag welding process variation in which filler metal is supplied by an electrode and its guiding member.

welding, diffusion (DFW): a solid-state welding process producing a weld between multiple layers of sheet or plate by the application of mechanical pressure at elevated temperature with no macroscopic deformation or relative motion of the work pieces. A solid filler metal may be inserted between the faying surfaces.

welding, electrogas (EGW): an arc welding process that uses an arc between a continuous filler metal electrode and the weld pool, employing approximately vertical welding progression with retainers to confine the weld metal. The process is used with or without an externally supplied shielding gas and without the application of pressure. Shielding for use with solid or metal-cored electrodes is obtained from a gas or gas mixture. Shielding for use with flux-cored electrodes may or may not be obtained from an externally supplied gas or gas mixture.

welding, electron beam (EBW): a welding process that produces coalescence with a concentrated beam composed primarily of high-velocity electrons, impinging on the joint. The process is used without shielding gas and without the application of pressure.

welding, electroslag (ESW): a welding process producing coalescence of metals with molten slag which melts the filler metal and the surfaces of the work to be welded. The molten weld pool is shielded by this slag which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc which

heats the slag. The arc is then extinguished and the conductive slag is maintained in a molten condition by its resistance to electric current passing between the electrode and the work. See electroslag welding electrode and consumable guide electroslag welding.

welding, explosion (EXW): a solid-state welding process producing a weld by high-velocity impact of the workpieces as a result of a controlled detonation.

welding, flux-cored arc (FCAW): a gas metal-arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure.

welding, friction (FRW): a solid state welding process that produces a weld under compressive force contact of workpieces rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces.

welding, friction stir (FSW): a variation of friction welding producing a weld by the friction heating and plastic material displacement caused by a rapidly rotating tool traversing the weld joint.

welding, friction, inertia and continuous drive: processes and types of friction welding (solid state welding process) wherein coalescence is produced after heating is obtained from mechanically induced sliding motion between rubbing surfaces held together under pressure. Inertia welding utilizes all of the kinetic energy stored in a revolving flywheel spindle system. Continuous drive friction welding utilizes the energy provided by a continuous drive source such as an electric or hydraulic motor.

welding, gas metal-arc (GMAW): an arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure.

welding, gas metal-arc, pulsed spray (GMAW-P): a variation of the gas metal-arc welding process in which the power is pulsed resulting in transfer of the metal across the arc in spray mode. See also *pulsed power welding*.

welding, gas metal-arc, short-circuiting arc (GMAW-S): a variation of the gas metal-arc welding process in which the consumable electrode is deposited during repeated short circuits. See also *short-circuiting transfer*.

welding, gas tungsten-arc (GTAW): an arc welding process which produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not be used and filler metal may or may not be used. (This process has sometimes been called TIG welding, a nonpreferred term.)

welding, gas tungsten-arc, pulsed arc (GTAW-P): a variation of the gas tungsten-arc welding process in which the current is pulsed. See also *pulsed power welding*.

welding, hybrid: welding in which two or more welding processes are used in the same weld pool.

welding, hybrid, process separation: the distance between each welding process as specified in the WPS.

welding, hybrid, process sequence: the order of each welding process with respect to the direction of travel.

welding, induction (IW): a welding process that produces coalescence of metals by the heat obtained from resistance of the workpieces to the flow of induced high frequency welding current with or without the application of pressure. The effect of the high-frequency welding current is to concentrate the welding heat at the desired location.

welding, laser beam (LBW): a welding process which produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging upon the members to be joined. Welding can be performed by using the melt-in technique [see also *welding, low-power density laser beam (LLBW)*] or by keyhole welding.

welding, low-power density laser beam (LLBW): a variation of the laser beam welding process in which the coherent light beam employs reduced power density, such that coalescence of materials is achieved by conduction (i.e., melt-in) without keyhole welding.

welding, machine: welding with equipment that has controls that can be adjusted by the welding operator, or adjusted under the welding operator's direction, in response to changes in the welding conditions. The torch, gun, or electrode holder is held by a mechanical device. See also *welding, automatic*.

welding, manual: welding wherein the entire welding operation is performed and controlled by hand.

welding, oxyfuel gas (OFW): a group of welding processes which produces coalescence by heating materials with an oxyfuel gas flame or flames, with or without the application of pressure, and with or without the use of filler metal.

welding, plasma-arc (PAW): an arc welding process which produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc), or the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the hot, ionized gas issuing from the torch orifice which may be supplemented by an auxiliary source of shielding gas. Shielding gas may be an inert gas or a mixture of gases. Pressure may or may not be used, and filler metal may or may not be supplied.

welding, projection (PW): a resistance welding process that produces coalescence by the heat obtained from the resistance of the flow of welding current. The resulting welds are localized at predetermined points by

projections, embossments, or intersections. The metals to be joined lap over each other.

welding, resistance (RW): a group of welding processes that produces coalescence of the faying surfaces with the heat obtained from resistance of the workpieces to the flow of the welding current in a circuit of which the workpieces are a part, and by the application of pressure.

welding, resistance seam (RSEW): a resistance welding process that produces a weld at the faying surfaces of overlapped parts progressively along a length of a joint. The weld may be made with overlapping weld nuggets, a continuous weld nugget, or by forging the joint as it is heated to the welding temperature by resistance to the flow of the welding current.

welding, resistance spot (RSW): a resistance welding process that produces a weld at the faying surfaces of a joint by the heat obtained from resistance to the flow of welding current through the workpieces from electrodes that serve to concentrate the welding current and pressure at the weld area.

welding, resistance stud: a resistance welding process wherein coalescence is produced by the heat obtained from resistance to electric current at the interface between the stud and the workpiece, until the surfaces to be joined are properly heated, when they are brought together under pressure.

welding, semiautomatic arc: arc welding with equipment which controls only the filler metal feed. The advance of the welding is manually controlled.

welding, shielded metal-arc (SMAW): an arc welding process with an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering, without the application of pressure, and with filler metal from the electrode.

welding, stud: a general term for the joining of a metal stud or similar part to a workpiece. Welding may be accomplished by arc, resistance, friction, or other suitable process with or without external gas shielding.

welding, submerged-arc (SAW): an arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

weldment: an assembly whose constituent parts are joined by welding, or parts which contain weld metal overlay.

wire-additive welding: the deposition of weld metal using a welding process and wire filler metal to create material either made entirely from weld metal or added to existing material.

Figure QG-109.2.1
Typical Single and Multibead Layers

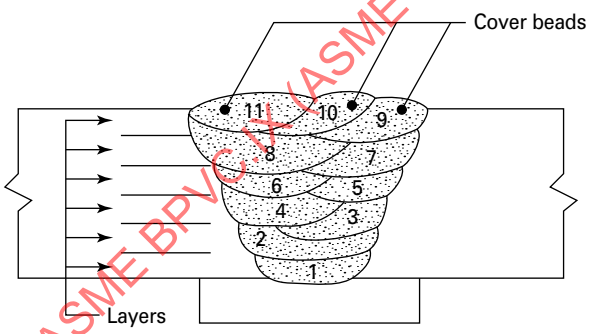
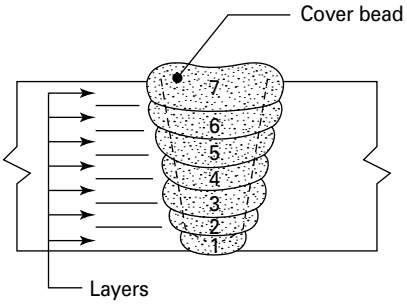


Figure QG-109.2.2
Typical Single Bead Layers



PART QW
WELDING

ARTICLE I
WELDING GENERAL REQUIREMENTS

QW-100 SCOPE

The rules in this Part apply to the preparation of Welding Procedure Specifications (WPS) and the qualification of welding procedures, welders, and welding operators for all types of manual and machine welding processes permitted in this Part. These rules may also be applied, insofar as they are applicable, to other manual or machine welding processes permitted in other Sections.

QW-101 PROCEDURE SPECIFICATION

A WPS used by an organization that will have responsible operational control of production welding shall be a WPS that has been qualified by that organization in accordance with Article II, or it shall be an AWS Standard Welding Procedure Specification (SWPS) listed in Mandatory Appendix E and adopted by that organization in accordance with Article V.

Both WPSs and SWPSs specify the variables (including ranges, if any) under which welding must be performed. These conditions include the base metals that are permitted, the filler metals that must be used (if any), preheat and postweld heat treatment requirements, etc.

A WPS shall address, as a minimum, the specific variables, both essential and nonessential, as provided in Article II for each process to be used in production welding. In addition, when referencing codes, standards, or specifications require toughness qualification of the WPS, the supplementary essential variables must be addressed in the WPS.

When a variable is outside the scope of a WPS (e.g., the variable applies to a P-Number not included on the WPS) or is addressed by another variable (e.g., the AWS Classification specifies the filler metal product form), that variable need not be specifically addressed on the WPS or PQRs that support the WPS.

QW-102 PERFORMANCE QUALIFICATION

In performance qualification, the basic criterion established for welder qualification is to determine the welder's ability to deposit sound weld metal. The purpose of the performance qualification test for the welding operator is to determine the welding operator's mechanical ability to operate the welding equipment.

QW-103 RESPONSIBILITY

QW-103.1 Welding. Each organization shall conduct the tests required in this Section to qualify the welding procedures used in the construction of the weldments built under this Code and the performance of welders and welding operators who apply these procedures.

QW-103.2 Records. Each organization shall maintain a record of the results obtained in welding procedure and welder and welding operator performance qualifications. Refer to recommended Forms in Nonmandatory Appendix B.

QW-110 WELD ORIENTATION

The orientations of welds are illustrated in Figure QW-461.1 or Figure QW-461.2.

QW-120 TEST POSITIONS FOR GROOVE WELDS

Groove welds may be made in test coupons oriented in any of the positions in Figure QW-461.3 or Figure QW-461.4 and as described in the following paragraphs, except that an angular deviation of ±15 deg from the specified horizontal and vertical planes, and an angular deviation of ±5 deg from the specified inclined plane are permitted during welding.

QW-121 PLATE POSITIONS

QW-121.1 Flat Position 1G. Plate in a horizontal plane with the weld metal deposited from above. Refer to Figure QW-461.3, illustration (a).

QW-121.2 Horizontal Position 2G. Plate in a vertical plane with the axis of the weld horizontal. Refer to Figure QW-461.3, illustration (b).

QW-121.3 Vertical Position 3G. Plate in a vertical plane with the axis of the weld vertical. Refer to Figure QW-461.3, illustration (c).

QW-121.4 Overhead Position 4G. Plate in a horizontal plane with the weld metal deposited from underneath. Refer to Figure QW-461.3, illustration (d).

QW-122 PIPE POSITIONS

QW-122.1 Flat Position 1G. Pipe with its axis horizontal and rolled during welding so that the weld metal is deposited from above. Refer to Figure QW-461.4, illustration (a).

QW-122.2 Horizontal Position 2G. Pipe with its axis vertical and the axis of the weld in a horizontal plane. Pipe shall not be rotated during welding. Refer to Figure QW-461.4, illustration (b).

QW-122.3 Multiple Position 5G. Pipe with its axis horizontal and with the welding groove in a vertical plane. Welding shall be done without rotating the pipe. Refer to Figure QW-461.4, illustration (c).

QW-122.4 Multiple Position 6G. Pipe with its axis inclined at 45 deg to horizontal. Welding shall be done without rotating the pipe. Refer to Figure QW-461.4, illustration (d).

QW-123 TEST POSITIONS FOR STUD WELDS

QW-123.1 Stud Welding. Stud welds may be made in test coupons oriented in any of the positions as described in QW-121 for plate and QW-122 for pipe (excluding QW-122.1). In all cases, the stud shall be perpendicular to the surface of the plate or pipe. See Figures QW-461.7 and QW-461.8.

QW-124 SPECIAL POSITIONS

QW-124.1 Test positions other than those defined in QW-120 through QW-123 are defined as "special positions."

QW-130 TEST POSITIONS FOR FILLET WELDS

Fillet welds may be made in test coupons oriented in any of the positions of Figure QW-461.5 or Figure QW-461.6, and as described in the following paragraphs, except that an angular deviation of ±15 deg from the specified horizontal and vertical planes is permitted during welding.

QW-131 PLATE POSITIONS

QW-131.1 Flat Position 1F. Plates so placed that the weld is deposited with its axis horizontal and its throat vertical. Refer to Figure QW-461.5, illustration (a).

QW-131.2 Horizontal Position 2F. Plates so placed that the weld is deposited with its axis horizontal on the upper side of the horizontal surface and against the vertical surface. Refer to Figure QW-461.5, illustration (b).

QW-131.3 Vertical Position 3F. Plates so placed that the weld is deposited with its axis vertical. Refer to Figure QW-461.5, illustration (c).

QW-131.4 Overhead Position 4F. Plates so placed that the weld is deposited with its axis horizontal on the underside of the horizontal surface and against the vertical surface. Refer to Figure QW-461.5, illustration (d).

QW-132 PIPE POSITIONS

QW-132.1 Flat Position 1F. Pipe with its axis inclined at 45 deg to horizontal and rotated during welding so that the weld metal is deposited from above and at the point of deposition the axis of the weld is horizontal and the throat vertical. Refer to Figure QW-461.6, illustration (a).

QW-132.2 Horizontal Positions 2F and 2FR.

(a) Position 2F. Pipe with its axis vertical so that the weld is deposited on the upper side of the horizontal surface and against the vertical surface. The axis of the weld will be horizontal and the pipe is not to be rotated during welding. Refer to Figure QW-461.6, illustration (b).

(b) Position 2FR. Pipe with its axis horizontal and the axis of the deposited weld in the vertical plane. The pipe is rotated during welding. Refer to Figure QW-461.6, illustration (c).

QW-132.3 Overhead Position 4F. Pipe with its axis vertical so that the weld is deposited on the underside of the horizontal surface and against the vertical surface. The axis of the weld will be horizontal and the pipe is not to be rotated during welding. Refer to Figure QW-461.6, illustration (d).

QW-132.4 Multiple Position 5F. Pipe with its axis horizontal and the axis of the deposited weld in the vertical plane. The pipe is not to be rotated during welding. Refer to Figure QW-461.6, illustration (e).

QW-133 SPECIAL POSITIONS

QW-133.1 Test positions other than those defined in QW-130 through QW-132 are defined as "special positions."

QW-140 TYPES AND PURPOSES OF TESTS AND EXAMINATIONS

QW-141 MECHANICAL TESTS

Mechanical tests used in procedure or performance qualification are specified in QW-141.1 through QW-141.5.

QW-141.1 Tension Tests. Tension tests as described in QW-150 are used to determine the ultimate strength of groove-weld joints.

QW-141.2 Guided-Bend Tests. Guided-bend tests as described in QW-160 are used to determine the degree of soundness and ductility of groove-weld joints.

QW-141.3 Fillet-Weld Tests. Tests as described in QW-180 are used to determine the size, contour, and degree of soundness of fillet welds.

QW-141.4 Toughness Tests. Tests as described in QW-171 and QW-172 are used to determine the toughness of the weldment.

QW-141.5 Stud-Weld Test. Deflection bend, hammering, torque, or tension tests as shown in Figures QW-466.4, QW-466.5, and QW-466.6, and a macro-examination performed in accordance with QW-202.5, respectively, are used to determine acceptability of stud welds.

(25) QW-142 VOLUMETRIC EXAMINATION FOR WELDERS

Radiographic or Ultrasonic examination per QW-191 may be substituted for mechanical testing of QW-141 for groove-weld performance qualification as permitted in QW-304 to prove the ability of welders to make sound welds.

(25) QW-143 VOLUMETRIC EXAMINATION FOR WELDING OPERATORS

Radiographic or Ultrasonic examination per QW-191 may be substituted for mechanical testing of QW-141 for groove weld performance qualification as permitted in QW-305 to prove the ability of welding operators to make sound welds.

QW-144 VISUAL EXAMINATION

Visual examination as described in QW-194 is used to determine that the final weld surfaces meet specified quality standards.

QW-150 TENSION TESTS

QW-151 SPECIMENS

Tension test specimens shall conform to one of the types illustrated in Figures QW-462.1(a) through QW-462.1(e) and shall meet the requirements of QW-153.

QW-151.1 Reduced Section — Plate. Reduced-section specimens conforming to the requirements given in Figure QW-462.1(a) may be used for tension tests on all thicknesses of plate.

(a) For thicknesses up to and including 1 in. (25 mm), a full thickness specimen shall be used for each required tension test.

(b) For plate thickness greater than 1 in. (25 mm), full thickness specimens or multiple specimens may be used, provided (c) and (d) are complied with.

(c) When multiple specimens are used, in lieu of full thickness specimens, each set shall represent a single tension test of the full plate thickness. Collectively, all of the specimens required to represent the full thickness of the weld at one location shall comprise a set.

(d) When multiple specimens are necessary, the entire thickness shall be mechanically cut into a minimum number of approximately equal strips of a size that can be tested in the available equipment. Each specimen of the set shall be tested and meet the requirements of QW-153.

QW-151.2 Reduced Section — Pipe. Reduced-section specimens conforming to the requirements given in Figure QW-462.1(b) may be used for tension tests on all thicknesses of pipe having an outside diameter greater than 3 in. (75 mm).

(a) For thicknesses up to and including 1 in. (25 mm), a full thickness specimen shall be used for each required tension test.

(b) For pipe thicknesses greater than 1 in. (25 mm), full thickness specimens or multiple specimens may be used, provided (c) and (d) are complied with.

(c) When multiple specimens are used, in lieu of full thickness specimens, each set shall represent a single tension test of the full pipe thickness. Collectively, all of the specimens required to represent the full thickness of the weld at one location shall comprise a set.

(d) When multiple specimens are necessary, the entire thickness shall be mechanically cut into a minimum number of approximately equal strips of a size that can be tested in the available equipment. Each specimen of the set shall be tested and meet the requirements of QW-153.

For pipe having an outside diameter of 3 in. (75 mm) or less, reduced-section specimens conforming to the requirements given in Figure QW-462.1(c) may be used for tension tests.

QW-151.3 Turned Specimens. Turned specimens conforming to the requirements given in Figure QW-462.1(d) may be used for tension tests.

(a) For thicknesses up to and including 1 in. (25 mm), a single turned specimen may be used for each required tension test, which shall be a specimen of the largest diameter *D* of Figure QW-462.1(d) possible for test coupon thickness [per Note (a) of Figure QW-462.1(d)].

(b) For thicknesses over 1 in. (25 mm), multiple specimens shall be cut through the full thickness of the weld with their centers parallel to the metal surface and not over 1 in. (25 mm) apart. The centers of the specimens adjacent to the metal surfaces shall not exceed $\frac{5}{8}$ in. (16 mm) from the surface.

(c) When multiple specimens are used, each set shall represent a single required tension test. Collectively, all the specimens required to represent the full thickness of the weld at one location shall comprise a set.

(d) Each specimen of the set shall be tested and meet the requirements of QW-153.

QW-151.4 Full-Section Specimens for Pipe. Tension specimens conforming to the dimensions given in Figure QW-462.1(e) may be used for testing pipe with an outside diameter of 3 in. (75 mm) or less.

QW-152 TENSION TEST PROCEDURE

The tension test specimen shall be ruptured under tensile load. The tensile strength shall be computed by dividing the ultimate total load by the least cross-sectional area of the specimen as calculated from actual measurements made before the load is applied.

QW-153 ACCEPTANCE CRITERIA — TENSION TESTS

(25) **QW-153.1 Tensile Strength.** Minimum values for procedure qualification are provided under the column heading "Minimum Specified Tensile, ksi" of Table QW/QB-422. In order to pass the tension test, the specimen shall have a tensile strength that is not less than

(a) the minimum specified tensile strength of the base metal; or

(b) the minimum specified tensile strength of the weaker of the two, if base metals of different minimum tensile strengths are used; or

(c) the minimum specified tensile strength of the weld metal when the referencing code, standard, or specification provides for the use of weld metal having lower room temperature strength than the base metal;

(d) if the specimen breaks in the base metal outside of the weld or weld interface, the test shall be accepted as meeting the requirements, provided the strength is not more than 5% below the minimum specified tensile strength of the base metal.

(e) the specified minimum tensile strength is for full thickness specimens including cladding for Aluminum Alclad materials (P-No. 21 through P-No. 23) less than $\frac{1}{2}$ in. (13 mm). For Aluminum Alclad materials $\frac{1}{2}$ in. (13 mm) and greater, the specified minimum tensile strength is for both full thickness specimens that include cladding and specimens taken from the core.

QW-160 GUIDED-BEND TESTS

QW-161 SPECIMENS

Guided-bend test specimens shall be prepared by cutting the test plate or pipe to form specimens of approximately rectangular cross section. The cut surfaces shall be designated the sides of the specimen. The other two surfaces shall be called the face and root surfaces, the face surface having the greater width of weld. The specimen thickness and bend radius are shown in Figures QW-466.1, QW-466.2, and QW-466.3. For materials with less than 3% elongation, a macro-etch specimen shall be used in lieu of bend test at each bend test location. Acceptance criteria shall be in accordance with QW-183(a). Figure QW-466.3 shows the recommended method of testing aluminum weldments. Guided-bend specimens are of five types, depending on whether the axis of the weld is transverse or parallel to the longitudinal axis of the specimen, and which surface (side, face, or root) is on the convex (outer) side of bent specimen. The five types are defined as follows.

QW-161.1 Transverse Side Bend. The weld is transverse to the longitudinal axis of the specimen, which is bent so that one of the side surfaces becomes the convex surface of the bent specimen. Transverse side-bend test specimens shall conform to the dimensions shown in Figure QW-462.2.

Specimens of base metal thickness equal to or greater than $1\frac{1}{2}$ in. (38 mm) may be cut into approximately equal strips between $\frac{3}{4}$ in. (19 mm) and $1\frac{1}{2}$ in. (38 mm) wide for testing, or the specimens may be bent at full width (see requirements on jig width in Figure QW-466.1). When the width of the weld is so large that a bend specimen cannot be bent so that the entire weld and heat affected zones are within the bent portion, multiple specimens across the entire weld and heat affected zones shall be used.

If multiple specimens are used in either situation above, one complete set shall be made for each required test. Each specimen shall be tested and meet the requirements in QW-163.

QW-161.2 Transverse Face Bend. The weld is transverse to the longitudinal axis of the specimen, which is bent so that the face surface becomes the convex surface of the bent specimen. Transverse face-bend test specimens shall conform to the dimensions shown in Figure QW-462.3(a). For subsize transverse face bends, see QW-161.4.

QW-161.3 Transverse Root Bend. The weld is transverse to the longitudinal axis of the specimen, which is bent so that the root surface becomes the convex surface of the bent specimen. Transverse root-bend test specimens shall conform to the dimensions shown in Figure QW-462.3(a). For subsize transverse root bends, see QW-161.4.

QW-161.4 Subsize Transverse Face and Root Bends. Bend specimens taken from small diameter pipe coupons may be subsized in accordance with General Note (b) of Figure QW-462.3(a).

QW-161.5 Longitudinal-Bend Tests. Longitudinal-bend tests may be used in lieu of the transverse side-bend, face-bend, and root-bend tests for testing weld metal or base metal combinations, which differ markedly in bending properties between

(a) the two base metals, or

(b) the weld metal and the base metal

QW-161.6 Longitudinal Face Bend. The weld is parallel to the longitudinal axis of the specimen, which is bent so that the face surface becomes the convex surface of the bent specimen. Longitudinal face-bend test specimens shall conform to the dimensions shown in Figure QW-462.3(b).

QW-161.7 Longitudinal Root Bend. The weld is parallel to the longitudinal axis of the specimen, which is bent so that the root surface becomes the convex side of the bent specimen. Longitudinal root-bend test specimens shall conform to the dimensions shown in Figure QW-462.3(b).

QW-162 GUIDED-BEND TEST PROCEDURE

QW-162.1 Jigs. Guided-bend specimens shall be bent in test jigs that are in substantial accordance with Figures QW-466.1 through QW-466.3. When using the jigs illustrated in Figure QW-466.1 or Figure QW-466.2, the side of the specimen turned toward the gap of the jig shall be the face for face-bend specimens, the root for root-bend specimens, and the side with the greater discontinuities, if any, for side-bend specimens. The specimen shall be forced into the die by applying load on the plunger until the curvature of the specimen is such that a $\frac{1}{8}$ in. (3 mm) diameter wire cannot be inserted between the specimen and the die of Figure QW-466.1, or the specimen is bottom ejected if the roller type of jig (see Figure QW-466.2) is used.

When using the wrap around jig (see Figure QW-466.3), the side of the specimen turned toward the roller shall be the face for face-bend specimens, the root for root-bend specimens, and the side with the greater discontinuities, if any, for side-bend specimens. The bending is considered complete once the outer roll has moved at least 180 deg from the starting point.

When specimens wider than $1\frac{1}{2}$ in. (38 mm) are to be bent as permitted in Figure QW-462.2, the test jig mandrel must be at least $\frac{1}{4}$ in. (6 mm) wider than the specimen width.

The plunger radius, *B*, shall be no larger than that given in Figure QW-466.1. When a bend specimen is tested from a coupon joining base metals having different *B* values, the larger of the two *B* values may be used.

QW-163 ACCEPTANCE CRITERIA — BEND TESTS (25)

The weld and heat-affected zone of a transverse bend test specimen shall be completely within the bent portion of the test specimen after bending. All bend test specimens shall be visually examined for discontinuities and shall meet the following acceptance criteria:

(a) Groove Welds. No open discontinuity in the weld or heat-affected zone exceeding $\frac{1}{8}$ in. (3 mm) measured in any direction is permitted on the convex surface of the test specimen after bending. Open discontinuities occurring on the corners of the specimen during bend testing shall not be considered unless it is evident that they result from lack of fusion, slag inclusions, or other internal discontinuities.

(b) Corrosion-Resistant Overlay. No open discontinuity exceeding $\frac{1}{16}$ in. (1.5 mm) measured in any direction is permitted on the convex surface of the overlay after bending, and no open discontinuity exceeding $\frac{1}{8}$ in. (3 mm) is permitted along the approximate weld interface.

QW-170 TOUGHNESS TESTS

QW-171 TOUGHNESS TESTS

QW-171.1 General. Toughness tests shall be made when required by referencing codes. Test procedures and apparatus shall conform to the requirements of the referencing code. When not specified by the referencing code, the test procedures and apparatus shall conform to the requirements of SA-370.

QW-171.2 Acceptance. The acceptance criteria shall be in accordance with that Section specifying toughness testing requirements.

QW-171.3 Location and Orientation of Test Specimen. The toughness test specimen removal and preparation requirements shall be as given in the Section requiring such tests.

When qualifying pipe in the 5G or 6G position, the toughness specimens shall be removed from the shaded portion of Figure QW-463.1(f).

QW-172 TOUGHNESS TESTS — DROP WEIGHT

QW-172.1 General. Drop-weight tests shall be made when required by referencing codes. Test procedures and apparatus shall conform to the requirements of

the referencing code. When not specified by the referencing code, the test procedures and apparatus shall conform to the requirements of ASTM specification E208.

QW-172.2 Acceptance. The acceptance criteria shall be in accordance with that Section requiring drop weight tests.

QW-172.3 Location and Orientation of Test Specimen. The drop weight test specimen, the crack starter location, and the orientation shall be as given in the Section requiring such tests.

When qualifying pipe in the 5G or 6G position, the toughness specimens shall be removed from the shaded portion of Figure QW-463.1(f).

QW-180 FILLET-WELD TESTS

QW-181 PROCEDURE AND PERFORMANCE QUALIFICATION SPECIMENS

QW-181.1 Procedure. The dimensions and preparation of the fillet-weld test coupon for procedure qualification as required in QW-202 shall conform to the requirements in Figure QW-462.4(a) or Figure QW-462.4(d). Both sides of the vertical plate shown in Figure QW-462.4(a) shall be welded. The test coupon for plate-to-plate shall be cut transversely to provide five test specimen sections, each approximately 2 in. (50 mm) long. For pipe-to-plate or pipe-to-pipe, the test coupon shall be cut transversely to provide four approximately equal test specimen sections. The test specimens shall be macro-examined to the requirements of QW-183.

QW-181.1.1 Production Assembly Mockups. Production assembly mockups may be used in lieu of QW-181.1. When a production assembly mockup is used, the range qualified shall be limited to the base metal thickness, fillet weld size, and configuration of the mockup. Alternatively, multiple production assembly mockups may be qualified. The range of thicknesses of the base metal qualified shall be not less than the thickness of the thinner member tested and not greater than the thickness of the thicker member tested. The range for fillet weld sizes qualified shall be limited to no less than the smallest fillet weld tested and no greater than the largest fillet weld tested. The configuration of production assemblies shall be the same as that used in the production assembly mockup. The mockups for plate-to-shape shall be cut transversely to provide five approximately equal test specimens not to exceed approximately 2 in. (50 mm) in length. For pipe-to-shape mockups, the mockup shall be cut transversely to provide four approximately equal test specimens. For small mockups, multiple mockups may be required to obtain the required number of test specimens. The test specimens shall be macro-examined to the requirements of QW-183.

QW-181.2 Performance. The dimensions and the preparation of the fillet-weld test coupon for performance qualification shall conform to the requirements in Figure QW-462.4(b) or Figure QW-462.4(c). The test coupon for plate-to-plate shall be cut transversely to provide a center section approximately 4 in. (100 mm) long and two end sections, each approximately 1 in. (25 mm) long. For pipe-to-plate or pipe-to-pipe, the test coupon shall be cut to provide two quarter sections test specimens opposite to each other. One of the test specimens shall be fracture tested in accordance with QW-182 and the other macro-examined to the requirements of QW-184. When qualifying pipe-to-plate or pipe-to-pipe in the 5F position, the test specimens shall be removed as indicated in Figure QW-463.2(h).

QW-181.2.1 Production Assembly Mockups. Production assembly mockups may be used in lieu of the fillet-weld test coupon requirements of QW-181.2. When production assembly mockups are used, the range qualified shall be limited to the fillet sizes, base metal thicknesses, and configuration of the mockup.

(a) Plate-to-Shape. The mockup for plate-to-shape shall be cut transversely to provide three approximately equal test specimens not to exceed approximately 2 in. (50 mm) in length. The test specimen that contains the start and stop of the weld shall be fracture tested in accordance with QW-182. A cut end of one of the remaining test specimens shall be macro-examined in accordance with QW-184.

(b) Pipe-to-Shape. The mockup for pipe-to-shape shall be cut transversely to provide two quarter sections approximately opposite to each other. The test specimen that contains the start and stop of the weld shall be fracture tested in accordance with QW-182. A cut end of the other quarter section shall be macro-examined in accordance with QW-184. When qualifying pipe-to-shape in the 5F position, the fracture specimen shall be removed from the lower 90-deg section of the mockup.

QW-182 FRACTURE TESTS

The stem of the 4 in. (100 mm) performance specimen center section in Figure QW-462.4(b) or the stem of the quarter section in Figure QW-462.4(c), as applicable, shall be loaded laterally in such a way that the root of the weld is in tension. The load shall be steadily increased until the specimen fractures or bends flat upon itself.

If the specimen fractures, the fractured surface shall show no evidence of cracks or incomplete root fusion, and the sum of the lengths of inclusions and porosity visible on the fractured surface shall not exceed $^{3}/_{8}$ in. (10 mm) in Figure QW-462.4(b) or 10% of the quarter section in Figure QW-462.4(c).

QW-183 MACRO-EXAMINATION — PROCEDURE SPECIMENS

One face of each cross section of the five test specimens in Figure QW-462.4(a) or four test specimens in Figure QW-462.4(d), as applicable shall be smoothed and etched with a suitable etchant (see QW-470) to give a clear definition to the weld metal and heat-affected zone. The examination of the cross sections shall include only one side of the test specimen at the area where the plate or pipe is divided into sections i.e., adjacent faces at the cut shall not be used. In order to pass the test

(a) visual examination of the cross sections of the weld metal and heat-affected zone shall show complete fusion and freedom from cracks

(b) there shall be not more than $\frac{1}{8}$ in. (3 mm) difference in the length of the legs of the fillet

QW-184 MACRO-EXAMINATION — PERFORMANCE SPECIMENS

The cut end of one of the end plate sections, approximately 1 in. (25 mm) long, in Figure QW-462.4(b) or the cut end of one of the pipe quarter sections in Figure QW-462.4(c), as applicable, shall be smoothed and etched with a suitable etchant (see QW-470) to give a clear definition of the weld metal and heat-affected zone. Visual examination of the cross section of the weld metal and heat-affected zone shall reveal

(a) no incomplete fusion

(b) no cracks

(c) no other linear indications with a length greater than $\frac{1}{32}$ in. (0.8 mm)

(d) no concavity or convexity greater than $\frac{1}{16}$ in. (1.5 mm)

(e) no more than $\frac{1}{8}$-in. (3-mm) difference between the fillet weld leg lengths

QW-185 DIFFUSION WELDING — PROCEDURE AND PERFORMANCE QUALIFICATION SPECIMENS

QW-185.1 The test block shall be a minimum of 8 in. × 8 in. (200 mm × 200 mm) and of a thickness such that there are at least 50 interface planes being welded.

QW-185.2 A minimum of three tension test specimens in accordance with the requirements of SA-370 shall be taken perpendicular to the interface planes and three parallel to the interface planes. The tension test results shall comply with QW-153.

(25) **QW-185.3** Microstructural evaluation shall be conducted in accordance with the requirements of ASTM E3 on a minimum of three cross-sections, one each from the top, center, and bottom one-third of the test coupon. Each cross section shall measure $\frac{1}{2}$ in. × $\frac{1}{2}$ in. (13 mm × 13 mm) minimum. The cross sections shall be polished, etched, and examined at 50X to 100X magnification. The samples shall exhibit no cracks or incomplete bond. Where bond lines exhibit porosity, three bond lines on each sample shall be evaluated at 500X magnification. A minimum of three randomly selected fields shall be evaluated on each bond line. Each field shall include a minimum of 200 μm of the bond line. The average pore density along the three bond lines for each sample shall be determined using the following formula:

$$\text{pore density (\%)} = \frac{\text{average pore size (μm) x number of pores in the examination length x 100}}{\text{examination length}}$$

The average pore density for each examined bond line shall not be greater than 26%.

QW-190 OTHER TESTS AND EXAMINATIONS

QW-191 VOLUMETRIC NDE

QW-191.1 Radiographic Examination.

QW-191.1.1 Method. The radiographic examination in QW-142 for welders and in QW-143 for welding operators shall meet the requirements of Section V, Article 2, except as follows:

(a) A written radiographic examination procedure is not required. Demonstration of image quality requirements on production or technique radiographs shall be considered satisfactory evidence of compliance with Section V, Article 2.

(b) Final acceptance of radiographs shall be based on the ability to see the prescribed image and the specified hole of a hole-type image quality indicator (IQI) or the designated wire of a wire-type IQI. The acceptance standards of QW-191.1.2 shall be met.

QW-191.1.2 Acceptance Criteria.

QW-191.1.2.1 Terminology.

(a) Linear Indications. Cracks, incomplete fusion, inadequate penetration, and slag are represented on the radiograph as linear indications in which the length is more than three times the width.

(b) Rounded Indications. Porosity and inclusions such as slag or tungsten are represented on the radiograph as rounded indications with a length three times the width or less. These indications may be circular, elliptical, or irregular in shape; may have tails; and may vary in density.

(c) Thickness. The term "thickness" or "*t*" refers to the thickness of the weld excluding any allowable reinforcement. For a groove weld joining two base metals having different thicknesses at the weld, thickness is the thinner of the two base metals being joined.

QW-191.1.2.2 Qualification Test Welds. Weld reinforcement may be removed or left in place but shall not be considered when determining the thickness for which the welder is qualified.

Welder and welding operator performance tests by radiography of welds in test assemblies shall be judged unacceptable when the radiograph exhibits any imperfections in excess of the limits specified below

(a) Linear Indications

(1) any type of indication characterized as a crack or zone of incomplete fusion or penetration

(2) any other elongated indication that has a length greater than

(-a) $\frac{1}{8}$ in. (3 mm) for t up to $\frac{3}{8}$ in. (10 mm), inclusive

(-b) $\frac{1}{3}t$ for t greater than $\frac{3}{8}$ in. to $2\frac{1}{4}$ in. (10 mm to 57 mm), inclusive

(-c) $\frac{3}{4}$ in. (19 mm) for t greater than $2\frac{1}{4}$ in. (57 mm)

(3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group

(b) Rounded Indications

(1) Relevant Indications. Only those rounded indications that exceed the following dimensions shall be considered relevant:

(-a) $\frac{1}{10}t$ for t less than $\frac{1}{8}$ in. (3 mm)

(-b) $\frac{1}{64}$ in. (0.4 mm) for t equal to $\frac{1}{8}$ in. to $\frac{1}{4}$ in. (3 mm to 6 mm), inclusive

(-c) $\frac{1}{32}$ in. (0.8 mm) for t greater than $\frac{1}{4}$ in. to 2 in. (6 mm to 50 mm), inclusive

(-d) $\frac{1}{16}$ in. (1.5 mm) for t greater than 2 in. (50 mm)

(2) Maximum Size of Rounded Indications

(-a) The maximum permissible dimension for rounded indications shall be 20% of t or $\frac{1}{8}$ in. (3 mm), whichever is smaller.

(-b) For welds in material less than $\frac{1}{8}$ in. (3 mm) in thickness, the maximum number of acceptable rounded indications shall not exceed 12 in a 6 in. (150 mm) length of weld. A proportionately fewer number of rounded indications shall be permitted in welds less than 6 in. (150 mm) in length.

(-c) For welds in material $\frac{1}{8}$ in. (3 mm) or greater in thickness, the charts in Figure QW-191.1.2.2(b)(4) represent the maximum acceptable types of rounded indications illustrated in typically clustered, assorted, and randomly dispersed configurations.

QW-191.1.2.3 Production Welds. The acceptance criteria for welders or welding operators who qualify on production welds by radiography as permitted in QW-304.1 or QW-305.1 shall be per QW-191.1.2.2

QW-191.2 Ultrasonic Examination

QW-191.2.1 Method

(a) The ultrasonic examination in QW-142 for welders and in QW-143 for welding operators may be conducted on test welds in material $\frac{1}{4}$ in. (6 mm) thick or greater.

(b) Ultrasonic examinations shall be performed using a written procedure in compliance with Section V, Article 1, T-150 and the requirements of Section V, Article 4 for methods and procedures.

(c) For terminology, see QW-191.1.2.1.

QW-191.2.2 Acceptance Criteria for Qualification Test Welds. Weld reinforcement may be removed or left in place but shall not be considered when determining the deposited weld thickness for which the welder is qualified.

Indications shall be sized using the applicable technique(s) provided in the written procedure for the examination method. Indications shall be evaluated for acceptance as follows:

(a) All indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

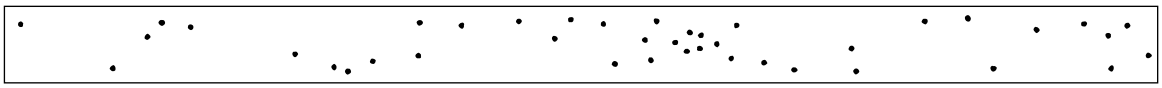
(b) Indications exceeding $\frac{1}{8}$ in. (3 mm) in length are considered relevant, and are unacceptable when their lengths exceed

(1) $\frac{1}{8}$ in. (3 mm) for thicknesses up to $\frac{3}{8}$ in. (10 mm), inclusive

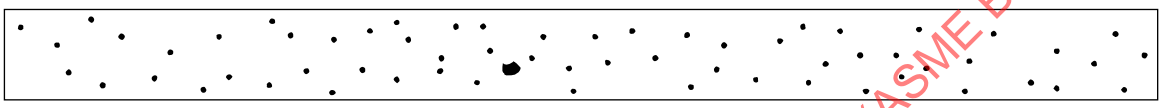
(2) $\frac{1}{3}$ the thickness for thicknesses greater than $\frac{3}{8}$ in. up to $2\frac{1}{4}$ in. (10 mm to 57 mm), inclusive

(3) $\frac{3}{4}$ in. (19 mm) for thicknesses greater than $2\frac{1}{4}$ in. (57 mm)

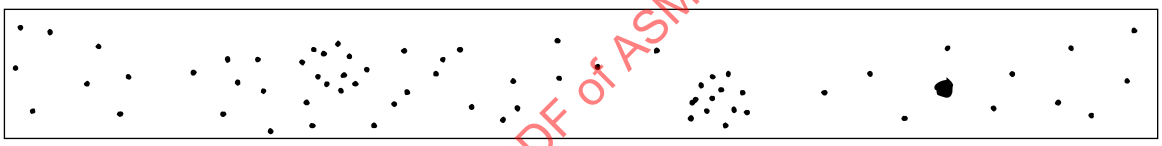
Figure QW-191.1.2.2(b)(4)
Rounded Indication Charts



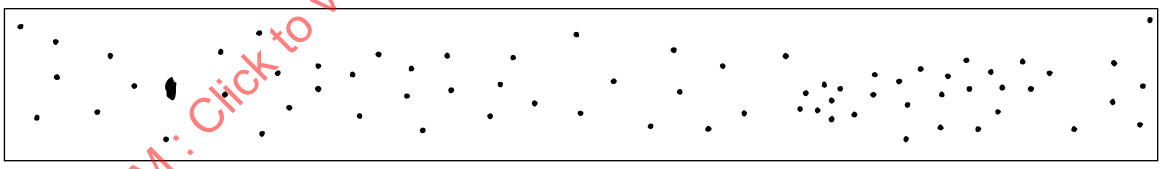
Typical Quantity and Size Permitted in 6 in. (150 mm) Length of Weld $^{1}/_{8}$ in. (3 mm) to $^{1}/_{4}$ in. (6 mm) Thickness



Typical Quantity and Size Permitted in 6 in. (150 mm) Length of Weld Over $^{1}/_{4}$ in. (6 mm) to $^{1}/_{2}$ in. (13 mm) Thickness



Typical Quantity and Size Permitted in 6 in. (150 mm) Length of Weld Over $^{1}/_{2}$ in. (13 mm) to 1 in. (25 mm) Thickness



Typical Quantity and Size Permitted in 6 in. (150 mm) Length of Weld Over 1 in. (25 mm) Thickness

QW-191.2.3 Acceptance Criteria for Production Welds. The acceptance criteria for welders or welding operators who qualify on production welds by ultrasonic examination as permitted in QW-304.1 or QW-305.1 shall be per QW-191.2.2.

QW-191.3 Record of Tests. The results of welder and welding operator performance tests evaluated by volumetric NDE shall be recorded in accordance with QW-301.4.

(25) **QW-191.4 Personnel Qualifications and Certifications.** Personnel performing volumetric examinations shall be qualified and certified following their employer's written practice, which shall meet the requirements of the current edition of Section V, Article 1.

Alternatively, when an organization is working to a code, standard, or specification that specifies personnel qualification to an earlier edition of Section V or to another national or international standard, personnel who examine test coupons and production welds may be qualified and certified according to the requirements of that national or international standard or the earlier edition of Section V.

QW-192 STUD-WELD TESTS

QW-192.1 Procedure Qualification Specimens.

QW-192.1.1 Required Tests. Ten stud-weld tests are required to qualify each procedure. The equipment used for stud welding shall be completely automatic except for manual starting.

Every other welding stud (five joints) shall be tested either by hammering over until one-fourth of its length is flat on the test piece, or by bending the stud to an angle of at least 15 deg and returning it to its original position using a test jig and an adapter location dimension that are in accordance with Figure QW-466.4.

The remaining five welded stud joints shall be tested in torque using a torque testing arrangement that is substantially in accordance with Figure QW-466.5. Alternatively, where torquing is not feasible, tensile testing may be used, and the fixture for tensile testing shall be similar to that shown in Figure QW-466.6, except that studs without heads may be gripped on the unwelded end in the jaws of the tensile testing machine.

QW-192.1.2 Acceptance Criteria — Bend and Hammer Tests. In order to pass the test(s), each of the five stud welds and heat-affected zones shall be free of visible separation or fracture after bending and return bending or after hammering.

QW-192.1.3 Acceptance Criteria — Torque Tests. In order to pass the test(s), each of the five stud welds shall be subjected to the required torque shown in the following table before failure occurs:

Required Torque for Testing Threaded Carbon Steel Studs

Nominal Diameter of Studs, in. (mm)	Threads/in. and Series Designated	Testing Torque, ft-lb (J)
1/4 (6.4)	28 UNF	5.0 (6.8)
1/4 (6.4)	20 UNC	4.2 (5.7)
5/16 (7.9)	24 UNF	9.5 (12.9)
5/16 (7.9)	18 UNC	8.6 (11.7)
3/8 (9.5)	24 UNF	17 (23.0)
3/8 (9.5)	16 UNC	15 (20.3)
7/16 (11.1)	20 UNF	27 (36.6)
7/16 (11.1)	14 UNC	24 (32.5)
1/2 (12.7)	20 UNF	42 (57.0)
1/2 (12.7)	13 UNC	37 (50.2)
9/16 (14.3)	18 UNF	60 (81.4)
9/16 (14.3)	12 UNC	54 (73.2)
5/8 (15.9)	18 UNF	84 (114.0)
5/8 (15.9)	11 UNC	74 (100.0)
3/4 (19.0)	16 UNF	147 (200.0)
3/4 (19.0)	10 UNC	132 (180.0)
7/8 (22.2)	14 UNF	234 (320.0)
7/8 (22.2)	9 UNC	212 (285.0)
1 (25.4)	12 UNF	348 (470.0)
1 (25.4)	8 UNC	318 (430.0)

Required Torque for Testing Threaded Austenitic Stainless Steel Studs

Nominal Diameter of Studs, in. (mm)	Threads/in. and Series Designated	Testing Torque, ft-lb (J)
1/4 (6.4)	28 UNF	4.5 (6.1)
1/4 (6.4)	20 UNC	4.0 (5.4)
5/16 (7.9)	24 UNF	9.0 (12.2)
5/16 (7.9)	18 UNC	8.0 (10.8)
3/8 (9.5)	24 UNF	16.5 (22.4)
3/8 (9.5)	16 UNC	14.5 (19.7)
7/16 (11.1)	20 UNF	26.0 (35.3)
7/16 (11.1)	14 UNC	23.0 (31.2)
1/2 (12.7)	20 UNF	40.0 (54.2)
1/2 (12.7)	13 UNC	35.5 (48.1)
5/8 (15.9)	18 UNF	80.00 (108.5)
5/8 (15.9)	11 UNC	71.00 (96.3)
3/4 (19.0)	16 UNF	140.00 (189.8)
3/4 (19.0)	10 UNC	125.00 (169.5)

Table continued

Required Torque for Testing Threaded Austenitic Stainless Steel Studs

Nominal Diameter of Studs, in. (mm)	Threads/in. and Series Designated	Testing Torque, ft-lb (J)
7/8 (22.2)	14 UNF	223.00 (302.3)
7/8 (22.2)	9 UNC	202.00 (273.9)
1 (25.4)	14 UNF	339.00 (459.6)
1 (25.4)	8 UNC	303.00 (410.8)

Alternatively, where torquing to destruction is not feasible, tensile testing may be used. For carbon and austenitic stainless steel studs, the failure strength shall be not less than 35,000 psi (240 MPa) and 30,000 psi (210 MPa), respectively. For other metals, the failure strength shall not be less than half of the minimum specified tensile strength of the stud material. The failure strength shall be based on the minor diameter of the threaded section of externally threaded studs, except where the shank diameter is less than the minor diameter, or on the original cross-sectional area where failure occurs in a nonthreaded, internally threaded, or reduced-diameter stud.

QW-192.1.4 Macro-Examination. In order to pass the macro-examination, each of the five sectioned specimens shall be smoothed and etched with a suitable etchant (see QW-470) to give clear definition of the stud welds and the heat-affected zones. The welds and heat-affected zones shall be free of cracks when examined at 10X magnification.

QW-192.2 Performance Qualification Specimens.

QW-192.2.1 Required Tests. Five stud-weld tests are required to qualify each stud-welding operator. The equipment used for stud welding shall be completely automatic except for manual starting. The performance test shall be welded in accordance with a qualified WPS per QW-301.2.

Each stud (five joints) shall be tested either by hammering over until one-fourth of its length is flat on the test piece or by bending the stud to an angle of at least 15 deg and returning it to its original position using a test jig and an adapter location dimension that are in accordance with Figure QW-466.4.

QW-192.2.2 Acceptance Criteria — Bend and Hammer Tests. In order to pass the test(s), each of the five stud welds and heat affected zones shall be free of visible separation or fracture after bending and return bending or after hammering.

QW-193 TUBE-TO-TUBESHEET TESTS

When the applicable Code Section requires the use of this paragraph for tube-to-tubesheet demonstration mockup qualification, QW-193.1 through QW-193.1.3 shall apply.

QW-193.1 Procedure Qualification Specimens. Ten (25) mockup welds are required for qualifying each tube-to-tubesheet welding procedure. The mockup assembly shall essentially duplicate the tube-to-tubesheet weld joint design to be used in production, within the limits of the essential variables of QW-288. The mockup test assembly shall be prepared with the tubesheet element having a thickness not less than the lesser of the thickness of the production tubesheet or 2 in. (50 mm). For tube-to-tubesheet welds to clad tubesheets, the cladding or overlay may be represented by a base material with a chemical composition that is essentially equivalent to the cladding composition. All welds and heat-affected zones in the mockup assembly shall be subjected to the following tests and shall meet the applicable acceptance criteria.

QW-193.1.1 Visual Examination. The accessible surfaces of the welds and heat-affected zones shall be examined visually with no magnification required. The welds shall show complete fusion, be free from visual cracks or porosity indications, and have no evidence of burning through the tube wall.

QW-193.1.2 Liquid Penetrant. The liquid penetrant examination shall meet the requirements of Section V, Article 6. The weld and heat-affected zone surfaces shall meet the requirements of QW-195.2. Liquid penetrant examiners shall meet the requirements in QW-195.3.

QW-193.1.3 Macro-Examination. The mockup welds shall be sectioned through the center of the tube for macro-examination. The four exposed surfaces shall be smoothed and etched with a suitable etchant (see QW-470) to give a clear definition of the weld and heat-affected zone. Using a magnification of 10X to 20X, the exposed cross sections of the weld and heat-affected zone shall confirm

(a) minimum leak path dimension required by the design

(b) no cracking

(c) complete fusion of the weld deposit into the tubesheet and tube wall face

QW-193.2 Performance Qualification Specimens. A minimum of five mockup tube-to-tubesheet welds are required to qualify each welder or welding operator. The same rules as those applicable for procedure qualification (see QW-193.1) shall be followed, with the following additional requirements and exceptions:

(a) The essential variables in QW-387 shall apply.

(b) Essential performance qualification variables applicable for each welding process listed in QW-350 or QW-360 shall also be observed in addition to the variables of Table QW-388.

(c) Postweld heat treatment may be omitted.

Only one mockup weld is required to renew a welder's or welding operator's qualification when that qualification has expired or has been revoked per the requirements of QW-322.

QW-194 VISUAL EXAMINATION — PERFORMANCE

Performance test coupons shall show no cracks and complete joint penetration with complete fusion of weld metal and base metal.

QW-195 LIQUID PENETRANT EXAMINATION

QW-195.1 The liquid penetrant examination in QW-214 for corrosion-resistant weld metal overlay shall meet the requirements of Section V, Article 6. The liquid penetrant examiners shall meet the requirements in QW-195.3. The acceptance standards of QW-195.2 shall be met.

QW-195.2 Liquid Penetrant Acceptance Criteria.

QW-195.2.1 Terminology.

relevant indications: indications with major dimensions greater than $^{1}/_{16}$ in. (1.5 mm)

linear indications: an indication having a length greater than three times the width.

rounded indications: an indication of circular or elliptical shape with the length equal to or less than three times the width.

QW-195.2.2 Acceptance Standards. Procedure and performance tests examined by liquid penetrant techniques shall be judged unacceptable when the examination exhibits any indication in excess of the limits specified in the following:

(a) relevant linear indications

(b) relevant rounded indications greater than $^{3}/_{16}$ in. (5 mm)

(c) four or more relevant rounded indications in a line separated by $^{1}/_{16}$ in. (1.5 mm) or less (edge-to-edge)

QW-195.3 Personnel Certification. The organization shall certify that personnel performing liquid penetrant examinations meet the following minimum requirements:

(a) The personnel shall have vision, with correction if necessary, to enable the reading of a Jaeger Type No. 2 Standard Chart at a distance of not less than 12 in. (300 mm). They shall also be capable of distinguishing and differentiating contrast between colors used. These requirements shall be checked annually.

(b) The personnel shall be competent in the techniques of the liquid penetrant examination method for which they are certified. This includes making the examination and interpreting and evaluating the results. Where the examination method consists of more than one operation, the examiner may be certified as being qualified for only one operation or for multiple operations.

QW-196 RESISTANCE WELD TESTING

QW-196.1 Macro-Examination.

QW-196.1.1 Welds shall be cross-sectioned, polished, and etched to reveal the weld metal. The section shall be examined at 10X magnification. Seam welding specimens shall be prepared as shown in Figure QW-462.7.3. The sectioned weldment shall be free of cracks, incomplete penetration, expulsions, and inclusions. Porosity shall not exceed one void in the transverse cross section or three voids in the longitudinal cross section of a specimen. The maximum dimension of any void shall not exceed 10% of the thickness of the weld bead.

QW-196.1.2 For spot and seam welds, the minimum diameter or width of the weld nugget shall be as follows in relation to thickness, *T*, of the thinner member.

Material Thickness, *T*, in. (mm)	Weld Nugget Width
<0.010 (0.25)	6*T*
≥0.010 (0.25) and <0.020 (0.50)	5*T*
≥0.020 (0.50) and <0.040 (1.00)	4*T*
≥0.040 (1.00) and <0.069 (1.75)	3*T*
≥0.069 (1.75) and <0.100 (2.54)	2.50*T*
≥0.100 (2.54) and <0.118 (3.00)	2.25*T*
≥0.118 (3.00) and <0.157 (4.00)	2*T*
≥0.157 (4.00)	1.80*T*

The weld depth (extent of fusion) shall be a minimum of 20% of the thickness of the thinner ply (in each member) and a maximum of 80% of the total thickness of all plies.

QW-196.1.3 For projection welds, the width of the nugget shall be not less than 80% of the width of the projection.

QW-196.2 Mechanical Testing.

QW-196.2.1 Shear test specimens shall be prepared as shown on Figure QW-462.9. For spot and projection welds, each test specimen shall produce a strength that, when calculated according to the following equation, is no less than that specified in Table QW/QB-422 for the weaker of the two base metals joined:

$$\text{strength} = \frac{\text{load to failure}}{\text{area of the nugget}}$$

where the area of the nugget = $\pi \times d^2/4$ and d equals the minimum diameter of the spot or projection weld at the faying surface. The diameter shall be no less than that specified in the table in QW-196.1.2 for the thinner of the two members joined.

QW-196.2.2 Peel test specimens shall be prepared as shown in Figure QW-462.8.1 for spot and projection welding and per Figure QW-462.8.2 for seam welding. The specimens shall be peeled or separated mechanically, and fracture shall occur in the base metal by tearing out of the weld in order for the specimen to be acceptable.

QW-197 LASER BEAM WELDING (LBW) LAP JOINT TESTS

QW-197.1 Procedure Qualification Specimens.

QW-197.1.1 Required Tests. Six tension shear specimens and eight macro specimens are required to qualify each procedure. The qualification test coupon shall be prepared in accordance with Figure QW-464.1. The tension shear specimens shall conform to the dimensions indicated in the table of Figure QW-464.1. The longitudinal and transverse sections indicated in Figure QW-464.1 shall be cross-sectioned as closely as possible through the centerline of the weld. A minimum of 1 in. (25 mm) shall be provided for examination of each longitudinal specimen. The transverse specimens shall be of sufficient length to include weld, the heat-affected zone, and portions of the unaffected base material. Cross-sections shall be smoothed and etched with a suitable etchant (see QW-470), and examined at a minimum magnification of 25X. The dimensions of the fusion zone and penetration of each weld of the transverse specimens shall be measured to the nearest hundredth of an inch and recorded.

QW-197.1.2 Acceptance Criteria — Tension Shear Tests. In order to pass the tension shear test(s), the requirements of QW-153 shall apply.

QW-197.1.3 Acceptance Criteria — Macro-Examination. In order to pass the macro-examination, each of the eight specimens shall meet the following criteria:

(a) The outline of the fusion zone shall be generally consistent in size and regular in shape and uniformity of penetration.

(b) The examination of the weld area shall reveal sound weld metal, complete fusion along the bond line, and complete freedom from cracks in the weld metal and heat-affected zone.

QW-197.2 Performance Qualification Specimens.

QW-197.2.1 Required Tests. A peel test specimen at least 6 in. (150 mm) long shall be prepared as shown in Figure QW-464.2 illustration (a) and macro specimens as shown in Figure QW-464.2 illustration (b). The peel test specimens shall be peeled apart to destruction and the fusion zone and penetration measured to the nearest hundredth of an inch. The end of each strip of the macro coupon shall be polished and etched to clearly reveal the weld metal. The width and depth of penetration of each weld shall be measured to the nearest hundredth of an inch. Each specimen shall be examined in accordance with QW-197.1.

QW-197.2.2 Acceptance Criteria — Peel Test and Macro-Examination. In order to pass the peel test and macro-examination, the dimensions of the fusion zone (averaged) and the penetration (averaged) shall be within the range of dimensions of those specified on the WPS that was used to make the test coupon.

QW-199 FLASH WELDING

QW-199.1 Procedure Qualification Test Coupons and Testing.

QW-199.1.1 Test Coupon Preparation. For coupons NPS 1 (DN 25) and smaller, four test welds shall be made, and for pipes over NPS 1 (DN 25), three test coupons shall be made using one set of welding parameters (i.e., the same equipment, base metals, joint preparation, and other essential variables to be utilized for production welding.) These variables shall be recorded on the qualification record.

QW-199.1.2 Tensile Tests. For pipes NPS 1 (DN 25) and smaller, and nontubular cross sections, two full-section tensile specimens shall be prepared in accordance with Figure QW-462.1(e). For pipes greater than NPS 1 (DN 25), two reduced section tension specimens shall be prepared in accordance with Figure QW-462.1(b) or Figure QW-462.1(c) from one coupon. For nontubular cross sections, two reduced section tension specimens shall be prepared in accordance with Figure QW-462.1(a) or Figure QW-462.1(d) from two of the coupons. The specimens shall be tested in accordance with QW-150.

QW-199.1.3 Section and Bend Testing. The entire circumference of each remaining pipe coupon shall be cut along the axis of the pipe into an even number of strips of a length sufficient to perform bend tests. The maximum width of each strip shall be $1^1/_2$ in. (38 mm) and the minimum width

$$w = T + D/4 \text{ for pipes NPS 2 (DN 50) and smaller}$$

$$w = T + D/8 \text{ for pipes greater than NPS 2 (DN 50)}$$

where

D = OD of the tube

T = nominal wall thickness
w = width of the specimen

One edge of one strip from each coupon shall be polished to a 600 grit finish with the final grinding parallel to the long axis of the strip. The polished surface shall be examined at 5X magnification. No incomplete fusion or other open flaws on the polished surface are acceptable. Defects occurring in the base metal not associated with the weld may be disregarded. For nontubular cross sections, four side-bend specimens shall be prepared from the two remaining coupons as specified in Figure QW-462.2 and polished for examination.

All flash shall be removed from the strips and the welds shall be visually examined per QW-194. Half of the strips from each pipe specimen shall then be prepared as root bend specimens and the remaining strips shall be prepared as face bend specimens in accordance with QW-160. The specimens shall be tested in accordance with QW-160, except for the following:

(a) For P-No. 1, Groups 2 through 4 materials, the minimum bend radius (dimension B in Figure QW-466.1) shall be three times the thickness of the specimen.

(b) In lieu of QW-163, the sum of lengths of individual open flaws on the convex surface of all the bend test specimens taken from each pipe individually shall not exceed 5% of the outside circumference of that test pipe.

QW-199.2 Flash Welding — Performance Qualification Test Coupons and Testing. One test coupon shall be welded, cut into strips, visually examined, and bend tested in accordance with QW-199.1.3. Polishing and examination of a cross-section is not required.

APPENDIX I
ROUNDED INDICATION CHARTS

(25)

DELETED

ARTICLE II
WELDING PROCEDURE QUALIFICATIONS

QW-200 GENERAL

QW-200.1 A Welding Procedure Specification is defined as follows:

(a) Welding Procedure Specification (WPS). A WPS is a written qualified welding procedure prepared to provide direction for making production welds to Code requirements. The WPS or other documents may be used to provide direction to the welder or welding operator to assure compliance with the Code requirements.

(b) Contents of the WPS. The completed WPS shall describe all the essential, nonessential, and, when required, supplementary essential variables for each welding process used in the WPS. These variables are listed for each process in QW-250 and are defined in Article IV, Welding Data.

The WPS shall reference the supporting Procedure Qualification Record(s) (PQR) described in QW-200.2. The WPS may include any other information that might be helpful in making a welding joint.

(c) Changes to the WPS. Changes may be made in the nonessential variables of a WPS to suit production requirements without requalification provided such changes are documented with respect to the essential, nonessential, and, when required, supplementary essential variables for each process. This may be by amendment to the WPS or by use of a new WPS.

Changes in essential or supplementary essential variables require requalification of the WPS (i.e., new or additional PQRs to support the change in essential or supplementary essential variables).

(d) Format of the WPS. The information required to be in the WPS may be in any format, written or tabular, to fit the needs of each organization, as long as every essential, nonessential, and, when required, supplementary essential variables outlined in QW-250 is included or referenced.

Form QW-482 (see Nonmandatory Appendix B) has been provided as a guide for the WPS. This Form includes the required data for the SMAW, SAW, GMAW, and GTAW processes. It is only a guide and does not list all required data for other processes. It also lists some variables that do not apply to all processes (e.g., listing shielding gas which is not required for SAW). The guide does not easily lend itself to multiple process procedure specification (e.g., GTAW root with SMAW fill).

QW-200.2 A Procedure Qualification Record is defined as follows:

(a) Procedure Qualification Record (PQR). The PQR is a record of variables recorded during the welding of the test coupons. It also contains the test results of the tested specimens. Recorded variables normally fall within a small range of the actual variables that will be used in production welding.

(b) Contents of the PQR. The completed PQR shall document all essential and, when required, supplementary essential variables of QW-250 for each welding process used during the welding of the test coupon. Nonessential or other variables used during the welding of the test coupon may be recorded at the organization's option. All variables, if recorded, shall be the actual variables (including ranges) used during the welding of the test coupon. If variables are not monitored during welding, they shall not be recorded. It is not intended that the full range or the extreme of a given range of variables to be used in production be used during qualification unless required due to a specific essential or, when required, supplementary essential variable.

The PQR shall be certified accurate by the organization. The organization may not subcontract the certification function. This certification is intended to be the organization's verification that the information in the PQR is a true record of the variables that were used during the welding of the test coupon and that the resulting tensile, bend, or macro (as required) test results are in compliance with Section IX.

One or more combinations of welding processes, filler metal, and other variables may be used when welding a test coupon. The approximate thickness of weld metal deposited, excluding weld reinforcement, shall be recorded for each set of essential and, when required, supplementary essential variables. Weld metal deposited using each set of variables shall be included in the tension, bend, toughness, and other mechanical test specimens that are required.

(c) Changes to the PQR. Changes to the PQR are not permitted except as described below. Editorial corrections or addenda to the PQR are permitted. An example of an editorial correction is an incorrect P-Number, F-Number, or A-Number that was assigned to a particular base metal or filler metal. An example of an addendum would be a change resulting from a

Code change. For example, Section IX may assign a new F-Number to a filler metal or adopt a new filler metal under an established F-Number. This may permit, depending on the particular construction Code requirements, an organization to use other filler metals that fall within that particular F-Number where, prior to the Code revision, the organization was limited to the particular electrode classification that was used during qualification. Additional information can be incorporated into a PQR at a later date provided the information is substantiated as having been part of the original qualification condition by lab record or similar data.

All changes to a PQR require recertification (including date) by the organization.

(d) Format of the PQR. Form QW-483 (see Nonmandatory Appendix B) has been provided as a guide for the PQR. The information required to be in the PQR may be in any format to fit the needs of each organization. Every essential and, when required, supplementary essential variable described in QW-250 shall be included in the PQR. Also, the type of tests, number of tests, and test results shall be listed in the PQR.

Form QW-483 does not easily lend itself to cover combinations of welding processes or more than one F-Number filler metal in one test coupon. Additional sketches or information may be attached or referenced to record the required variables.

(e) Availability of the PQR. The PQR shall be available for review but need not be made available to the welder or welding operator.

(f) Multiple WPSs With One PQR or Multiple PQRs With One WPS. Several WPSs may be prepared from the data on a single PQR (e.g., a 1G plate PQR may support WPSs for the F, V, H, and O positions on plate or pipe within all other essential variables). A single WPS may cover several sets of essential variable ranges as long as a supporting PQR exists for each essential and, when required, supplementary essential variable [e.g., a single WPS may cover a thickness range from $\frac{1}{16}$ in. (1.5 mm) through $1\frac{1}{4}$ in. (32 mm) if PQRs exist for both the $\frac{1}{16}$ in. (1.5 mm) through $\frac{3}{16}$ in. (5 mm) and $\frac{3}{16}$ in. (5 mm) through $1\frac{1}{4}$ in. (32 mm) thickness ranges].

QW-200.3 To reduce the number of welding procedure qualifications required, P-Numbers are assigned to base metals dependent on characteristics such as composition, weldability, and mechanical properties, where this can logically be done; and for steel and steel alloys (see Table QW/QB-422) Group Numbers are assigned additionally to P-Numbers. These Group Numbers classify the metals within P-Numbers for the purpose of procedure qualification where toughness requirements are specified. The assignments do not imply that base metals may be indiscriminately substituted for a base metal which was used in the qualification test without consideration of the compatibility from the standpoint of metallurgical properties, postweld heat treatment, design, mechanical properties, and service requirements. Where toughness is a consideration, it is presupposed that the base metals meet the specific requirements.

In general, toughness requirements are mandatory for all P-No. 11 quenched and tempered metals, for low temperature applications of other metals as applied to Section VIII, and for various classes of construction required by Section III. Acceptance criteria for the toughness tests are as established in the other Sections of the Code.

QW-200.4 Combination of Welding Procedures.

(a) More than one WPS having different essential, supplementary essential, or nonessential variables may be used in a single production joint. Each WPS may include one or a combination of processes, filler metals, or other variables. These provisions also apply to special process WPSs as defined in QW-251.4.

Where more than one WPS specifying different processes, filler metals, or other essential or supplementary essential variables is used, QW-451 or Table QW-453, as applicable, shall be used to determine the range of base metal thickness and maximum weld metal thickness qualified for each process, filler metal, or set of variables, and those limits shall be observed.

When following a WPS that has more than one welding process, filler metal, or set of variables, each process, filler metal, or set of variables may be used individually or in different combinations, provided

(1) the essential, nonessential, and required supplementary essential variables associated with the process, filler metal, or set of variables are applied

(2) the base metal and deposited weld metal thickness limits of QW-451 or Table QW-453, as applicable, for each process, filler metal, or set of variables are applied

(b) As an alternative to (a), a production weld may be made using a WPS that is supported by more than one PQR, provided the following conditions are met:

(1) All PQRs were qualified

(-a) with GTAW, SMAW, GMAW, FCAW, PAW, LBW, LLBW, or SAW, or combinations of these processes

(-b) on test coupons at least $\frac{1}{2}$ in. (13 mm) thick

(2) Note (1) of Tables QW-451.1 and QW-451.2 shall apply to the WPS. The WPS may be used to deposit

(-a) root layers with the process or combinations of processes on one PQR for weld metal deposits up to $2t$

(-b) fill layers with the process(es) on the other PQR(s) on base metal up to the maximum thickness qualified by the other PQR(s)

QW-201 ORGANIZATIONAL RESPONSIBILITY

The organization shall certify that they have qualified each Welding Procedure Specification, performed the procedure qualification test, and documented it with the necessary Procedure Qualification Record (PQR).

QW-202 TYPE OF TESTS REQUIRED

QW-202.1 Mechanical Tests. The type and number of test specimens that shall be tested to qualify a groove weld procedure are given in QW-451, and shall be removed in a manner similar to that shown in Figures QW-463.1(a) through QW-463.1(f). If any test specimen required by QW-451 fails to meet the applicable acceptance criteria, the test coupon shall be considered as failed.

When it can be determined that the cause of failure is not related to welding parameters, another test coupon may be welded using identical welding parameters.

Alternatively, if adequate material of the original test coupon exists, additional test specimens may be removed as close as practicable to the original specimen location to replace the failed test specimens.

When it has been determined that the test failure was caused by an essential or supplementary essential variable, a new test coupon may be welded with appropriate changes to the variable(s) that was determined to cause the test failure. If the new test passes, the essential and supplementary essential variables shall be documented on the PQR.

When it is determined that the test failure was caused by one or more welding related factors other than essential or supplementary essential variables, a new test coupon may be welded with the appropriate changes to the welding related factors that were determined to cause the test failure. If the new test passes, the welding related factors that were determined to cause the previous test failure shall be addressed by the organization to ensure that the required properties are achieved in the production weldment.

Where qualification is for fillet welds only, the requirements are given in QW-202.2(c); and where qualification is for stud welds only, the requirements are given in QW-202.5.

(25) **QW-202.2 Groove and Fillet Welds.**

(a) Qualification for Groove Full Penetration Welds. Groove-weld test coupons shall qualify the thickness ranges of both base metal and deposited weld metal to be used in production. The qualified thickness ranges of both base metal and deposited weld metal shall be defined by the welding process variables in QW-250. The thickness, *t*, of deposited weld metal in QW-451 shall be exclusive of weld reinforcement. WPS qualification for groove welds shall be made on groove welds using tension and guided-bend specimens. Toughness tests shall be made when required by other Section(s) of the Code. The WPS shall be qualified for use with groove welds within the range of essential variables listed.

When dissimilar thickness test coupons are welded, the qualified thickness range of each base metal shall be determined individually for each base metal in the test coupon. When the thicker test coupon is tapered to provide a thickness transition at the weld, the qualified range shall be based on the base metal thickness adjacent to the toe of the weld at the thinnest end of the transition. The test specimens for tensile and bend tests may be machined to the thickness required for the thinner base metal prior to testing.

(b) Qualification for Partial Penetration Groove Welds. Partial penetration groove welds shall be qualified for both base metal and deposited weld metal thickness as defined by the welding process variables in QW-250, except there is no upper limit on the qualified base metal thickness when the test coupon has a nominal thickness of $1\frac{1}{2}$ in. (38 mm) or more. When dissimilar thickness test coupons are welded, the provisions of (a) for dissimilar thickness test coupons shall be met.

(c) Qualification for Fillet Welds. WPS qualification for fillet welds shall be made on groove-weld test coupons using test specimens specified in (a) or (b). These qualifications may be used for welding all thicknesses of base metal for all sizes of fillet welds, and all diameters of pipe or tube in accordance with Table QW-451.4. Non-pressure-retaining fillet welds, as defined in other Sections of the Code, may as an alternate be qualified with fillet weld qualification tests. Tests shall be made in accordance with QW-180. Limits of qualification shall be in accordance with Table QW-451.3.

QW-202.3 Weld Repair and Buildup. WPS qualified on groove welds shall be applicable for repairs made by welding and for weld metal buildup under the following conditions: (25)

(a) There is no limitation on the thickness of base metal or deposited weld metal for fillet welds.

(b) For other than fillet welds, the thickness range for base metal and deposited weld metal for each welding process shall be in accordance with QW-451, except there need be no upper limit on the base metal thickness provided qualification was made on base metal having a thickness of $1\frac{1}{2}$ in. (38 mm) or more.

QW-202.4 Dissimilar Base Metal Thicknesses. WPS qualified on groove welds shall be applicable for production welds between dissimilar base metal thicknesses provided: (25)

(a) the thickness of the thinner member shall be within the range permitted by QW-451

(b) the thickness of the thicker member shall be as follows:

(1) For P-No. 8, P-No. 41, P-No. 42, P-No. 43, P-No. 44, P-No. 45, P-No. 46, P-No. 51, P-No. 52, P-No. 53, P-No. 54, P-No. 61, P-No. 62, and P-No. 81 metal, there shall be no limitation on the maximum thickness of the thicker production member provided qualification was made on base metal having a thickness of $\frac{1}{4}$ in. (6 mm) or greater.

(2) For all other metal, the thickness of the thicker member shall be within the range permitted by QW-451, except there need be no limitation on the maximum thickness of the thicker production member provided qualification was made on base metal having a thickness of 1½ in. (38 mm) or more.

More than one procedure qualification may be required to qualify for some dissimilar thickness combinations.

QW-202.5 Stud Welding. Procedure qualification tests for stud welds shall be made in accordance with QW-192. The procedure qualification tests shall qualify the welding procedures for use within the range of the essential variables of Table QW-261. Except for studs used for extended heating surfaces and studs welded to P-No. 1 metals, five additional welds shall be made and subjected to a macrotest in accordance with QW-192.1.4

QW-202.6 Tube-to-Tubesheet Qualification. When the applicable Code Section requires the use of QW-193 for tube-to-tubesheet demonstration mockup qualification tests, QW-193.1 shall apply. If specific qualification test requirements are not specified by the applicable Code Section, tube-to-tubesheet welds shall be qualified with one of the following methods:

(a) groove welds per the requirements of QW-202.2 and QW-202.4

(b) a demonstration mockup per the requirements of QW-193.1

(c) fillet welds per the requirements of QW-202.2(c) (for non-pressure-retaining tube-to-tubesheet welds only)

QW-203 LIMITS OF QUALIFIED POSITIONS FOR PROCEDURES

Unless specifically required otherwise by the welding variables (see QW-250), a qualification in any position qualifies the procedure for all positions. The welding process and electrodes must be suitable for use in the positions permitted by the WPS. A welder or welding operator making and passing the WPS qualification test is qualified for the position tested (see QW-303).

QW-210 PREPARATION OF TEST COUPON

QW-211 BASE METAL

The base metals may consist of either plate, pipe, or other product forms. Qualification in plate also qualifies for pipe welding and vice versa. The dimensions of the test coupon shall be sufficient to provide the required test specimens.

QW-211.1 A weld metal overlay deposited on the base metal following a qualified WPS may be considered as the same P-Number as any base metal having a nominally matching chemical analysis.

QW-212 TYPE AND DIMENSIONS OF GROOVE WELDS

Except as otherwise provided in QW-250, the type and dimensions of the welding groove are not essential variables.

QW-214 CORROSION-RESISTANT WELD METAL OVERLAY

QW-214.1 The size of test coupons, limits of qualification, required examinations and tests, and test specimens shall be as specified in QW-214.2 and Table QW-453.

QW-214.2 The qualification test coupon for procedure qualification shall consist of base metal not less than 6 in. (150 mm) × 6 in. (150 mm). The weld overlay cladding shall be a minimum of 1½ in. (38 mm) wide by approximately 6 in. (150 mm) long. For qualification on pipe, the pipe length shall be a minimum of 6 in. (150 mm) and the diameter shall be the minimum needed to allow the required number of test specimens. The weld overlay shall be continuous around the circumference of the test coupon.

(a) The corrosion-resistant surface shall be examined by the liquid penetrant method and shall meet the requirements specified in QW-195.

(b) Following the liquid penetrant examination, four guided side-bend tests shall be made from the test coupon in accordance with QW-161. The test specimens shall be cut so that there are either two specimens parallel and two specimens perpendicular to the direction of the welding, or four specimens perpendicular to the direction of the welding. For coupons that are less than ⅜ in. (10 mm) thick, the width of the side-bend specimens may be reduced to the thickness of the test coupon. The side-bend specimens shall be removed from locations specified in Figure QW-462.5(c) or Figure QW-462.5(d).

(c) When a chemical composition is specified in the WPS, chemical analysis specimens shall be removed at locations specified in Figure QW-462.5(b) or Figure QW-462.5(e). The chemical analysis shall be performed in accordance with Figure QW-462.5(a) and shall be within the range specified in the WPS. This chemical analysis is not required when a chemical composition is not specified on the WPS.

QW-214.3 Essential variables shall be as specified in QW-250 for the applicable welding process.

QW-215 ELECTRON BEAM WELDING, LASER BEAM WELDING, AND LOW-POWER DENSITY LASER BEAM WELDING

QW-215.1 For electron beam welding and laser beam welding (excluding low-power density laser beam welding), the WPS qualification test coupon shall be prepared with the joint geometry duplicating that to be used in production. If the production weld is to

include a lap-over (completing the weld by rewelding over the starting area of the weld, as for a girth weld), such lap-over shall be included in the WPS qualification test coupon.

QW-215.2 The mechanical testing requirements of QW-451 shall apply.

QW-215.3 Essential variables shall be as specified in Tables QW-260, QW-264, and QW-264.2 for the applicable welding process.

(25) **QW-215.4** A laser beam WPS or electron beam WPS previously qualified in accordance with QW-215.1 through QW-215.3 for groove welds may be further qualified for depositing partial-penetration groove welds provided the following conditions are met:

(a) The partial-penetration groove welds are deposited in P-No. 8, P-No. 41, P-No. 42, P-No. 43, P-No. 44, P-No. 45, P-No. 46, P-No. 51, P-No. 52, P-No. 53, P-No. 54, P-No. 61, P-No. 62, or P-No. 81 metals or any combination of these metals.

(b) A workmanship test coupon is prepared following the previously qualified WPS, with the following exceptions:

(1) The workmanship test coupon shall consist of production parts joined by a partial-penetration groove weld with a joint geometry and dimensions falling within the specified tolerances of the production weld.

(2) For electron beam welding, the following variables may be revised from those given in the previously qualified WPS: QW-402.6, QW-404.1, QW-404.8 (change in amount only), QW-409.6, QW-409.7, and QW-410.7.

(3) For laser beam welding, the following variables may be revised from those given in the previously qualified WPS: QW-402.26, QW-403.3, QW-404.8 (change in amount only), QW-408.12, QW-409.21, QW-410.7, QW-410.14, QW-410.37, QW-410.66, and QW-410.80.

(c) A minimum of four cross sections of the partial-penetration groove weld in each workmanship test coupon shall be sectioned, polished, and etched with a suitable etchant to reveal the weld and heat-affected zone (see QW-470). If the workmanship test coupon includes a lap-over, then one of the cross sections shall be taken from that location.

(d) The workmanship test coupon shall be acceptable when the weld and heat-affected zones of each cross section exhibit complete fusion and are free of cracks when visually examined at 10X magnification. Any indications $\frac{1}{32}$ in. (0.8 mm) in length at the root of the weld may be disregarded. The depth of penetration of each cross section shall be measured to within 0.01 in. (0.3 mm) and shall meet the specified production requirements.

(e) A workmanship PQR shall be prepared to document the workmanship test and shall include the information listed in (1) through (4).

(1) the essential variables observed when preparing the workmanship test coupon

(2) the geometric configuration and dimensions of the production parts at the weld joint

(3) a photomicrograph of at least one cross section

(4) the observed depth of weld-joint penetration, measured to within 0.01 in. (0.3 mm), for all four cross sections

(f) A workmanship WPS shall be prepared based on the workmanship PQR and shall include the information listed in (1) through (4).

(1) reference to the previously qualified groove-weld PQR and the workmanship PQR

(2) the essential variable ranges based on the observed and recorded information on the workmanship PQR

(3) the geometric configuration and dimensions of the production parts to be welded

(4) the minimum required depth of weld penetration

(g) When more than one workmanship PQR has been developed to address different configurations of the production parts, a separate workmanship WPS shall be prepared for each of the production configurations to be welded.

QW-216 HARD-FACING WELD METAL OVERLAY

Hard-facing weld metal overlay refers to weld deposits made, using a variety of processes, to deter the effects of wear and/or abrasion. The requirements specified in QW-216.1 through QW-216.5 apply regardless of which hard-facing process is used.

QW-216.1 The size of test coupons, limits of qualification, required examinations and tests, and test specimens shall be as specified in Table QW-453.

QW-216.2 The test base metal coupon for procedure qualification shall have minimum dimensions of 6 in. (150 mm) wide × approximately 6 in. (150 mm) long with a hard-faced layer a minimum of $1\frac{1}{2}$ in. (38 mm) wide × 6 in. (150 mm) long. The minimum hard-faced thickness shall be as specified in the WPS. Alternatively, the qualification may be performed on a test base metal coupon that represents the size of the production part. For qualification on pipe, the pipe length shall be 6 in. (150 mm) minimum and the diameter shall be the minimum needed to allow the required number of test specimens. The weld overlay shall be continuous around the circumference of the test coupon.

(a) The hard-facing surface shall be examined by the liquid penetrant method and shall meet the acceptance standards in QW-195.2 or as specified in the WPS. Liquid penetrant examiners shall meet the requirements in QW-195.3. Surface conditioning prior to liquid penetrant examination is permitted.

(b) After surface conditioning to the minimum thickness specified in the WPS, a minimum of three hardness readings shall be made on each of the specimens from the locations shown in Figure QW-462.5(b) or Figure

QW-462.5(e). All readings shall meet the requirements of the WPS.

(c) The base metal shall be sectioned transversely to the direction of the hard-facing overlay. The two faces of the hard facing exposed by sectioning shall be polished and etched with a suitable etchant and shall be visually examined with 5X magnification for cracks in the base metal or the heat-affected zone, lack of fusion, or other linear defects. The overlay and base metal shall meet the requirements specified in the WPS. All exposed faces shall be examined. See Figure QW-462.5(b) for pipe and Figure QW-462.5(e) for plate.

(d) When a chemical composition is specified in the WPS, chemical analysis specimens shall be removed at locations specified in Figure QW-462.5(b) or Figure QW-462.5(e). The chemical analysis shall be performed in accordance with Figure QW-462.5(a) and shall be within the range specified in the WPS. This chemical analysis is not required when a chemical composition is not specified on the WPS.

QW-216.3 Welding variables shall be as specified in QW-250 for the applicable process.

QW-216.4 Where Spray Fuse methods of hard facing (e.g., Oxyfuel and Plasma Arc) are to be used, the coupons for these methods shall be prepared and welding variables applied in accordance with QW-216.1 and QW-216.3, respectively.

QW-216.5 If a weld deposit is to be used under a hard-facing weld metal overlay, a base metal with an assigned P-Number and a chemical analysis nominally matching the weld deposit chemical analysis may be substituted to qualify the PQR.

QW-217 JOINING OF CLAD MATERIALS

The WPS for groove welds in clad metal shall be qualified by method A [see (a)] when any part of the cladding thickness, as permitted by the referencing Code Section, is included in the design calculations. Either method A [see (a)] or method B [see (b)] may be used when the cladding thickness is not included in the design calculations.

(a) Method A.

(1) The essential and nonessential variables of QW-250 shall apply for each welding process used in production.

(2) The clad material (base metal with cladding) procedure qualification test coupon shall be made using the same P-Number or unassigned base metal, cladding (major alloying elements nominal chemical composition), welding process(es), and filler metal combinations to be specified in the WPS.

(3) The qualified thickness range for the base metals (P-Number or unassigned base metal and cladding) and filler metal(s) used to weld each material shall be based on the actual test coupon thickness for each material (base metal and cladding) as applied to QW-451, except that the minimum thickness of filler metal joining the cladding portion of the weldment shall be based on a chemical analysis performed in accordance with QW-216.2(d).

(4) The groove weld tension and side-bend test specimens (only type bend specimens permitted for this method) and number required by QW-451 shall contain as much of the full thickness base metal and cladding thickness in the tested portion of the specimens as possible.

(5) The acceptance criteria for tensile tests shall be based on the tensile strength of the P-Number or unassigned base metal applied to the full thickness of the test coupon to the requirements of QW-151.1(a), QW-151.1(b), or QW-151.1(c), unless specified otherwise by the applicable Construction Code.

(6) The bend test requirements and acceptance criteria for side-bend specimens shall be according to QW-162 and QW-163. For the side-bend specimens, the bond line between the original cladding and base metal may be disregarded when evaluating the tested bend specimens if the cladding was applied by a process other than fusion welding.

(b) Method B.

(1) The essential and nonessential variables of QW-250 shall apply for each welding process used in production for joining the base metal portion of the weldment. The PQRs that support this portion of the WPS need not be based on test coupons made with clad metal. For the corrosion-resistant overlay portion of the weld, the essential variables of QW-251.4 shall apply and the test coupon and testing shall be in accordance with Table QW-453. The WPS shall limit the depth of the groove, which will receive the corrosion-resistant overlay in order to ensure development of the full strength of the underlying weld in the base metal.

(2) For qualification of single-sided joints in which cladding is located at the root area, separate qualification for base metal and cladding according to QW-202.2 may be performed. Alternatively, qualification using clad material may be made according to rules in method A with the following exceptions:

(-a) The qualified thickness range for the base metals (P-Number or unassigned base metal and cladding) and filler metals used to weld each material shall be based on the actual test coupon thickness for each material (base metal and cladding) as applied to QW-451.

(-b) The tensile specimens shall not contain the clad portion of the test coupon.

(-c) The acceptance criteria for the tensile test shall be based on the tensile strength of the P-Number or the unassigned base metal.

(-d) The chemical analysis, if required, shall be performed in accordance with QW-216.2(d).

(-e) The variables of QW-250 apply to the base metal, cladding, and filler metal.