

Specification for the Design of Welded Joints in Machinery and Equipment



American Welding Society®



AWS D14.4/D14.4M:2012
An American National Standard

Approved by the
American National Standards Institute
April 18, 2012

Specification for the Design of Welded Joints in Machinery and Equipment

4th Edition

Supersedes AWS D14.4/D14.4M:2005

Prepared by the
American Welding Society (AWS) D14 Committee Machinery and Equipment

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This specification establishes common acceptance criteria for classifying and applying carbon and low-alloy steel welded joints used in the manufacture of machines and equipment. It also covers weld joint design, workmanship, quality control requirements and procedures, welding operator and welding procedure qualification, weld joint inspection (visual, radiographic, ultrasonic, magnetic particle, liquid penetrant), repair of weld defects, and heat treatment.



American Welding Society®

8669 Doral Blvd., Doral, FL 33166

International Standard Book Number: 978-0-87171-812-9
American Welding Society
8669 Doral Blvd., Doral, FL 33166
© 2012 by American Welding Society
All rights reserved
Printed in the United States of America

Photocopy Rights. No portion of this standard may be reproduced, stored in a retrieval system, or transmitted in any form, including mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright owner.

Authorization to photocopy items for internal, personal, or educational classroom use only or the internal, personal, or educational classroom use only of specific clients is granted by the American Welding Society provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, tel: (978) 750-8400; Internet: <www.copyright.com>.

Statement on the Use of American Welding Society Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society (AWS) are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute (ANSI). When AWS American National Standards are either incorporated in, or made part of, documents that are included in federal or state laws and regulations, or the regulations of other governmental bodies, their provisions carry the full legal authority of the statute. In such cases, any changes in those AWS standards must be approved by the governmental body having statutory jurisdiction before they can become a part of those laws and regulations. In all cases, these standards carry the full legal authority of the contract or other document that invokes the AWS standards. Where this contractual relationship exists, changes in or deviations from requirements of an AWS standard must be by agreement between the contracting parties.

AWS American National Standards are developed through a consensus standards development process that brings together volunteers representing varied viewpoints and interests to achieve consensus. While the AWS administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its standards.

AWS disclaims liability for any injury to persons or to property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this standard. AWS also makes no guarantee or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this standard available, AWS is neither undertaking to render professional or other services for or on behalf of any person or entity, nor is AWS undertaking to perform any duty owed by any person or entity to someone else. Anyone using these documents should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. It is assumed that the use of this standard and its provisions is entrusted to appropriately qualified and competent personnel.

This standard may be superseded by the issuance of new editions. This standard may also be corrected through publication of amendments or errata. It may also be supplemented by publication of addenda. Information on the latest editions of AWS standards including amendments, errata, and addenda are posted on the AWS web page (www.aws.org). Users should ensure that they have the latest edition, amendments, errata, and addenda.

Publication of this standard does not authorize infringement of any patent or trade name. Users of this standard accept any and all liabilities for infringement of any patent or trade name items. AWS disclaims liability for the infringement of any patent or product trade name resulting from the use of this standard.

The AWS does not monitor, police, or enforce compliance with this standard, nor does it have the power to do so.

On occasion, text, tables, or figures are printed incorrectly, constituting errata. Such errata, when discovered, are posted on the AWS web page (www.aws.org).

Official interpretations of any of the technical requirements of this standard may only be obtained by sending a request, in writing, to the appropriate technical committee. Such requests should be addressed to the American Welding Society, Attention: Managing Director, Technical Services Division, 8669 Doral Blvd., Doral, FL 33166 (see Annex C). With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. These opinions are offered solely as a convenience to users of this standard, and they do not constitute professional advice. Such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

This standard is subject to revision at any time by the AWS D14 Committee on Machinery and Equipment. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are required and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D14 Committee on Machinery and Equipment and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS D14 Committee on Machinery and Equipment to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

This page is intentionally blank.

Personnel

AWS D14 Committee on Machinery and Equipment

T. J. Landon, Chair	<i>Chicago Bridge & Iron Company</i>
L. L. Schweinegruber, 1st Vice Chair	<i>Consultant</i>
B. K. Banzhaf, 2nd Vice Chair	<i>CNH America LLC</i>
M. Rubin, Secretary	<i>American Welding Society</i>
D. B. Ashley	<i>Hartford Steam Boiler</i>
T. J. Bruno	<i>Link-Belt Construction Equipment Company</i>
J. E. Campbell	<i>WeldTech Solutions Corporation</i>
D. J. Landon	<i>Vermeer Manufacturing Company</i>
R. Larsen	<i>John Deere</i>
A. P. Mortale	<i>Deere & Company</i>
J. D. Splike	<i>Rosenboom Machine & Tool, Incorporated</i>
W. A. Svekric	<i>Welding Consultants, Incorporated</i>
J. L. Warren	<i>CNH America LLC</i>
E. G. Yevick	<i>Weld-Met International Group</i>

Advisors to the AWS D14 Committee on Machinery and Equipment

M. D. Bell	<i>Preventive Metallurgy</i>
P. Collins	<i>WeldCon Engineering</i>
R. T. Hemzacek	<i>Consultant</i>
B. D. Horn	<i>Consultant</i>
D. J. Malito	<i>Girard Machine Company, Incorporated</i>
M. R. Malito	<i>Girard Machine Company, Incorporated</i>
D. C. Martinez	<i>Consultant</i>
H. W. Mishler	<i>Consultant</i>
J. G. Nelson	<i>Northrop Grumman</i>
A. R. Olsen	<i>ARO Testing, Incorporated</i>
P. J. Palzkill	<i>Consultant</i>

AWS D14B Subcommittee on General Design and Practices

D. J. Landon, Chair	<i>Vermeer Manufacturing Company</i>
M. Rubin, Secretary	<i>American Welding Society</i>
D. B. Ashley	<i>Hartford Steam Boiler</i>
B. K. Banzhaf	<i>CNH America LLC</i>
T. J. Bruno	<i>Link-Belt Construction Equipment Company</i>
R. Larsen	<i>John Deere</i>
D. K. Miller	<i>The Lincoln Electric Company</i>
R. Warke	<i>Le Tourneau University</i>

Advisors to the AWS D14B Subcommittee on General Design and Practices

D. J. Malito	<i>Girard Machine Company, Incorporated</i>
M. R. Malito	<i>Girard Machine Company, Incorporated</i>
D. C. Martinez	<i>Consultant</i>
H. W. Mishler	<i>Consultant</i>
A. R. Olsen	<i>ARO Testing, Incorporated</i>
J. L. Warren	<i>CNH America LLC</i>
E. G. Yevick	<i>Weld-Met International Group</i>
V. R. Zegers	<i>R E Technical Services, Incorporated</i>

This page is intentionally blank.

Foreword

This foreword is not part of AWS D14.4/D14.4M:2012, *Specification for the Design of Welded Joints in Machinery and Equipment*, but is included for informational purposes only.

In 1967, the Technical Activities Committee of AWS established a technical committee to provide standards and recommended practices for the welding and fabrication of industrial equipment and machinery. The scope of that technical committee, identified as D14 committee, was to collect, review, and promulgate minimum requirements considered necessary for the control of welding in the fabrication of industrial machinery and equipment. This included weld design data, welding process selection, materials control, fabrication practices, quality standards, inspection and testing. The committee determined that a single universal standard and guide covering all machinery and equipment was impractical due to differences in utilization and operational requirements. Therefore it became the policy of the D14 committee to establish subcommittees as may be required to consider specific types of machinery and equipment within the scope of the main committee. A listing of the subcommittees for D14 at the time of approval of this document is as follows:

- D14B – Subcommittee on General Design and Practices
- D14C – Subcommittee on Earthmoving and Construction Equipment
- D14E – Subcommittee on Welding Cranes and Presses
- D14G – Subcommittee on Welding Rotating Equipment
- D14H – Subcommittee on the Surfacing of Industrial Rolls and Equipment
- D14I – Subcommittee on Hydraulic Cylinders

The first edition of this Standard was published in 1977 to provide a standard for the classification of welded joints for machinery and equipment. It included weld joint design, welding fabrication practices, quality control, and inspection indices to meet general machinery performance requirements. Over time, other standards for specific areas in the machinery and equipment field were developed by the D14 committee (see list on back page of this document) and this standard then served as a supplement to these standards and continued to provide a basis for other areas in the machinery and equipment field not served by a specific standard. Today, this standard is still intended to be referenced by all D14 standards as applicable.

Thus, as the purpose of this document has undergone a subtle change, the committee has changed the title of this document to *Specification for the Design of Welded Joints in Machinery and Equipment* from its former titles of *Specification for Welded Joints in Machinery and Equipment* and *Classification of Welded Joints for Machinery and Equipment*.

The purpose of this Specification is not to restrict the use of other proven methods and procedures for welding machinery and equipment. Where such methods and procedures exist, this Specification should be referenced as a supplement.

This fourth edition includes new clauses on general design requirements and welded connection design as well as the inclusion of measurable criteria for the control of excessive convexity utilizing the reentrant angle on welds.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D14 Committee on Machinery and Equipment, American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

This document will be reviewed periodically to assure its success in serving all parties concerned with its provisions. Revisions will be issued when warranted.

This page is intentionally blank.

Table of Contents

	Page No.
<i>Personnel</i>	v
<i>Foreword</i>	vii
<i>List of Tables</i>	xi
<i>List of Figures</i>	xii
1. Scope	1
1.1 General	1
1.2 Limitations	1
1.3 Units of Measurement	1
1.4 Safety and Health	1
2. Normative References	2
2.1 American Welding Society (AWS)	2
2.2 American Society of Mechanical Engineers (ASME)	2
2.3 American Society of Testing and Materials (ASTM)	2
2.4 American Society for Nondestructive Testing (ASNT)	3
3. Definitions	3
4. General Design Requirements	3
4.1 Weldment Classifications	3
4.2 Weld Classifications	4
4.3 Loading Classification	4
4.4 Combined Unit Stresses	4
4.5 Charpy V-Notch Impact Requirements	4
4.6 Filler Metals	4
4.7 Nondestructive Testing	4
4.8 Requirements for Secondary Welds	5
5. Welded Connection Design	5
5.1 Principal Structural Weldments-General	5
5.2 Cyclically Loaded Principal Structural Weldments	5
5.3 Prohibited Joints and Welds in Principal Structural Weldments	15
5.4 Prohibited Joints and Welds in Cyclically Loaded Principal Structural Weldments	15
5.5 Lap Joints	16
5.6 Combinations of Welds	16
5.7 Welds In Combination with Rivets and Bolts	16
5.8 Fillet Weld Details	16
5.9 Eccentricity of Connections	16
5.10 Connections or Splices in Tension and Compression Members	17
5.11 Connections or Splices in Compression Members with Milled Joints	17
5.12 Connections of Components of Built-Up Members	17
5.13 Transition of Thicknesses or Widths at Butt Joints	17
5.14 Girders and Beams	17
5.15 Effective Weld Areas, Lengths, and Sizes	19
5.16 Fillers	21

5.17	Joint Details	22
5.18	Details of Fillet Welds	22
5.19	Details of Plug and Slot Welds	24
5.20	Complete Joint Penetration (CJP) Groove Welds	26
5.21	Partial Joint Penetration (PJP) Groove Welds	26
5.22	Beam Copes and Weld Access Holes	26
6.	Workmanship	26
6.1	General	26
6.2	Preparation of Materials	27
6.3	Assembly	28
7.	Welding Procedure and Performance Qualification	30
8.	Inspection	30
8.1	Visual Inspection	31
8.2	Radiographic Testing	38
8.3	Ultrasonic Testing	48
8.4	Magnetic Particle Testing	59
8.5	Liquid Penetrant Testing	61
9.	Repair	62
9.1	Weld Repairs	62
9.2	Base-Metal Repairs	63
9.3	Repair Procedure	65
10.	Postweld Treatments	65
10.1	Introduction	65
10.2	Thermal Residual Stress Reduction	65
10.3	Peening	66
10.4	Vibratory Conditioning	66
	Annex A (Normative) — Illustrative Examples of Prohibited Joints and Welds	69
	Annex B (Informative) — Typical Weld Joints Details	73
	Annex C (Informative) — Guidelines for the Preparation of Technical Inquiries	105
	Annex D (Informative) — Bibliography	107
	List of AWS Documents on Machinery and Equipment	109

List of Tables

Table		Page No.
1	Base Metal and Filler Metal Relationship	5
2	Allowable Stresses in Weld Metal	6
3	Fatigue Stress Design Parameters (see 5.2)	8
4	Allowable Fatigue Stress Range	15
5	Effective Size of Flare-Groove Welds Filled Flush	20
6	Minimum Single Pass Fillet Weld Size for Heat Input	23
7	Minimum Size of Full Strength Double Fillet Welds ^a	24
8	Z Loss Dimension (Nontubular)	25
9	Z Loss Dimensions for Calculating PJP T-, Y-, and K-Tubular Connection Minimum Weld Sizes	25
10	Minimum Weld Size for Partial Joint Penetration Groove Welds	27
11	Heat Input Calculations	31
12	Acceptance Criteria for Inspection	32
13	NDT and Visual Inspection Requirements ^a	37
14	Standard Hole-Type and Wire Image Quality Indicator Requirements	40
15	Examples of Acceptable Indications ^a	44
16	Limits on Acceptability and Repair of Cut Edge Discontinuities of Plate	63

List of Figures

Figure	Page No.
1	Illustrative Examples for Table 4 7
2	Fillet and Combined Weld Dimension 7
3	Size and Effective Throat Measurements for Fillet and Partial Penetration Groove Welds with Reinforcing Fillet Welds 16
4	Staggered Intermittent Fillet Weld 18
5	Classification of Welded Joints 19
6	Transition of Butt Joints in Parts of Unequal Thickness. 21
7	Transition of Width at Butt Joints of Parts Having Unequal Width (see 6.11.3) 21
8	Edge Discontinuities in Cut Material (see 5.3.3) 22
9	Pneumatic Hammer Peening (see 7.8.4) 23
10	Unacceptable Submerged Arc Weld Pass where the Depth and Width Exceed the Face Width 24
11	Positions of Test Plates for Groove Welds 29
12	Positions of Test Pipe or Tubing for Groove Welds 33
13	Positions of Test Plates for Fillet Welds 34
14	Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 10 in [250 mm] and Greater in Length 40
15	Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less Than 10 in [250 mm] in Length 41
16	Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints 10 in [250 mm] and Greater in Length. 41
17	Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints Less Than 10 in [250 mm] in Length 42
18	Examples of Aligned Rounded Indications. 45
19	Examples of Groups of Aligned Rounded Indications 45
20	Charts for Thickness Equal to 1/8 in. [3 mm] to 1/4 in. [6 mm], Inclusive 45
21	Charts for Thickness Over 1/4 in. [6 mm] to 3/8 in. [10 mm], Inclusive 46
22	Charts for Thickness Over 3/8 in. [10 mm] to 3/4 in. [20 mm], Inclusive 46
23	Charts for Thickness Over 3/4 in. [20 mm] to 2 in [50 mm], Inclusive. 47
24	Charts for Thickness Over 2 in [50 mm] to 4 in [100 mm], Inclusive 47
25	Charts for Thickness Over 4 in [100 mm]. 48
26	70° Calibration Standard 50
27	60° Calibration Standard 51
28	45° Calibration Standard 52
29	Typical Screen Calibration 54
30	Test Procedure—CJP Groove Weld in Butt Joints 54
31	Method of Detecting Longitudinal Discontinuities in CJP Groove Weld in Butt Joints Not Ground Flush 55
32	Method of Detecting Longitudinal Discontinuities in CJP Groove Weld in Butt Joints Ground Flush 56
33	Method for Detecting Longitudinal Discontinuities in CJP Groove Welds in Corner Joints Not Ground Flush 56
34	Procedure for Testing CJP Groove Welds in T-Joints 57
35	Method of Using Procedure for Testing CJP Groove Welds in T-Joints 57
36	Edge Discontinuities in Cut Material 64
B.1	Typical Complete Joint Penetration Groove Welded Joints 73
B.2	Typical Partial Joint Penetration Groove Welded Joints 94

Specification for the Design of Welded Joints in Machinery and Equipment

1. Scope

1.1 General

This specification sets forth requirements dealing with the allowable stresses, welded joint design, workmanship, procedure and performance qualification, inspection, repair and post weld treatments of welded connections used in machinery and equipment, subject to static and cyclic loading. It is intended to be used in conjunction with other specifications that provide application specific requirements (such as D14.1, D14.3, etc.). In the event a conflict arises between the application specific standard and AWS D14.4/D14.4M, the application specific standard shall take precedence. The intent of this document is to establish the effect of weld joint geometry, welding practices, and quality control on allowable stress levels. The specification also provides practices that can be used for examination of welded joints used in fabrication of machinery and equipment.

1.2 Limitations

This specification does not dictate load determination, design assumptions, safety factors, or calculation methods. It is not the intent of this specification to restrict the use of other proven welding methods and procedures that are not mentioned herein, which achieve acceptable results and which have been agreed to in writing by the Owner and Manufacturer.

1.3 Units of Measurement

This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore each system must be used independently of the other without combining in any way. The specification with the designation D14.4 uses U.S. Customary Units. The specification D14.4M uses SI Units. The latter are shown in appropriate columns in tables and figures or within brackets [] when used in the text. Detailed dimensions on figures are in inches. A separate tabular form that relates the U.S. Customary Units with SI Units may be used in tables and figures.

1.4 Safety and Health

Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Material Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers Applicable Regulatory Agencies

2. Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this AWS Standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.1 American Welding Society (AWS)¹

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*

AWS A3.0, *Standard Welding Terms and Definitions*

AWS A5.1/5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*

AWS A5.5/5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*

AWS A5.17/5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.18/5.18M, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*

AWS A5.20/5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*

AWS A5.23/5.23M, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.28/5.28M, *Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding*

AWS A5.29/5.29M, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*

AWS A5.32/5.32M (ISO 14175), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS B2.1, *Specification for Welding Procedure and Performance Qualification*

AWS B4.0-98, *Standard Methods for Mechanical Testing of Welds* (U. S. Customary units only)

AWS B4.0M:2000, *Standard Methods for Mechanical Testing of Welds* (SI units only)

AWS QC1, *Standard and Guide for Qualification and Certification of Welding Inspectors*

AWS QC7, *Standard for Certified Welders*

2.2 American Society of Mechanical Engineers (ASME)²

ASME Section VIII-Div 1, *ASME Boiler and Pressure Vessel Code, Section VIII, Division 1: Design and Fabrication of Pressure Vessels*

ASME Section VIII-Div 2, *ASME Boiler and Pressure Vessel Code, Section VIII, Division 2: Alternative Rules*

2.3 American Society of Testing and Materials (ASTM)³

ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling*

ASTM A370, *Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A435/435M, *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*

ASTM E94, *Standard Guide for Radiographic Examination*

ASTM E164, *Standard Practice for Contact Ultrasonic Testing of Weldments*

ASTM E587, *Standard Practice for Ultrasonic Angle Beam Contact Testing*

¹ AWS standards are published by the American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

² ASME standards are published by the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016.

³ ASTM standards are published by the American Society for Testing and Materials, PO Box C700, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ASTM E747, *Standard Practice Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*

ASTM E1025, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole Type Image Quality Indicators (IQI) Used for Radiology*

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*

2.4 American Society for Nondestructive Testing (ASNT)⁴

ANSI/ASNT CP-189, *ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel*

SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*

3. Definitions

The terms that follow are defined for the purposes of this specification. Other terms used in this specification are defined in AWS A3.0, *Standard Welding Terms and Definitions*.

attachment. A component connected to a principal structural weldment, by welding or mechanical means, not required to carry the main working loads during normal operations.

Engineer. The responsible technical authority.

Manufacturer. The organization responsible for the performance of the work covered by this specification.

Owner. The person, company, or agency exercising legal ownership of the machinery or equipment produced in accordance with this standard.

principal structural weldments. Any weldments that carries the main working loads during normal operations.

primary weld. Any weld on a principal structural weldment directly transferring the main working load(s).

stress range. The algebraic difference between the maximum stress and minimum stress.

secondary weld. Any weld that does not directly transfer the main working loads through components that make up the principal structural weldment. All welds on secondary weldments are secondary welds. Welds that join attachments to principal structural weldments are secondary welds. A secondary weld can fail through the throat and not affect the normal operation of the equipment.

secondary member. Any component not carrying the main working loads during normal operations.

secondary weldment. A welded secondary member.

tensile strength of the weld metal. The minimum tensile strength specified for the filler metal classification as published in the applicable filler metal specification.

4. General Design Requirements

4.1 Weldment Classifications

4.1.1 Principal Structural Weldments. The Engineer shall determine which weldment(s) carry the main working load(s) during normal operations, and are therefore principal structural weldment(s). Weldments that do not carry main working load(s) during normal operations may be considered secondary weldments.

⁴ ASNT standards are published by the American Society for Nondestructive Testing, P.O. Box 28518, 1711 Arlingate Lane, Columbus, OH 43228-0518.

4.1.1.1 Roll Over Protective System/Falling Object Protective System (ROPS/FOPS). All weldments that are part of the ROPS or FOPS shall be considered as principal structural weldments.

4.1.1.2 Transportation weldments. Weldments through which normal transportation loads are carried shall be considered as principal structural weldments. Transportation loads associated with the initial shipping of the product are not considered normal transportation loads.

4.1.2 Welded Attachments. Attachments to principal structural weldments that are connected with welds that are 4 inches [100 mm] or longer in length in the direction of principal stress shall be considered to be part of the principal structural weldment. Attachments that are welded to principal structural weldments that are connected with welds that are less than 4 inches [100 mm] in length in the direction of principal stress may be considered secondary weldments.

4.1.3 Mechanically Fastened Attachments. Attachments that are mechanically fastened to principal structural weldments may be considered secondary members.

4.1.4 Secondary Weldments Identification. Drawings of all secondary weldments shall identify the weldment as secondary. Weldments that are not identified on drawings as secondary weldments shall be considered principal structural weldments.

4.2 Weld Classifications

4.2.1 Primary Welds. The Engineer shall determine which welds are primary welds. Primary welds shall include all welds on principal structural weldments that directly transfer main working loads through the weldment. Primary welds shall be subject to the restrictions of clauses 5.3 and 5.4.

4.2.2 Secondary Welds. The Engineer shall determine which welds are secondary welds. Welds that are less than 4 inches [100 mm] in length that connect attachments to principal structural weldments are not primary welds. All secondary welds on principal structural weldments shall be identified on drawings.

4.2.3 Unidentified Welds. Welds on principal structural weldments that are not identified as secondary welds shall be considered as primary welds.

4.3 Loading Classification

4.3.1 Static versus Cyclic loading. The Engineer shall determine which principal structural weldments are subject to cyclic loading under normal operating conditions. Weldments subject to fewer than 20,000 cycles of live load during the normal service life shall be considered to be statically loaded.

4.3.2 Statically loaded principal structural weldments shall be subject to the requirements of 5.1.

4.3.3 Cyclically loaded principal structural weldments shall be subject to the requirements of 5.2.

4.4 Combined Unit Stresses. In the case of axial stress combined with bending, the allowable unit stress of each kind shall be governed by the requirements of 5.1 and 5.2, and the maximum combined unit stresses calculated shall be limited in accordance with the requirements of the contract.

4.5 Charpy V-Notch Impact Requirements. For principal structural weldments which operate below 32°F [0°C] that are subject to tensile stress, consideration should be given to the requirement of supplemental impact properties specification.⁵

4.6 Filler Metals. All primary welds on principal structural weldments shall meet the requirements of Table 1 and Table 2.

4.7 Nondestructive Testing

4.7.1 Standard Inspection. All welds shall be subject to the NDT requirements of 8.1.3.1. Additionally, all primary welds on the principal structural weldment shall be subject to the NDT requirements of Table 13, as applicable.

4.7.2 Additional NDT. When nondestructive testing beyond the requirements of Table 13 is to be performed, the extent of testing shall be furnished to the bidder.

⁵ A suggested source of information: J. M. Barson and S. T. Rolfe, Fracture and Fatigue Control in Structures, Third Edition, 1999, published by ASTM, West Conshohocken, PA.

Table 1
Base Metal and Filler Metal Relationship

Minimum Tensile Strength of Base Metal ksi [MPa] ^a	Filler Metal Tensile Series (US Customary Units) ^{b,c,d,e}	Filler Metal Tensile Series (SI Units) ^{b,c,d,e}
45 to 75 [310 to 515]	E60XX, E70XX, E70XX-X E80XX-X, E90XX-X E100XX-X, E110XX-X	E43XX, E49XX, E49XX-X, E55XX-X, E62XX-X, E69XX-X, E76XX-X
>75 to 85 [>515 to 585]	E80XX-X, E90XX-X E100XX-X, E110XX-X	E55XX-X, E62XX-X, E69XX-X, E76XX-X
>85 to 95 [>585 to 655]	E90XX-X, E9018M, E100XX-X, E10018M, E110XX-X, E11018M	E62XX-X, E6218M, E69XX-X, E6918M, E76XX-X, E7218M
>95 to 105 [>655 to 725]	E100XX-X, E10018M, E110XX-X, E11018M	E69XX-X, E6918M, E72XX-X, E7218M
>105 to 115 [>725 to 795] ^f	E110XX-X, E11018M	E72XX-X, E7218M

Notes:

^a For joining base metals of different strength levels, the lower strength level shall determine the filler metal tensile series.

^b Filler metals for use with welding processes other than SMAW shall be of the same filler metal tensile series, when classified in the “as welded condition,” as indicated above for each base metal strength level.

^c Filler metals of alloy groups B3, B3L, B3H, B4, B4L, B5, B6, B6L, B6H, B7, B7L, B8, B8L, or B9 in AWS A5.5/A5.5M, A5.23/A5.23M, A5.28/A5.28M, or A5.29/A5.29M or those classified in appropriate specifications, are not prequalified for use in the as-welded condition.

^d See Annex D for filler metal specifications.

^e Use of under matching filler materials are not allowed for complete joint penetration welds.

^f Use of matching filler metals with base metals greater than 115 ksi [795 MPa] requires welding procedure qualification.

4.7.3 The required NDT of Table 13 may be modified as agreed upon by the Owner and the Manufacturer as validated by the use of finite element analysis, in conjunction with representative sample testing or prototype testing.

4.8 Requirements for Secondary Welds. Secondary welds are not required to conform to Clause 5, Welded Connection Design. All other clauses are required for secondary welds, as applicable.

5. Welded Connection Design

5.1 Principal Structural Weldments-General

5.1.1 Maximum allowable stress. The maximum stress on principal structural weldment connections shall not exceed the values listed in Table 2.

5.1.2 Prohibited Details: The restrictions of clause 5.3 shall apply to all primary welds on principal structural weldments.

5.2 Cyclically Loaded Principal Structural Weldments

5.2.1 Number of Loading Cycles: For cyclically loaded principal structural weldments, the Engineer shall determine the number of cycles of live load that the weldment is expected to endure in its lifetime.

5.2.2 Stress Ranges: For cyclically loaded principal structural weldments, the Engineer shall determine the stress range applied to all members and connections.

5.2.3 Stress Category: For cyclically loaded principal structural weldments, the Engineer shall determine the applicable stress category, consistent with Figures 1 and 2 and Tables 3 and 4. Such a determination shall be made for every connection with a primary weld and for every welded attachment made to a principal structural weldment.

5.2.4 The fatigue stress provisions of Figures 1 and 2 and Tables 3 and 4 may be modified by other rationale analysis such as finite element analysis, when agreed upon by the Owner and Manufacturer.

5.2.5 Base metal repairs: For cyclically loaded principal structural weldments, the Engineer shall determine the effect, if any, of base metal repairs on the fatigue performance of the weldment.

Table 2
Allowable Stresses (see 5.1 and 5.2)

Type of Applied Stress	Allowable Stress	Required Filler Metal Strength Level
CJP Groove Welds		
Tension normal to the effective area ^a	Same as base metal	Matching filler metal shall be used ^b
Compression normal to effective area	Same as base metal	Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal may be used.
Tension or compression parallel to axis of the weld ^c	Not a welded joint design consideration	Filler metal with a strength level equal to or less than matching filler metal may be used
Shear on effective area	0.30 × classification tensile strength of filler metal except shear on the base metal shall not exceed 0.40 × yield strength of the base metal	
PJP Groove Welds		
Tension normal to the effective area	0.30 × classification tensile strength of filler metal	Filler metal with a strength level equal to or less than matching filler metal may be used
Compression normal to effective area of weld in joints designed to bear	0.90 × classification tensile strength of filler metal, but not more than 0.90 × yield strength of the connected base metal	
Compression normal to effective area of weld in joints not designed to bear	0.75 × classification tensile strength of filler metal	
Tension or compression parallel to axis of the weld ^c	Not a welded joint design consideration	
Shear parallel to axis of effective area	0.30 × classification tensile strength of filler metal except shear on the base metal shall not exceed 0.40 × yield strength of the base metal	
Fillet Welds		
Shear on effective area or weld	0.30 × classification tensile strength of filler metal except that the base metal net section shear area stress shall not exceed 0.40 × yield strength of the base metal ^d	Filler metal with a strength level equal to or less than matching filler metal may be used
Tension or compression parallel to axis of the weld ^c	Not a welded joint design consideration	
Plug and Slot Welds		
Shear parallel to the faying surface on the effective area ^e	0.30 × classification tensile strength of filler metal	Filler metal with a strength level equal to or less than matching filler metal may be used

^a For definitions of effective areas, see 5.15.

^b For joining base metals of different strength levels, the lower strength level shall determine the matching filler metal tensile series.

^c Fillet welds and groove welds joining components of built-up members are allowed to be designed without regard to the tension and compression stresses in the connected components parallel to the weld axis although the area of the weld normal to the weld axis may be included in the cross-sectional area of the member.

^d The limitation on stress in the base metal to $0.40 \times$ yield point of base metal does not apply to stress on the diagrammatic weld leg; however, a check shall be made to assure that the strength of the connection is not limited by the thickness of the base metal on the net area around the connection, particularly in the case of a pair of fillet welds on opposite sides of a plate element.

^e The strength of the connection shall also be limited by the tear-out load capacity of the thinner base metal on the perimeter area around the connection.

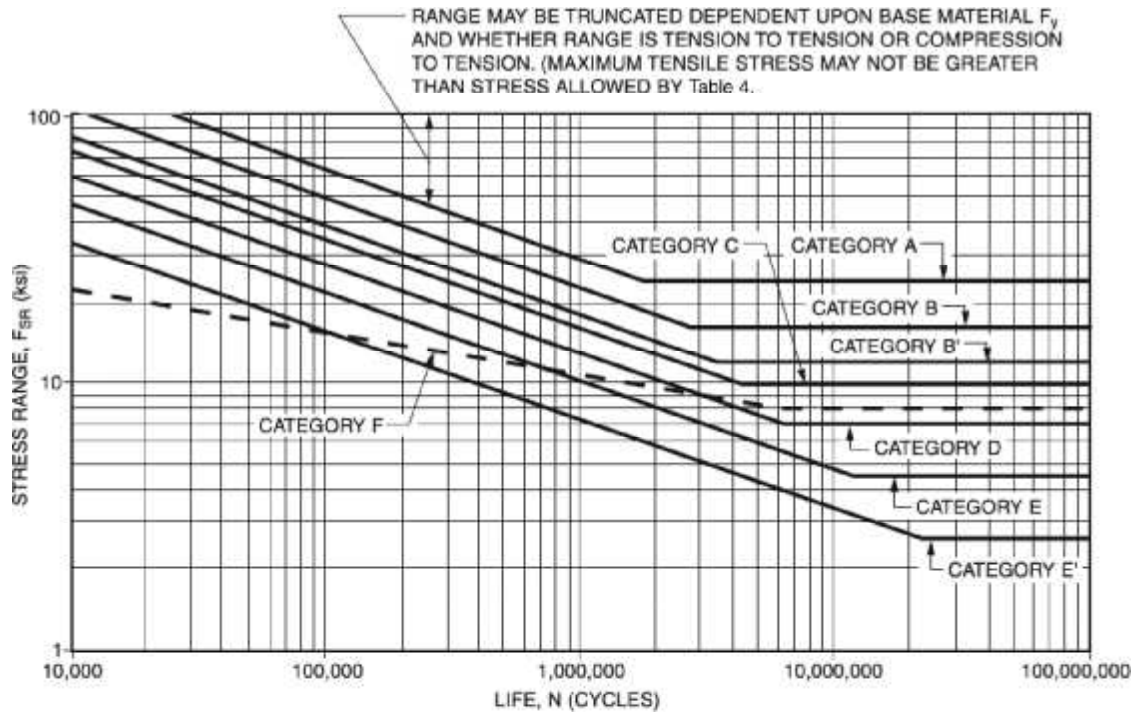


Figure 1—Allowable Stress Range for Cyclically Applied Load (Fatigue) – US Customary Units

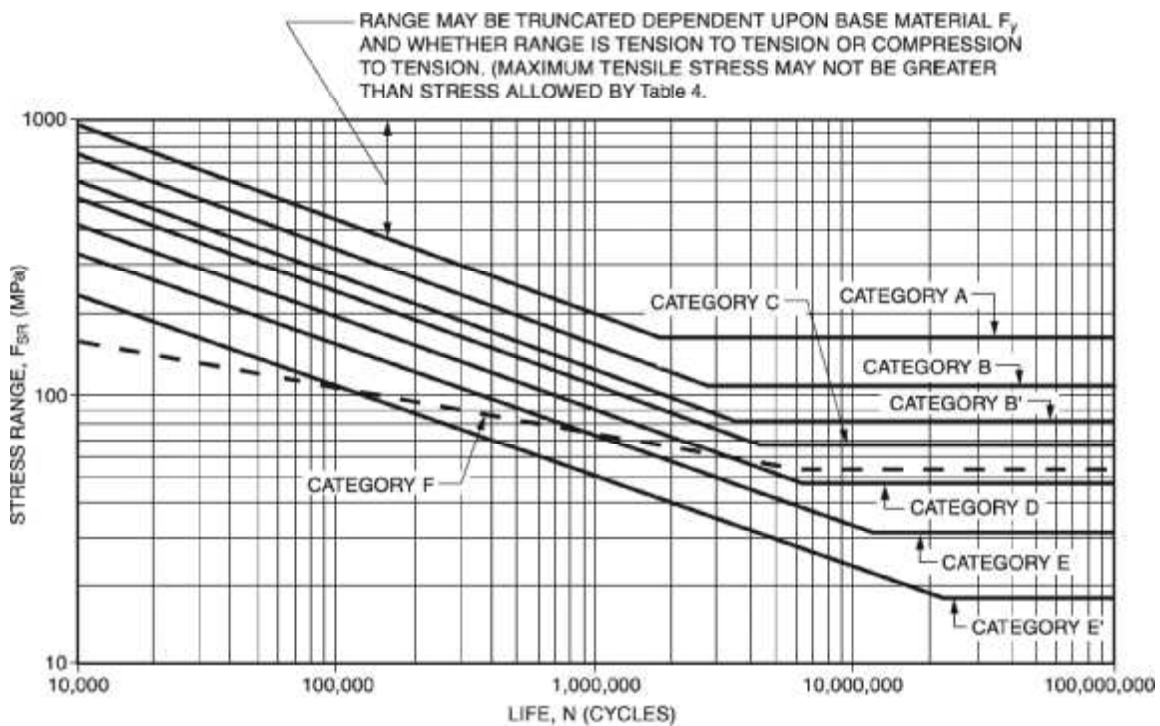


Figure 2—Allowable Stress Range for Cyclically Applied Load (Fatigue) – SI Units

Table 3
Fatigue Stress Design Parameters (see 5.2)

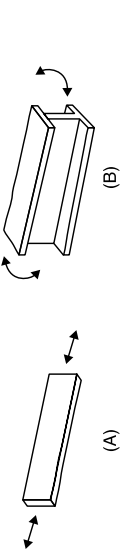
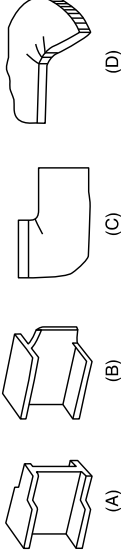
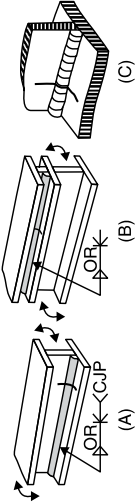
Description	Stress Category	Inspection Class	Potential Crack Initiation Point	Illustrative Examples
Section 1—Plain Material Away from Any Welding				
1.1 Base metal, except non-coated weathering steel, with rolled or cleaned surface and rolled or flame-cut edges with ANSI smoothness of 1000 or less, but without reentrant corners.	A	N.A.	Away from all welds or structural connections	
1.2 Non-coated weathering steel base metal with rolled or cleaned surface and with rolled or flame-cut edges with ANSI smoothness of 1000 or less.	B	N.A.	Away from all welds or structural connections	
1.3 Thermal-cut reentrant corners, except weld access holes, meeting the requirements ANSI smoothness of 1000 or less.	B	N.A.	From irregularities in surface of reentrant corner	
1.4 Weld access holes made to the requirements of 5.22.	C	N.A.	From irregularities in surface of reentrant corner of weld access hole	
Section 2—Connected Material in Mechanically Fastened Joints-Not Used^a				
Section 3—Welded Joints Joining Components of Built-Up Members				
3.1 Base metal and weld metal in members without attachments built-up or plates or shapes connected by continuous longitudinal CJP groove welds, backgouged and welded from second side, or by continuous fillet welds.	B	III	From surface or internal discontinuities in weld away from end of weld	

Table 3 (Continued)
Fatigue Stress Design Parameters (see 5.2)

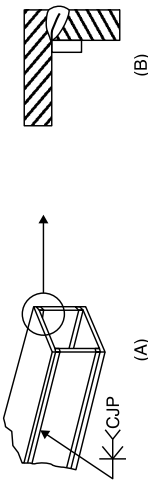
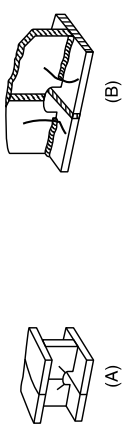
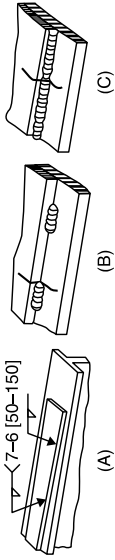
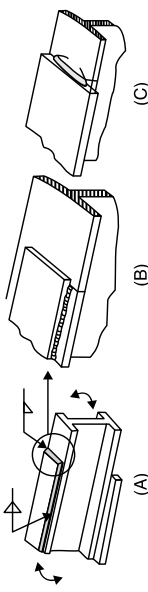
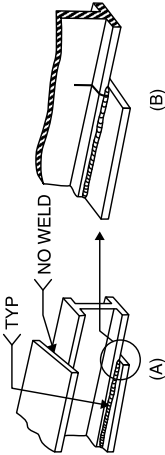
Description	Stress Category	Inspection Class	Potential Crack Initiation Point	Illustrative Examples
3.2 Base metal and weld metal in members without attachments built-up of plates or shapes connected by continuous longitudinal CJP groove welds with backing not removed, or by continuous PJP groove welds.	B'	III	From surface or internal discontinuities in weld, including weld attaching backing	
3.3 Base metal and weld metal at termination of longitudinal fillet at weld access holes in built-up members.	D	IV	From the weld termination into the web or flange	
3.4 Base metal at ends of longitudinal intermittent fillet weld segments.	E	IV	In connected material at start and stop locations of any weld deposit	
3.5 Base metal at ends of partial length welded cover plates narrower than the flange having square or tapered ends, with or without welds across the ends or coverplates wider than the flange with welds across the ends. Flange thickness ≤ 0.8 in [20 mm] Flange thickness > 0.8 in [20 mm]	E E'	IV IV	In flange at toe of end weld or in flange at termination of longitudinal weld or in edge of flange with wide coverplates	
3.6 Base metal at ends of partial length welded coverplates wider than the flange without welds across the ends.	E'	IV	In edge of flange at end of coverplate weld	

Table 3 (Continued)
Fatigue Stress Design Parameters (see 5.2)

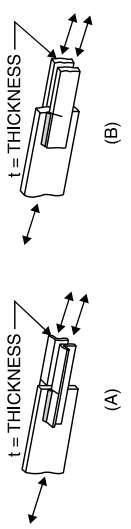
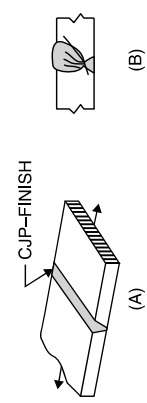
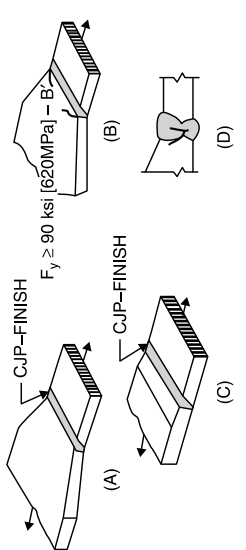
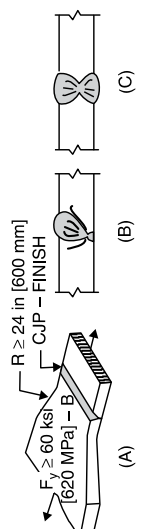
Description	Stress Category	Inspection Class	Potential Crack Initiation Point	Illustrative Examples
Section 4—Longitudinal Fillet Welded Connections				
4.1 Base metal at junction of axially loaded members with longitudinally welded end connections. Welds lengths shall be proportioned on each side of axis to balance weld stresses. $t \leq 0.8$ in [20 mm] $t > 0.8$ in [20 mm]	E E'	IV IV	Initiating from end of any weld termination extending into the base metal	
Section 5—Welded Joints Transverse to Direction of Stress				
5.1 Base metal and weld metal in or adjacent to CJP groove welded splices in rolled or welded cross section with welds ground essentially parallel to the direction of stress.	B	I	From internal discontinuities in weld metal or along fusion boundary	
5.2 Base metal and filler metal in or adjacent to CJP groove welded splices with welds ground essentially parallel to the direction of stress at transitions in thickness or width made on a slope no greater than 1 to 2-1/2. $F_y < 90$ ksi [620 MPa] $F_y \geq 90$ ksi [620 MPa]	B B'	I I	From internal discontinuities in weld metal or along fusion boundary or at start of transition when $F_y \geq 90$ ksi [620 MPa]	
5.3 Base metal with F_y equal to or greater than 90 ksi [620 MPa] and filler metal in or adjacent to CJP groove welded splices with welds ground essentially parallel to the direction of stress at transitions in width made on a radius of not less than 2 ft [600 mm] with the point of tangency at the end of the groove weld.	B	I	From internal discontinuities in filler metal or discontinuities along the fusion boundary	

Table 3 (Continued)
Fatigue Stress Design Parameters (see 5.2)

Description	Stress Category	Inspection Class	Potential Crack Initiation Point	Illustrative Examples
5.4 Base metal and filler metal in or adjacent to the toe of CJP. T- or corner joints with backing removed or splices, with or without transitions in thickness having slopes no greater than 1 to 2-1/2 when weld reinforcement is not removed.	C	II	From surface discontinuity at toe of weld extending into base metal or along fusion boundary	
5.4.1 Base metal and filler metal in or adjacent to CJP groove welded butt splices with backing left in place. Tack welds inside groove Tack welds outside the groove and not closer than 1/2 in [12 mm] to edge of base metal	D E	IV IV	From the toe of the groove weld or the toe of the weld attaching backing	
5.5 Base metal and filler metal at transverse end connections of tension-loaded plate elements using PJP butt, T-, or corner joints, with reinforcing or contouring fillets. Crack initiating from weld toe Crack initiating from weld root	C C'	IV IV	Initiating from discontinuity at weld toe extending into base metal or initiating from root due to tension extending up and then out through the weld	
5.6 Base metal and weld metal at transverse end connections of tension-loaded plate elements using a pair of fillet welds on opposite sides of the plate. Crack initiating from weld toe Crack initiating from weld root	C C''	IV IV	Initiating from discontinuity at weld toe extending into base metal or initiating from root due to tension extending up and then out through the weld	

Table 3 (Continued)
Fatigue Stress Design Parameters (see 5.2)

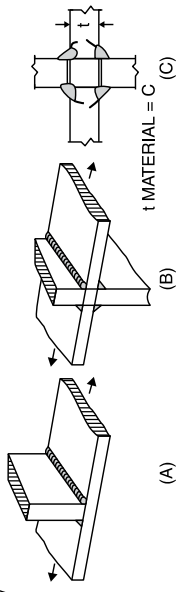
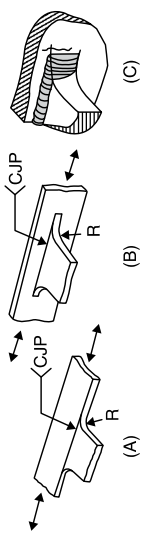
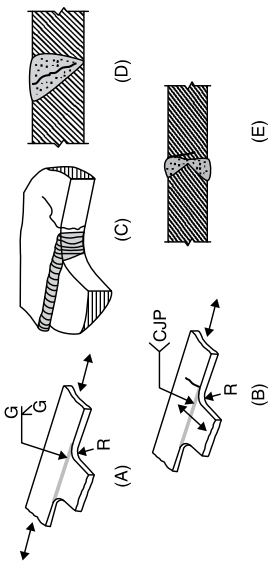
Description	Stress Category	Inspection Class	Potential Crack Initiation Point	Illustrative Examples
5.7 Base metal of tension loaded plate elements at toe of transverse fillet welds, and, base metal at toe of welds on girders and rolled beam webs or flanges adjacent to welded transverse stiffeners.	C	IV	From geometric discontinuity at toe of fillet extending into base metal	
Section 6—Base Metal at Welded Transverse Member Connections				
6.1 Base metal at details attached by CJP groove welds subject to longitudinal loading only when the detail embodies a transition radius, R, with the weld termination ground smooth. $R \geq 24$ in [600 mm] 24 in [600 mm] $> R \geq 6$ in [150 mm] 6 in [150 mm] $> R \geq 2$ in [50 mm] 2 in [50 mm] $> R$	B C D E	III IV IV IV	Near point of tangency of radius at edge of member	
6.2 Base metal at details of equal thickness attached by CJP groove welds subject to transverse loading with or without longitudinal loading when the detail embodies a transition radius, R, with the weld termination ground smooth. When weld reinforcement is removed: $R \geq 24$ in [600 mm] 24 in [600 mm] $> R \geq 6$ in [150 mm] 6 in [150 mm] $> R \geq 2$ in [50 mm] 2 in [50 mm] $> R$ When weld reinforcement not removed: $R \geq 24$ in [600 mm] 24 in [600 mm] $> R \geq 6$ in [150 mm] 6 in [150 mm] $> R \geq 2$ in [50 mm] 2 in [50 mm] $> R$	B C D E C C D E	III IV IV IV IV IV IV IV	Near points of tangency of radius or in the weld or at fusion boundary or member or attachment At toe of the weld either along edge of member or the attachment	

Table 3 (Continued)
Fatigue Stress Design Parameters (see 5.2)

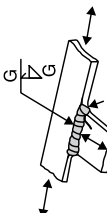
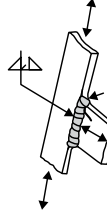
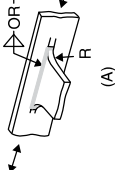
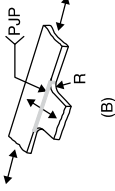
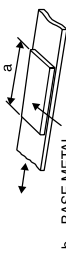
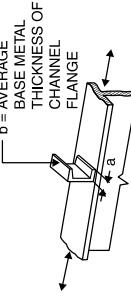
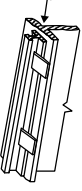
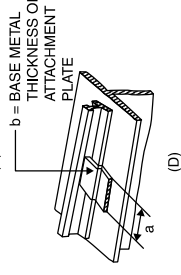
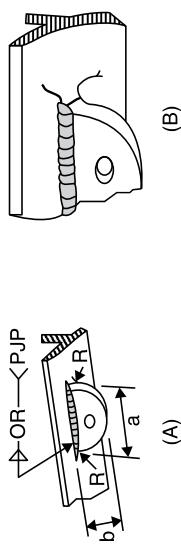
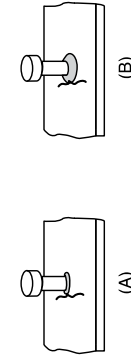
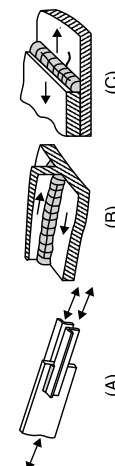
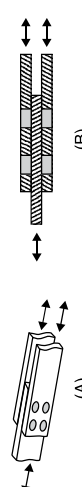
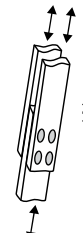
Description	Stress Category	Inspection Class	Potential Crack Initiation Point	Illustrative Examples
6.3 Base metal at details of unequal thickness attached by CJP groove welds subject to transverse loading with or without longitudinal loading when the detail embodies a transition radius, R, with the weld termination ground smooth. When weld reinforcement is removed: $R > 2$ in [50 mm] $R \leq 2$ in [50 mm] When weld reinforcement not removed: Any radius	D E E	IV IV IV	At toe of weld along edge of thinner material	   
6.4 Base metal subject to longitudinal stress at transverse members, with or without transverse stress, attached by fillet or PJP groove welds parallel to direction of stress when the detail embodies a transition radius, R, with weld termination ground smooth. $R > 2$ in [50 mm] $R \leq 2$ in [50 mm]	D E	IV IV	In weld termination or from the toe of the weld extending into member	  
Section 7—Base Metal at Short Attachments^b				
7.1 Base metal subject to longitudinal loading at details attached by fillet welds parallel or transverse to direction of stress where the detail embodies no transition radius, and with detail length in direction of stress, a, and attachment height normal to the surface of the member b: $a < 2$ in [50 mm] 2 in [50 mm] $\leq a \leq 12b$ or 4 in [100 mm] $a > 12b$ or 4 in [100 mm] when b is ≤ 1 in [25 mm] $a > 12b$ or 4 in [100 mm] when b is > 1 in [25 mm]	C D E E'	IV IV IV IV	In the member at the end of the weld	   

Table 3 (Continued)
Fatigue Stress Design Parameters (see 5.2)

Description	Stress Category	Inspection Class	Potential Crack Initiation Point	Illustrative Examples
7.2 Base metal subject to longitudinal stress at details attached by fillet or PJP groove welds, with or without transverse load on detail, when the detail embodies a transition radius, R, with weld termination ground smooth. D $R > 2$ in [50 mm] E $R \leq 2$ in [50 mm]	D E	IV IV	In weld termination extending into member 7.2	
Section 8—Miscellaneous				
8.1 Base metal stud-type at shear connectors attached by fillet or electric stud welding	C	IV	At toe of weld in base metal 8.1	
8.2 Shear on throat of continuous or intermittent longitudinal or transverse fillet welds including fillet welds in holes or slots	F	IV	In throat of weld 8.2	
8.3 Base metal at plug or slot welds	E	IV	At end of weld in base metal 8.3	
8.4 Shear on plug or slot welds	F	IV	At faying surface 8.4	

^a Adapted by permission from AISC, *Specification for Structural Steel Buildings*, AISC 360–05, Table A-3.1. AWS D14.4/D14.4M deals only with welded details. To maintain consistency and to facilitate cross referencing with other governing specifications, Section 2—Connected Material in Mechanically Fastened Joints, and Description 8.5 of Table A-3.1 of AISC 360–05 are not used in this table.

^b “Attachment,” as used herein, is defined as any steel detail welded to a member which, by its mere presence and independent of its loading, causes a discontinuity in the stress flow in the member and thus reduces the fatigue resistance.

Table 4
Allowable Fatigue Stress Range

Stress Category (See Table 3)	Allowable Range of Stress, ksi [MPa]			
	For 20 000 to 100 000 cycles	For up to 500 000 cycles	For up to 2 000 000 cycles	For over 2 000 000 cycles
A	63 [435]	37 [255]	24 [165]	24 [165]
B	49 [340]	29 [200]	18 [125]	16 [110]
B*	39 [270]	23 [160]	15 [105]	12 [85]
C	35 [240]	21 [145]	13 [90]	10 [70] 12 [85] ^a
D	28 [195]	16 [110]	10 [70]	7 [50]
E	22 [150]	13 [90]	8 [55]	5 [35]
E*	16 [110]	9 [60]	6 [40]	3 [20]
F	15 [105]	12 [85]	9 [60]	8 [55]

^a At toe of transverse stiffener welds on girder webs or flanges.

5.3 Prohibited Joints and Welds in Principal Structural Weldments. The following shall be prohibited for all primary welds on all principal structural weldments, whether subject to static or cyclic loading: (see Annex A for illustrative examples).

5.3.1 Butt joints with single sided PJP groove welds, loaded in tension perpendicular to the weld axis.

5.3.2 Tee joints with single sided fillet or PJP groove welds, loaded in tension perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

5.3.3 Corner joints with single sided PJP groove welds, loaded in tension perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

5.3.4 Any CJP groove weld with no particular joint preparation, unless the joint conforms to Annex B.

5.3.5 Any edge joint where the loading is not parallel to the weld axis.

5.4 Prohibited Joints and Welds in Cyclically Loaded Principal Structural Weldments. In addition to the restrictions of 5.3, the following shall be prohibited for all primary welds on principal structural weldments subject to cyclic loading: (see Annex A for illustrative examples).

5.4.1 Butt joints with single sided PJP groove welds, loaded in compression perpendicular to the weld axis.

5.4.2 Tee joints with single sided fillet or PJP groove welds, loaded in compression perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

5.4.3 Corner joints with single sided PJP groove welds, loaded in compression perpendicular to the longitudinal axis of the weld, where rotation about the weld root is not restricted.

5.4.4 Butt, tee, and corner joints with single sided CJP groove welds made without steel backing where primary bending stresses are imposed on the root of the weld, unless weld root is inspected with MT in accordance with clause 8.4 or PT in accordance with clause 8.5.

5.4.5 Butt, tee, and corner joints with single sided CJP groove welds made with removable backing (ceramic, copper, or other) or with no backing, where primary bending stresses are imposed on the root of the weld, unless the WPS is qualified in accordance with this specification, and the weld root is inspected with MT in accordance with clause 8.4 or PT in accordance with clause 8.5.

5.4.6 Tee and corner joints with single sided CJP groove welds made with left in place steel backing, where primary bending stresses are imposed on the root of the weld.

5.4.7 Tee and corner joints with double sided groove welds without reinforcing (contouring) fillet welds.

5.5 Lap Joints

5.5.1 The minimum overlap of parts in principal structural weldments, lap joints shall be five times the thickness of the thinner part, but not less than 1 inch [25 mm]. Unless lateral deflection of the parts is prevented, they shall be double fillet welded or joined by at least two transverse lines of plug, or slot welds or by two or more longitudinal fillet or slot welds.

5.5.2 If longitudinal fillet welds are used alone in lap joints of end connections, the length of each fillet weld shall be no less than the perpendicular distance between them. The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 16 times the thickness of the connected thinner part, unless suitable provision is made (as by intermediate plug or slot welds) to prevent buckling or separation of the parts. The longitudinal fillet welds may be either at the edges of the member or in slots.

5.5.3 When fillet welds in holes or slots are used, the clear distance from the edge of the hole or slot to the adjacent edge of the part containing it, measured perpendicular to the direction of stress, shall be no less than five times the thickness of the part, nor less than two times the width of the hole or slot. The strength of the part shall be determined from the critical net section of the base metal.

5.6 Combinations of Welds. If two or more of the general types of welds (groove, fillet, plug, or slot) are combined in a single joint, their allowable capacity shall be computed with reference to the axis of the group in order to determine the allowable capacity of the combination. However, such methods of adding individual capacities of welds do not apply to fillet welds reinforcing groove welds (see 5.15.4).

5.7 Welds In Combination with Rivets and Bolts Rivets and bolts in combination with welds shall not be considered as sharing the stress, and the welds shall be provided to carry the entire stress for which the connection is designed. Bolts or rivets used in assembly may be left in place if their removal is not specified. If bolts are to be removed, the plans should indicate whether or not holes should be filled, and in what manner.

5.8 Fillet Weld Details

5.8.1 Fillet welds which support a tensile force that is not parallel to the axis of the weld shall not terminate at corners of parts or members, but shall be returned continuously, full size, around the corner for a length equal to twice the weld size where such return can be made in the same plane. Boxing shall be indicated on design and detail drawings.

5.8.2 Fillet welds deposited on the opposite sides of a common plane of contact between two parts shall be interrupted at a corner common to both welds (see Figure 3).

5.9 Eccentricity of Connections

5.9.1 Eccentricity between intersecting parts and members shall be avoided insofar as practicable.

5.9.2 In designing welded joints, adequate provision shall be made for bending stresses due to eccentricity, if any, in the disposition and section of base metal parts and in the location and types of welded joints.

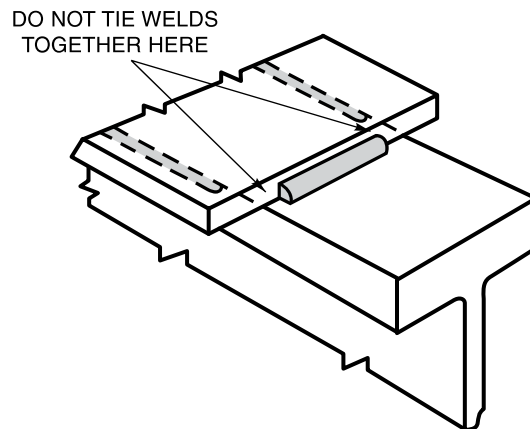


Figure 3—Fillet Welds on Opposite Sides of a Common Plane of Contact

5.9.3 For members having symmetrical cross-sections, the connection welds shall be arranged symmetrically about the axis of the member, or proper allowance shall be made for unsymmetrical distribution of stresses.

5.9.4 For axially stressed angle members, the center of gravity of the connecting welds shall lie between the line of the center of gravity of the angle's cross-section and the centerline of the connected leg. If the center of gravity of the connecting weld lies outside of this zone, the total stresses, including those due to the eccentricity from the center of gravity of the angle, shall not exceed those permitted by this specification.

5.10 Connections or Splices in Tension and Compression Members. Connections or splices of tension or compression members which are made by groove welds shall have complete joint penetration. Connections or splices made with fillet or plug welds, except as noted in 5.11, shall be designed for an average of the calculated stress and the strength of the member, but not less than 75% of the strength of the member.

5.11 Connections or Splices in Compression Members with Milled Joints. If members subject to compression only are spliced, and full-milled bearing is provided, the splice material and its welding shall be arranged, unless otherwise stipulated by the applicable general specifications, to hold all parts in alignment and shall be proportioned to carry 50% of the computed stress in the member. Where such members are in full-milled bearing on base plates, there shall be sufficient welding to hold all parts securely in place.

5.12 Connections of Components of Built-Up Members. When a member is built up of two or more pieces, the pieces shall be connected along their longitudinal joints by sufficient weld to make the pieces act in unison.

5.13 Transition of Thicknesses or Widths at Butt Joints

5.13.1 Butt joints in principal structural weldments between parts having unequal thicknesses and subject to tensile stress shall have a smooth transition between the offset surfaces at a slope of no more than 1 in 2.5 with the surface of either part. The transition may be accomplished by sloping weld surfaces, by chamfering the thicker part, or by a combination of the two methods (see Figure 4).

5.13.2 In butt joints in principal structural weldments between parts of unequal thickness that are subject only to shear or compressive stress, transition of thickness shall be accomplished, as specified in Figure 4, when the offset between surfaces at either side of the joint is greater than the thickness of the thinner part connected. When the offset is equal to or less than the thickness of the thinner part connected, the face of the weld shall be sloped no more than 1 in 2.5 from the surface of the thinner part or shall be sloped to the surface of the thicker part if this requires a lesser slope with the following exception: truss member joints and beam and girder flange joints shall be made with smooth transitions of the type specified in 5.13.1.

5.13.3 Butt joints in principal structural weldments between parts having unequal width and subject to tensile stress shall have a smooth transition between offset edges at a slope of no more than 1 in 2.5 with the edge of either part or shall be transitioned with a 2.0 ft [0.6 m] minimum radius tangent to the narrower part of the center of the butt joints (see Figure 5). An increased stress range may be used for steel having yield stress greater than 90 ksi [620 MPa] with details incorporating the radius.

5.14 Girders and Beams

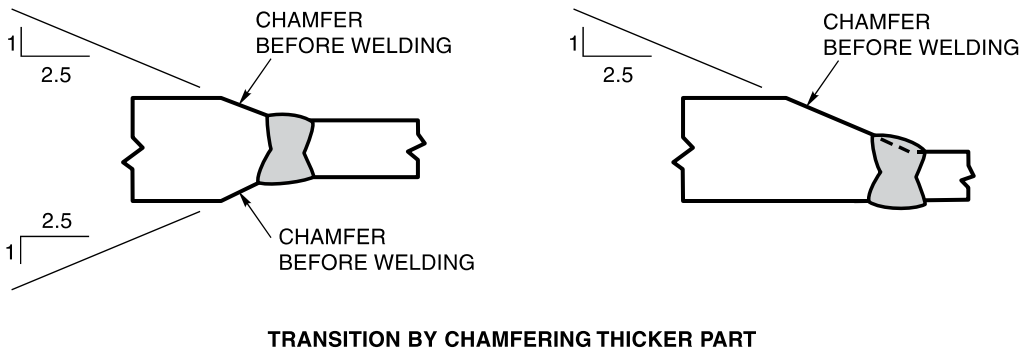
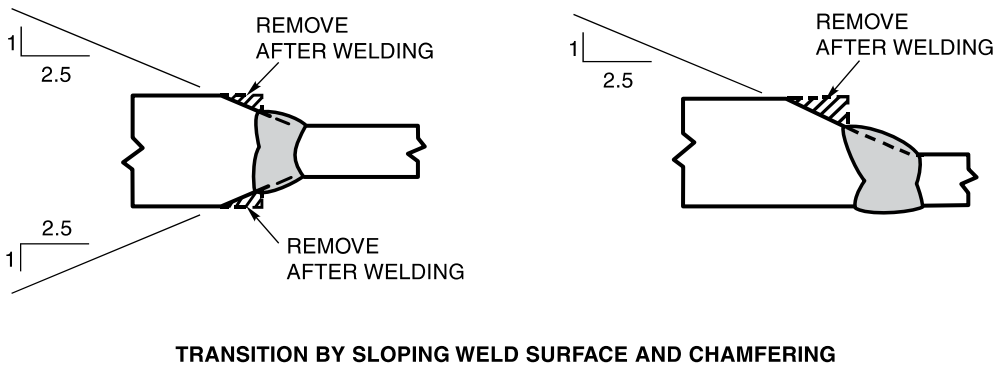
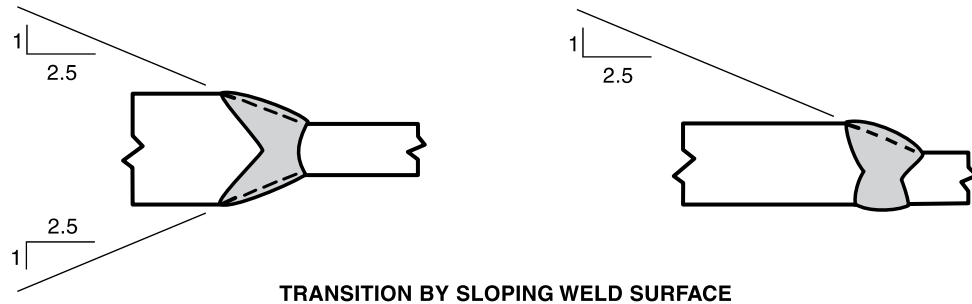
5.14.1 Connections or splices in beams or girders when made by groove welds shall have complete joint penetration welds. Connections or splices made with fillet or plug welds shall be designed for the average of the calculated stress and the strength of the member, but no less than 75% of the strength member. Where there is repeated loading, the maximum stress or stress range shall not exceed the fatigue stress permitted by this specification.

5.14.2 Splices between sections of rolled beams or built-up girders shall preferably be made in a single transverse plane. Shop splices of webs and flanges in built-up girders made before the webs and flanges are joined to each other may be located in a single transverse plane or multiple transverse planes, but the fatigue stress provisions of this specification shall apply.

5.14.3 Stiffeners

5.14.3.1 Intermittent fillet welds used to connect stiffeners to beams and girders shall comply with the following requirements:

- (1) Minimum length of each weld shall be 1 1/2 in [40 mm].
- (2) Welds shall be made on both sides of the joint for at least 25% of its length.



CENTERLINE ALIGNMENT
(PARTICULARLY APPLICABLE
TO WEB PLATES)

OFFSET ALIGNMENT
(PARTICULARLY APPLICABLE
TO FLANGE PLATES)

Notes:

1. Groove may be of any permitted or qualified type and detail.
2. Transition slopes shown are the maximum permitted.

Figure 4—Transition of Thickness at Butt Joints of Parts Having Unequal Thickness

Figure 5—Transition of Width at Butt Joints of Parts Having Unequal Width

- 5.14.3.2** Stiffeners, if used, should be arranged in pairs on opposite sides of the web. Stiffeners may be welded to tension or compression flanges. The fatigue stress or stress ranges at the points of attachment to the tension flange or tension portions of the web shall comply with the fatigue requirements of this specification. Transverse fillet welds may be used for welding stiffeners to flanges.

5.14.3.4 Unless otherwise specified, fillet welds connecting attachments shall start or terminate not less than the weld size from the end of the joint. For stiffeners on girders, the weld joining the stiffeners to the web shall start or terminate not less than four times the thickness of the web from the face of the flange.

5.14.5 Cover Plates. Cover plates should be limited to one on any flange. The maximum thickness of cover plates on a flange (total thickness of all cover plates if more than one is used) shall be not greater than one and one-half times the thickness of the flange to which the cover plate is attached. The thickness and width of a cover plate may be varied by welding of butt joint parts of different thickness or width on transitions conforming to the requirements of 5.13. Such plates shall be assembled and welds ground smooth before being attached to the flange. The width of a cover plate, with recognition of dimensional tolerance allowed by ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling*, shall allow suitable space for a fillet weld along each edge of the joint between the flange and the cover plate.

5.15.1 Groove Welds. The effective area shall be the effective weld length multiplied by the weld size.

5.15.1.1 The effective weld length for any groove weld, square or skewed, shall be the width of the part joined, perpendicular to the direction of stress.

5.15.1.2 The weld size of a complete joint penetration groove weld shall be the thickness of the thinner part joined. No increase is permitted for weld reinforcement.

5.15.1.3 The weld size of a partial joint penetration groove weld shall be the depth of bevel less 1/8 in [3 mm] for grooves having a groove angle less than 60° but no less than 45° at the root of the groove, when made by shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW), or flux cored arc welding (FCAW).

The weld size of a partial joint penetration groove weld shall be the depth of bevel, without reduction, for grooves having the following:

- (1) a groove angle of 60° or greater at the root of the groove when made by any of the following welding processes: SMAW, SAW, GMAW, FCAW; or
- (2) a groove angle not less than 45° at the root of the groove when made in flat or horizontal positions by GMAW or FCAW if the specific weld joint detail is proven through procedure qualification.

5.15.1.4 The effective weld size for flare groove welds, when filled flush to the surface of a bar, or 90 degree bend in a formed section, or a rectangular tube, shall be as shown in Table 5.

- (1) When required by the Engineer, test sections shall be used to verify that the effective weld size is consistently obtained.
- (2) For a given set of procedural conditions, if the Manufacturer has demonstrated consistent production of larger effective weld sizes than those shown in Table 5, the Manufacturer may establish such larger effective weld sizes by validations.
- (3) Validation required by 5.15.1.4(2) shall consist of sectioning the radiused member, normal to its axis, at mid-length and at the ends of the weld. Such sectioning shall be made on a number of combinations of material sizes representative of the range used by the Manufacturer in construction or as required by the Engineer.

5.15.2 Fillet Welds. The effective area shall be the effective weld length multiplied by the effective throat. Stress in a fillet weld shall be considered as applied to this effective area, for any direction of applied load.

5.15.2.1 The effective length of a fillet weld shall be the overall length of the full-size fillet, including boxing. No reduction in effective length shall be made for either the start or crater of the weld if the weld is full size throughout its length.

5.15.2.2 The effective length of a curved fillet weld shall be measured along the center line of the effective throat. If the weld area of a fillet weld in a hole or slot computed from this length is greater than the area found from 5.15.3, then this latter area shall be used as the effective area of the fillet weld.

5.15.2.3 The minimum effective length of a fillet weld shall be at least four times the nominal size, or the size of the weld shall not exceed one fourth its effective length.

5.15.2.4 The effective throat shall be the minimum distance, minus any convexity between the weld root and the face of a fillet weld. See 5.19.1.6 for skewed fillet welds.

Table 5
Effective Size of Flare-Groove Welds Filled Flush

Welding Process	Flare-Bevel-Groove	Flare-V-Groove
SMAW and FCAW-S	5/16R	5/8R
GMAW ^a and FCAW-G	5/8R	3/4R
SAW	5/16R	1/2R

^a Except GMAW-S.

Note: R = radius of outside surface.

5.15.3 Plug and Slot Welds. The effective area shall be the nominal area of the hole or slot in the plane of the faying surface.

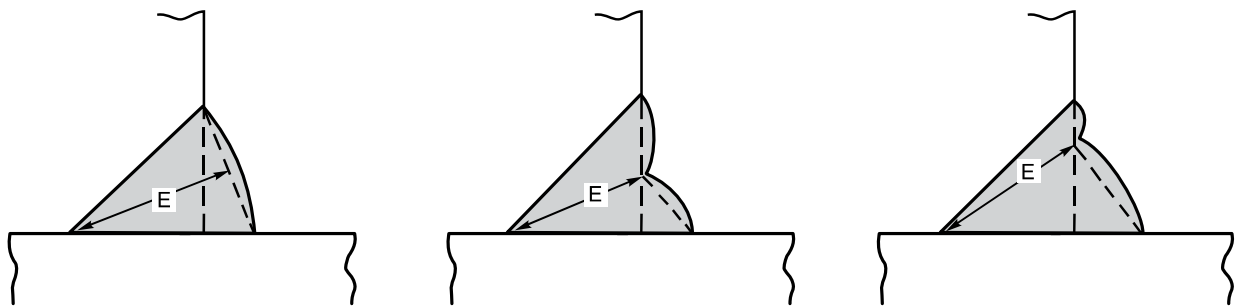
5.15.4 Combination Weld. The effective throat of a combination partial joint penetration groove weld and a fillet weld shall be the minimum distance from the joint root to the weld face of the fillet weld minus 1/8 in [3 mm] (see Figure 6).

5.15.5 Stress on the effective throat area of fillet welds (see 5.15.2) is considered as shear stress regardless of the direction of application.

5.16 Fillers (see Figures 7 and 8)

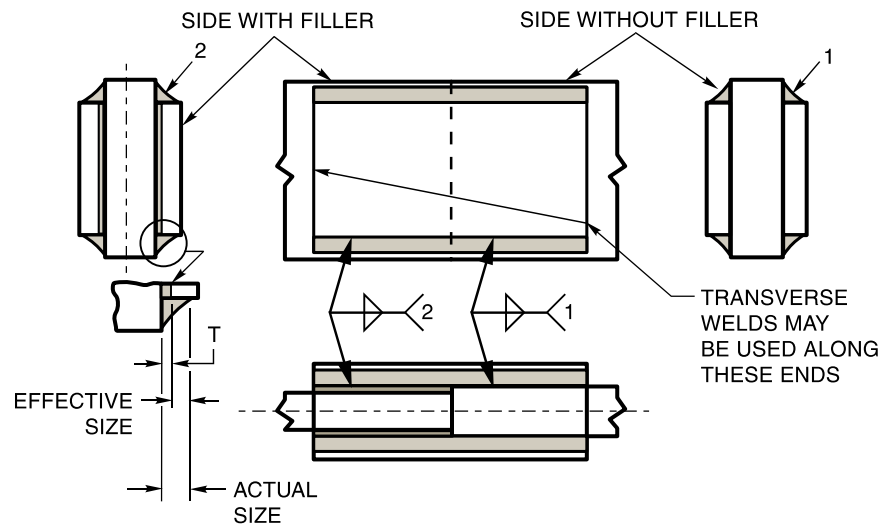
5.16.1 Fillers may be used in the following:

- (1) Splicing parts of different thicknesses;
- (2) Connections that, due to existing geometric alignment, must accommodate offsets to permit simple framing.



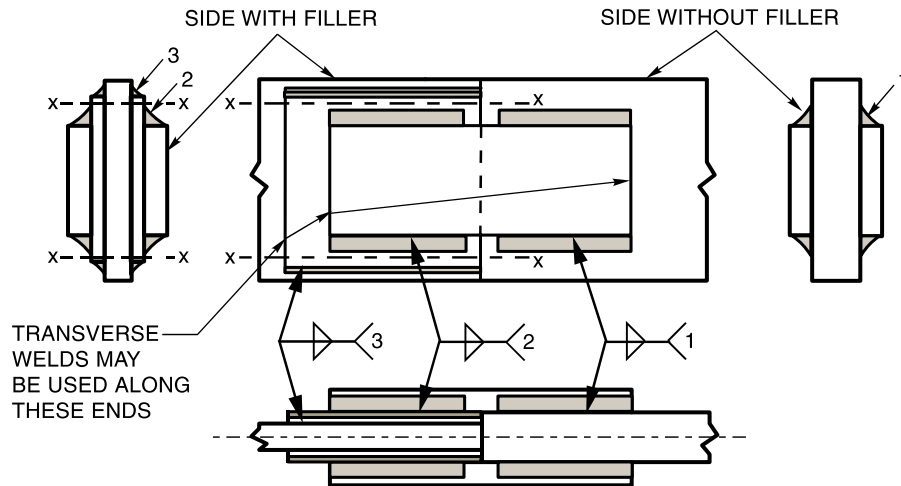
Note: The effective throat of a weld (E in this figure) is the minimum distance from the root of the joint to its face, with or without a deduction of 1/8 in [3mm].

Figure 6—Combination of Bevel Groove and Fillet Weld Profiles



Note: The effective area of Weld 2 shall equal that of Weld 1, but its size shall be its effective size plus the thickness of the filler T.

Figure 7—Splices or Connections with Fillers Less Than 1/4 in [6 mm] Thick



Notes:

1. The effective area of Weld 2 shall equal that of Weld 1. The length of Weld 2 shall be sufficient to avoid overstressing the filler in shear along the planes x-x.
2. The effective area of Weld 3 shall equal that of Weld 1, and there shall be no overstress of the ends of Weld 3 resulting from the eccentricity of the forces acting on the filler.

Figure 8—Splices or Connections with Fillers 1/4 in [6 mm] or Thicker

5.16.2 A filler less than 1/4 in [6 mm] thick shall not be used to transfer stress but shall be kept flush with the welded edges of the stress-carrying part. The sizes of welds along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler (see Figure 7).

5.16.3 Any filler 1/4 in [6 mm] or more in thickness shall extend beyond the edges of the splice plate or connecting material. It shall be welded to the part on which it is flat fitted, and the joint shall be of sufficient strength to transmit the splice plate or connection material stress applied to the surface of the filler as an eccentric load. The welds joining the splice plate or connection material to the filler shall be sufficient to transmit the splice plate or connection material stress and shall be long enough to avoid overstressing the filler along the toe of the weld (see Figure 8).

5.17 Joint Details

5.17.1 Typical joint details can be found in Annex B. The standard welding symbols used to describe joint details shall comply with AWS A2.4, *Standard Symbols for Welding Brazing, and Nondestructive Examination*.

5.18 Details of Fillet Welds

5.18.1 Details for fillet welds are listed in 5.18.1.1 through 5.18.1.6 and detailed in Figure 9.

5.18.1.1 The minimum single pass fillet weld size that is required to provide adequate heat input, except for fillet welds used to reinforce groove welds, shall be as shown in Table 6. In both cases, the minimum size applies if it is sufficient to satisfy design requirements. The use of minimum weld sizes is not intended to preclude the use of appropriate preheat which may be required because of joint restraint or base metal composition.

5.18.1.2 The minimum fillet weld size to develop to the full strength of the thinner member joined is given in Table 7. These values are only applicable when the filler metal is properly matched with the base metal; the welds are loaded statically and the thinner plate or leg is fillet welded continuously on both sides (double fillet weld).

5.18.1.3 The maximum fillet weld size detailed along edges of material shall be the following:

- (1) The thickness of the base metal, for metal less than 1/4 in [6 mm] thick as detailed in Figure 9A; or
- (2) 1/16 in [2 mm] less than the thickness of base metal, for metal 1/4 in [6 mm] or more in thickness, as detailed in Figure 9B, unless the weld is designated on the drawing to be built out to obtain full throat thickness. In the as-welded

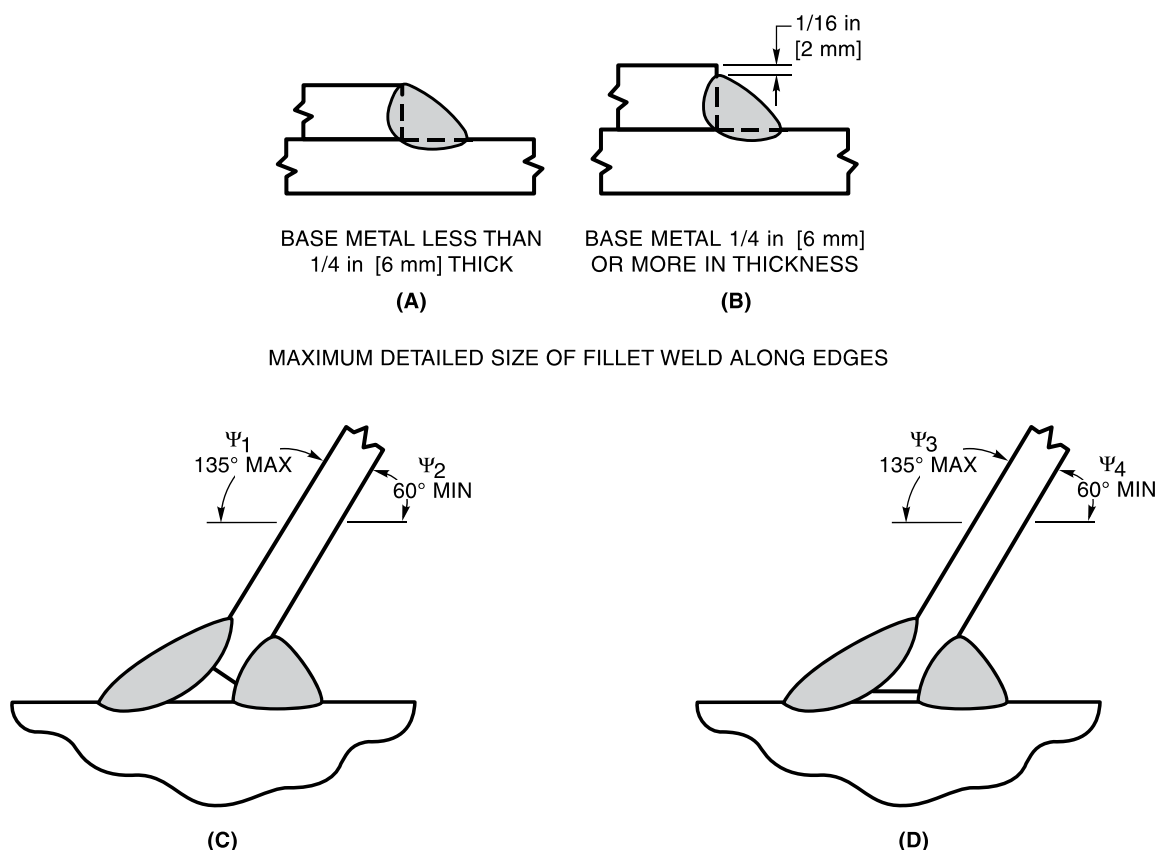


Figure 9—Details for Fillet Welds

Table 6
Minimum Single Pass Fillet Weld Size for Heat Input

Base metal thickness of Thicker part (T) in [mm]	Minimum size ^a of Single pass fillet weld in [mm]
$T \leq 1/4$ [6]	1/8 [3]
$1/4$ [6] < $T \leq 1/2$ [13]	3/16 [5]
$1/2$ [13] < $T \leq 3/4$ [20]	1/4 [6]
$3/4$ [20] < T	5/16 [8]

^a The weld size need not exceed the thickness of the thinner part joined.

condition, the distance between the edge of the base metal and the toe of the weld may be less than 1/16 in. [2 mm], provided the weld size is clearly verifiable.

5.18.1.4 Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. These fillet welds may overlap, subject to the provisions in 5.15.2.2. Fillet welds in holes or slots are not to be considered as plug or slot welds.

5.18.1.5 Fillet welds may be used in skewed T-joints having a dihedral angle of not less than 60° nor greater than 135° (see Figures 9C and 9D).

5.18.1.6 When welding is required in an acute angle that is less than 60° but equal to or greater than 30° [Figure 10 (Nontubular and Tubular)], the effective throat shall be increased by the Z-loss allowance (Table 8 and Table 9). The

Table 7
Minimum Size of Full Strength Double Fillet Welds^a

Thinner Plate Thickness (t)		Full Strength ^b Weld ($S = 3/4 t$) ^c		Thinner Plate Thickness (t)		Full Strength ^b Weld ($S = 3/4 t$) ^c	
in	mm	in	mm	in	mm	in	mm
1/4	6	3/16	5	1 3/8	35	1 1/32	26
5/16	8	15/64	6	1 1/2	38	1 1/8	28
3/8	10	9/32	8	1 5/8	41	1 7/32	31
7/16	11	21/64	9	1 3/4	45	1 5/16	34
1/2	13	3/8	10	2	50	1 1/2	38
9/16	14	27/64	11	2 1/8	54	1 19/32	41
5/8	16	15/32	12	2 1/4	57	1 11/16	43
3/4	20	9/16	15	2 3/8	60	1 25/32	45
7/8	22	21/32	16	2 1/2	64	1 7/8	48
1	25	3/4	20	2 5/8	67	1 31/32	50
1 1/8	29	27/32	22	2 3/4	70	2 1/16	53
1 1/4	32	15/16	24	3	75	2 1/4	56

^a The fillet sizes listed do not take into consideration the effective throat thickness obtainable from GMAW, FCAW and SAW processes.

^b Filler metal properties match with base metal strength

^c S = Leg size of fillet.

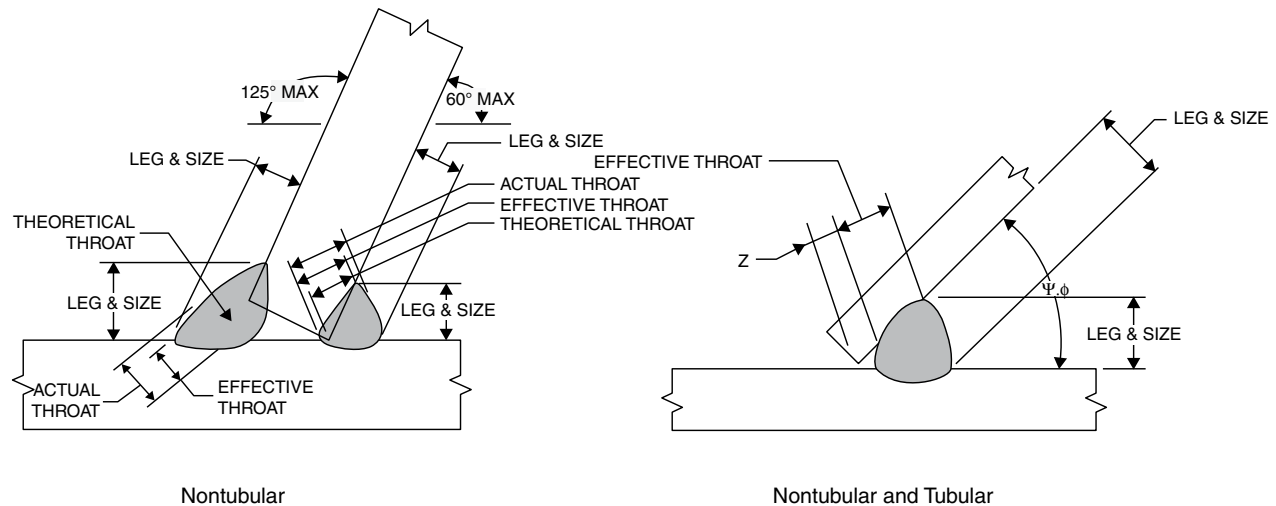


Figure 10—Skewed T-Joints

contract documents shall specify the required effective throat. The shop drawings shall show the required leg dimensions to satisfy the required effective throat, increased by the Z-loss allowance in Tables 8 and 9.

5.18.1.7 The minimum length of an intermittent fillet weld shall be 1–1/2 in [40 mm], and spacing shall not exceed 12 times the thickness of thinner part, but not more than 6 in [150 mm].

5.18.1.8 Minimum spacing and dimensions of holes or slot when fillet welding is used shall conform to the requirements of 5.19.

5.19 Details of Plug and Slot Welds

5.19.1 The minimum diameter of the hole for a plug weld shall be no less than the thickness of the part containing it plus 5/16 in [8 mm], preferably rounded to the next greater odd 1/16 in [even 2 mm] increment. The maximum

Table 8
Z Loss Dimension (Nontubular)

Dihedral Angle ψ	Position of Welding: V or OH			Position of Welding: H or F		
	Process	Z(in)	Z(mm)	Process	Z(in)	Z(mm)
$60^\circ > \psi \geq 45^\circ$	SMAW	1/8	3	SMAW	1/8	3
	FACW-S	1/8	3	FCAW-S	0	0
	FACW-G	1/8	3	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
$45^\circ > \psi \geq 30^\circ$	SMAW	1/4	6	SMAW	1/4	6
	FACW-S	1/4	6	FCAW-S	1/8	3
	FACW-G	3/8	10	FCAW-G	1/4	6
	GMAW	N/A	N/A	GMAW	1/4	6

Table 9
Z Loss Dimensions for Calculating PJP T-, Y-, and K-Tubular Connection Minimum Weld Sizes

Joint Included Angle ϕ	Position of Welding: V or OH			Position of Welding: H or F		
	Process	Z (in)	Z (mm)	Process	Z (in)	Z (mm)
$\phi \geq 60^\circ$	SMAW	0	0	SMAW	0	0
	FCAW-S	0	0	FCAW-S	0	0
	FCAW-G	0	0	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
	GMAW-S	0	0	GMAW-S	0	0
$60^\circ > \phi \geq 45^\circ$	SMAW	1/8	3	SMAW	1/8	3
	FCAW-S	1/8	3	FCAW-S	0	0
	FCAW-G	1/8	3	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
	GMAW-S	1/8	3	GMAW-S	1/8	3
$45^\circ > \phi \geq 30^\circ$	SMAW	1/4	6	SMAW	1/4	6
	FCAW-S	1/4	6	FCAW-S	1/8	3
	FCAW-G	3/8	10	FCAW-G	1/4	6
	GMAW	N/A	N/A	GMAW	1/4	6
	GMAW-S	3/8	10	GMAW-S	1/4	6

diameter shall equal the minimum diameter plus 1/8 in [3 mm], or 2–1/4 times the thickness of the member, whichever is greater.

5.19.2 The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

5.19.3 The length of the slot for a slot weld shall not exceed ten times the thickness of the part containing it. The width of the slot shall be no less than the thickness of the part containing it plus 5/16 in [8 mm], preferably rounded to the next greater odd 1/16 in [even 2 mm] increment. The maximum width shall equal the minimum width plus 1/8 in [3 mm] or 2 1/4 times the thickness of the member, whichever is greater.

5.19.4 Plug and slot welds are not permitted in quenched and tempered steels.

5.19.5 The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except those ends which extend to the edge of the part.

5.19.6 The minimum spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center-to-center spacing in a longitudinal direction of any line shall be two times the length of the slot.

5.19.7 The depth of filling of plug or slot welds in metal $5/8$ in [16 mm] thick, or less, shall be equal to the thickness of the material. In metal over $5/8$ in [16 mm] thick, it shall be at least one-half the thickness of the material, but no less than $5/8$ in [16 mm].

5.19.8 The effective area of plug and slot welds (see 5.15.3) is considered to resist shear stresses only.

5.20 Complete Joint Penetration (CJP) Groove Welds

5.20.1 Details for complete joint penetration groove welds are found in Annex B, Figure B.1 and are subject to the limitations specified in 5.20.2 through 5.20.5.

5.20.2 Dimensional Tolerances. Dimensions of groove welds specified in 5.20.1 may vary on design or detailed drawings within the limits or tolerances shown in the “As Detailed” column in Figure A.1. J- and U-grooves may be prepared before or after assembly.

5.20.3 Joints detailed in Annex B for shielded metal arc welded joints may be used for GMAW or FCAW.

5.20.4 Joint Root Openings. Joint root openings may vary as noted in 5.20 and 5.21. However, for automatic or machine welding using the FCAW, GMAW, and SAW processes, the maximum root opening variation (minimum to maximum opening as fit-up) should not exceed $1/8$ in [3 mm]. Variations greater than $1/8$ in [3 mm] should be locally corrected prior to automatic or machine welding.

5.20.5 Corner Joints. For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive melting.

5.21 Partial Joint Penetration (PJP) Groove Welds

5.21.1 Details of partial joint penetration groove welds are found in Annex B, Figure B.2 and are subject to the limitations specified in 5.21.2.

5.21.1.1 Definition. Except as provided in Figure A.1, groove welds without steel backing welded from one side, and groove welds welded from both sides, but without backgouging, are considered partial joint penetration groove welds. Skewed T-joint welds, with angles smaller than 60° , are considered to be partial joint penetration groove welds (see Figure 9).

5.21.2 Dimensional Tolerances. Dimensions of groove welds specified in 5.21.1 may vary on design or detailed drawings within the limits or tolerances shown in the “As Detailed” column in Figure A.2. J- and U-grooves may be prepared before or after assembly.

5.21.3 Minimum Weld Size. The minimum weld size of partial joint penetration square-, single-, or double-V-, bevel-, J-, and U-groove welds required to provide adequate heat input shall be as shown in Table 10. The use of minimum weld sizes is not intended to preclude the use of appropriate preheat which may be required because of joint restraint or base metal composition.

Shop or working drawings shall specify the depth of bevel (S) applicable for the weld size (E) required for the welding process and position of welding to be used (see Figure B.2).

5.21.4 Joints detailed in Annex B for shielded metal arc welded joints may be used for GMAW or FCAW.

5.22 Beam Copes and Weld Access Holes Radii of beam copes and weld access holes shall provide a smooth transition free of notches or cutting past the points of tangency between adjacent surfaces and shall meet the surface requirements of 6.2.2.

6. Workmanship

6.1 General

6.1.1 All applicable paragraphs of this section shall be observed in the production and inspection of weldments produced by any process under this specification.

Table 10
Minimum Weld Size for Partial Joint Penetration Groove Welds

Base Metal Thickness of Thicker Part Joined in [mm]	Minimum Weld Size ^a in [mm]
1/8 [3] to 3/16 [5] inclusive	1/16 [2]
Over 3/16 [5] to 1/4 [6] inclusive	1/8 [3]
Over 1/4 [6] to 1/2 [13] inclusive	3/16 [5]
Over 1/2 [13] to 3/4 [20] inclusive	1/4 [6]
Over 3/4 [20] to 1 1/2 [40] incl.	5/16 [8]
Over 1 1/2 [40] to 2 1/4 [60] inclusive	3/8 [10]
Over 2 1/4 [60] to 6 [150] inclusive	1/2 [13]
Over 6 [150]	5/8 [16]

^a Except the weld size need not exceed the thickness of the thinner part.

6.1.2 All items of equipment for welding and cutting shall be designed, manufactured, and maintained in such condition as to enable qualified welders, welding operators, and tack welders to follow qualified welding procedures and attain the results required by this specification.

6.1.3 Welding shall not be done when the ambient temperature is lower than 0°F [−18°C]. *NOTE: 0°F [−18°C] does not mean the ambient environmental temperature, but the temperature in the immediate vicinity of the weld. The ambient environmental temperature may be below 0°F [−18°C], but a heated structure or shelter around the area being welded could maintain the temperature adjacent to the weldment at 0°F [−18°C] or higher.* In addition, welding shall not be done when surfaces are wet, exposed to rain, snow, or high wind, or when welders are otherwise exposed to inclement weather conditions.

6.1.4 The sizes and lengths of welds shall not be less than nor substantially more than those specified by design requirements and detailed drawings. The location of welds shall not be changed unless approved by the Engineer.

6.1.5 The Manufacturer's adherence to this specification shall include responsibility for the following:

- (1) producing welds as designated on drawings by appropriate symbols and notes, with sufficient detail to show joint preparation compatible with applied processes;
- (2) providing and using written welding procedure specifications (WPSs);
- (3) ensuring that qualified welders are used to make welds;
- (4) recording and maintaining results of all welder performance and procedure qualification tests;
- (5) controlling use of designated base metals and consumables;
- (6) inspecting the welds to the requirements of this specification;
- (7) ensuring a safe welding environment and safe welding practice; and
- (8) having a quality system in place. The requirements of AWS B5.17, *Specification for the Qualification of Welding Fabricators* may be used as a guide in establishing this quality program. Accreditation of quality systems of welding fabricators may be obtained through the AWS Certified Welding Fabricator (CWF) or equivalent programs.

6.2 Preparation of Materials

6.2.1 Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, cracks, and other defects which would adversely affect the quality or strength of the weld. Surfaces to be welded and surfaces adjacent to them shall be free from scale, slag, rust, grease, or other foreign material that will prevent proper welding or produce objectionable fumes.

6.2.2 Mechanical or thermal processes may be used for weld joint preparation. The resulting surfaces shall be reasonably smooth for welding. As a guide for thermal cut surfaces, refer to AWS C4.6M:2006 (ISO 9013:2002 IDT), *Thermal Cutting*

– *Classification of Thermal Cuts – Geometric Product Specification and Quality Tolerances*. Backgouging or the removal of unacceptable work or material may be carried out by any appropriate means such as chipping, grinding, carbon arc, plasma arc, or oxyfuel gas gouging. Caution shall be taken when oxyfuel gas cutting or gouging is used on any structural weldment where stresses due to adverse heating conditions may be considered detrimental to the end product. The gouged or cut surfaces may require grinding to remove a carburized layer resulting from these operations. Exercising care in the use of the gouging or cutting process may produce surfaces which are usable without subsequent preparation. .

6.2.3 Backing strips, rings, and spacer blocks shall be of the same general type of material as the base metal or as specified by the design drawings or approved welding procedure specification.

6.3 Assembly

6.3.1 Fillet Welds

6.3.1.1 The parts to be joined by fillet welds shall be brought into as close contact as practicable. The root opening shall not exceed 3/16 in [5 mm] except in cases involving either shapes or plates 3 in [75 mm] or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in [8 mm] is acceptable provided a backing weld or suitable backing is used.⁶ If the separation is greater than 1/16 in [2 mm], the leg of the fillet weld shall be increased by the amount of the root opening or the Manufacturer shall demonstrate that the required effective throat has been obtained.

6.3.1.2 The separation between faying surfaces of plug and slot welds, and of butt joints landing on a backing, shall not exceed 1/16 in [2 mm]. The use of fillers is prohibited except as specified on the drawings or as specially approved by the Engineer.

6.3.1.3 The reentrant angle at the toe of the fillet weld shall not be less than 110° for welded joints with inspection Class II and III. The reentrant angle at the toe of the fillet weld shall not be less than 90° for welded joints inspection Class IV. (See Figure 13)

6.3.2 Groove Welds

6.3.2.1 The parts to be joined by partial joint penetration groove welds parallel to the length of the member, shall be brought into as close contact as practicable. The root opening between parts shall not exceed 3/16 in [5 mm] except in cases involving rolled shapes or plates 3 in [75 mm] or greater in thickness if, after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance. In such cases, a maximum root opening of 5/16 in [8 mm] is applicable provided a backing weld or suitable backing is used and the final weld meets the requirements for weld size.

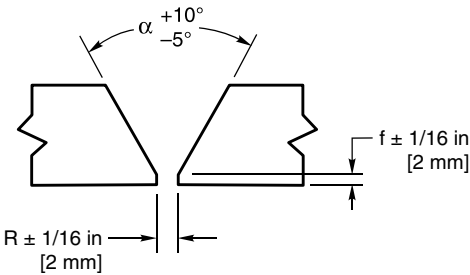
6.3.2.2 Parts to be joined by groove welded butt joints shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, an offset not exceeding 10% of the thickness of the thinner part joined, but in no case more than 1/8 in [3 mm], shall be permitted as a departure from the theoretical alignment. In correcting misalignment in such cases, the parts shall not be drawn in to a greater slope than 0.5 in 12. Measurement of offset shall be based upon the center line of parts unless otherwise shown on the drawings.

6.3.2.3 The reentrant angle at the toe of the groove weld shall not be less than 135° for welded joints with inspection Classes II and III. The reentrant angle at the toe of the groove weld for welded joints with inspection Class IV shall not be less than 110°. (See Figure 13)

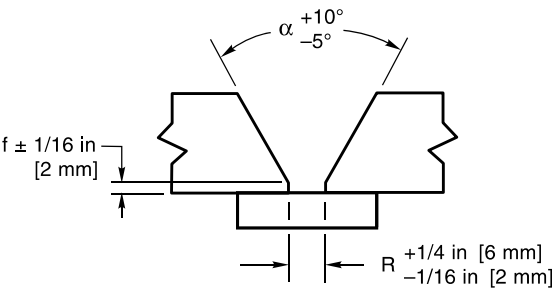
6.3.2.4 With the exclusion of electroslag and electrogas welding, and with the exception of 6.3.2.4 (1), the dimensions of the cross section of the groove welded joints which vary from those shown on the detail drawings by more than the following tolerances shall be referred to the Engineer for approval or correction.

(1) Root openings wider than those permitted in Figure 11, but not greater than twice the thickness of the thinner part or 3/4 in [20 mm], whichever is less, may be corrected by welding to acceptable dimensions prior to joining the parts by welding.

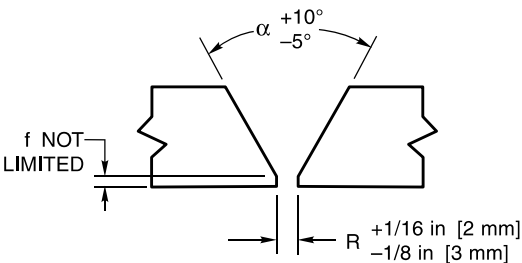
⁶ Backing may be of flux, glass tape, Iron powder, or similar materials; by means of shielded metal arc welding root passes deposited with low hydrogen electrodes or other arc welding processes.



(A) GROOVE WELD WITHOUT BACKING—
ROOT NOT BACKGOUGED



(B) GROOVE WELD WITH BACKING—
ROOT NOT BACKGOUGED



(C) GROOVE WELD WITHOUT BACKING—
ROOT BACKGOUGED

	Root Not Backgouged		Root Backgouged	
	in	mm	in	mm
(1) f Root face	$\pm 1/16$	± 2	Not limited	
(2) R Root opening without backing	$\pm 1/16$	± 2	$+1/16, -1/8$	$+2, -3$
R Root opening with backing	$+1/4, -1/16$	$+6, -2$	Not applicable	
(3) α Groove angle	$+10^\circ, -5^\circ$		$+10^\circ, -5^\circ$	

Figure 11—Workmanship Tolerances in Assembly of Groove Welded Joints

(2) Root openings wider than those correctable in accordance with 6.3.4.1 may be corrected by welding only with the approval of the Engineer.

6.3.2.5 Grooves produced by gouging shall be in conformance to the groove profile dimensions as specified in Figures B.1 and B.2 (Annex B).

6.3.3 Members to be welded shall be brought into correct alignment and held in position by bolts, clamps, wedges, guy lines, struts, and other suitable devices, or by tack welds until welding has been completed. The use of jigs and fixtures is recommended where practicable. Suitable allowances shall be made for warpage and shrinkage.

6.3.4 All tack welds shall be made using the same grade welding electrode or filler metal as the final weld, unless otherwise specified and qualified by testing. Tack welds may be incorporated in the final weld if they have been deposited by qualified welders using an approved welding procedure specification, and after visual examination shows them to be of acceptable quality. Multiple-pass tack welds shall be deposited by a cascaded sequence.

6.3.5 Welding procedures with complete joint penetration where the joint is welded from both sides shall require either backgouging of the underside of the root pass before welding the second side or it shall be demonstrated by actual welding tests that backgouging may be omitted without detriment to the weld. Backgouging shall require removal of the underside of the root pass to sound metal as indicated by liquid penetrant or magnetic particle inspection. Welding procedures that omit backgouging shall be tested to demonstrate that the resulting welds are consistently free of weld defects as indicated by close examination of weld cross-sections and side-bend tests.

6.3.6 Each pass of deposited weld metal that is covered with a slag or other oxide that will prevent fusion on subsequent passes or interfere with visual inspection shall be thoroughly cleaned using slagging picks, grinding wheels, or wire brushes. Pneumatic chippers may be used provided they do not peen or distort the weld.

6.3.7 Preheating and interpass temperature control shall ensure that the full thickness of the weld joint preparation and adjacent base metal for a distance at least equal to the thickness of the thickest welded part (but not less than 3 in. [75 mm]) in all directions from the point of welding are within the temperature range specified by the welding procedure specification.

6.3.7.1 Preheat and interpass temperatures shall be sufficient to prevent crack formation and shall be specified in the welding procedure specification. For quenched and tempered steel, such as material group 11B in AWS B2.1/B2.1M, the maximum preheat and interpass temperature should not exceed 400°F [205°C] for thickness up to 1-1/2 in [38 mm], inclusive and 450°F [230°C] for greater thickness. When welding quenched and tempered steel, heat input should not exceed the steel producer's recommendations.

6.3.7.2 Where heat input is determined to be critical to maintain base metal mechanical properties, the heat input limitation is to be specified in the welding procedure specification. The formulas for calculating heat input from welding are listed in Table 11.

6.3.8 When required by contract plans or specifications, welded assemblies shall be stress relieved by the process specified in the contract (see Clause 10).

7. Welding Procedure and Performance Qualification

7.1 Welding procedure and performance qualification shall be in accordance with AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

7.2 AWS Standard Welding Procedure Specifications (SWPS) are acceptable for use to this standard.

7.3 Welding procedures and performance qualification that were qualified to a previous edition of this standard are considered qualified to this edition.

8. Inspection

Inspectors responsible for acceptance or rejection of material and workmanship shall be qualified, and the basis of inspector qualification shall be documented. If the Engineer elects to specify the basis of inspector qualification, it shall be so stated in contract documents.

Table 11
Heat Input Calculations

Units of Measure	Formula for Calculation
Joules per inch (J/in)	$(\text{Amps} \times \text{Volts} \times 60) / \text{Travel Speed}^a$
Kilojoules per inch (KJ/in)	$(\text{Amps} \times \text{Volts} \times 60) / (\text{Travel Speed}^a \times 1000)$
Joules per millimeter (J/mm)	$(\text{Amps} \times \text{Volts} \times 60) / \text{Travel Speed}^b$
Kilojoules per meter (KJ/m)	$(\text{Amps} \times \text{Volts} \times 60) / (\text{Travel Speed}^c \times 1000)$

^a Travel Speed measured in inches per minute.

^b Travel Speed measured in millimeters per minute.

^c Travel Speed measured in meters per minute.

For welds subject to nondestructive testing in accordance to this section, the final acceptance may begin immediately after the completed welds have cooled to ambient temperature. Acceptance for ASTM A 514, A 517, and A 709 Grade 100 and 100W steels shall be based on nondestructive testing performed not less than 48 hours after completion of the welds.

8.1 Visual Inspection

8.1.1 General. The procedures and standards set forth in this section are to govern visual examination of all welds.

8.1.2 Personnel qualification shall be according to the following:

- (1) Current certification as an AWS Senior Certified Welding Inspector (SCWI) or Certified Welding Inspector (CWI) in conformance to the provisions of AWS QC1, *Standard and Guide for Qualification and Certification of Welding Inspectors*; or
- (2) Current qualification by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) Standard W178.2, *Certification of Welding Inspectors*; or
- (3) An engineer or technician who, by training or experience, or both, in metals fabrication, inspection and testing, is competent to perform inspection of the work including visual acuity verification per AWS QC1.

8.1.3 Extent of Visual Inspection Required

8.1.3.1 All welds shall be visually inspected in their entirety for discontinuities given in 8.1.4(1) and listed in Table 12.

8.1.3.2 All principal structural weldments shall be visually inspected in their entirety for dimensional defects given in 8.1.4(2).

8.1.3.3 Visual examination for cracks in welds and base metal and other defects should be aided by a strong light, magnifiers, or other such devices that may be helpful.

8.1.4 Visual Weld Discontinuities and Dimensional Defects. Weld discontinuities and dimensional defects are identified as follows:

(1) Discontinuities in Welds

- (a) cracks
- (b) undercut
- (c) incomplete joint penetration
- (d) incomplete fusion
- (e) surface porosity
- (f) weld bead irregularities and profiles

(2) Dimensional Defects

- (a) incorrect joint geometry,

Table 12
Acceptance Criteria for Inspection

Extent of Weld Discontinuities Allowed					
Inspection Classification	Cracks	Undercut	Incomplete Joint Penetration (Underfill), Incomplete Fusion	Surface Porosity Including Piping Porosity ^a	Weld Bead Irregularities and Profiles
Class I	None	Visually free from undercut in the direction transverse to primary stress. 0.01 in [0.25 mm] maximum depth smoothly contoured undercut parallel to direction of primary stress.	Free from all evidence of incomplete joint penetration or other types of fusion discontinuities.	The frequency of porosity shall not exceed one in 4 in [100 mm] of weld length, and the maximum diameter shall not exceed 1/32 in [1 mm].	See 8.1.5.6.
Class II	None	0.01 in [0.25 mm] maximum depth for smoothly contoured undercut transverse to direction of primary stress. 1/32 in [1 mm] maximum depth for undercut parallel to direction of primary stress.	Free from all evidence of incomplete joint penetration or other types of fusion discontinuities.	The frequency of porosity shall not exceed one in 4 in [100 mm] of weld length, and the maximum diameter shall not exceed 1/32 in [1 mm].	Rough, irregular welds and excess reinforcement to be ground smooth. (See Figure 13) Reentrant angle at the toe of the weld shall be no less than 135° for groove welds and 110° for fillet welds.
Class III	None	1/32 in [1 mm] maximum depth for undercut transverse and parallel to direction of primary stress.	1/3T or 1/2 in [13 mm] maximum length incomplete penetration. Sum of all discontinuities not to exceed 1 in [25 mm] in 12 in [300 mm].	The sum of diameters 1/16 in [2 mm] or greater shall not exceed 1/4 in [6 mm] in any linear inch [25mm] of weld, or 1/2 in [13 mm] in 12 in [300 mm] length.	Rough, irregular welds and excess reinforcement to be ground smooth. (See Figure 13) Reentrant angle at the toe of the weld shall be no less than 135° for groove welds and 110° for fillet welds.
Class IV	None	1/32 in [1 mm] maximum depth for undercut transverse and parallel to direction of primary stress.	2/3 T or 3/4 in [20 mm] maximum length incomplete penetration. Sum of all discontinuities not to exceed 1 in [25 mm] in 6 in [150 mm].	The sum of diameters 3/32 in [2.5 mm] or greater shall not exceed 3/8 in [10 mm] in any linear inch [25mm] of weld, or 1/2 in [13 mm] in 12 in [300 mm] length.	Reentrant angle at the toe of the weld shall be no less than 110° for groove welds and 90° for fillet welds. (See Figure 13)

^a Piping porosity is elongated porosity whose major dimension lies in a direction approximately normal to the weld surface. Frequently it is referred to as "pin holes" when the porosity extends to the surface.

- (b) incorrect weld size, and
- (c) incorrect final dimensions.

8.1.5 Description of Weld Discontinuities

8.1.5.1 Crack. A crack is a fracture-type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement. (See AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*.)

(1) Figure 12 illustrates the various types of weld-related cracking most of which can be detected by visual examination.

(2) Weld metal cracks include longitudinal cracks, transverse cracks, and crater cracks.

(3) Base-metal cracks include toe cracks adjacent to weld edges and transverse cracks extending from the weld metal into the base metal. Subsurface (underbead) cracks are not detectable by visual inspection.

8.1.5.2 Undercut. Undercut is a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal as illustrated in Figure 13.

8.1.5.3 Incomplete Joint Penetration. Incomplete joint penetration is a joint root condition in a groove weld in which weld metal does not extend through the joint thickness.

8.1.5.4 Incomplete Fusion. Incomplete fusion is a weld discontinuity in which fusion did not occur between weld metal and fusion faces or adjoining weld beads.

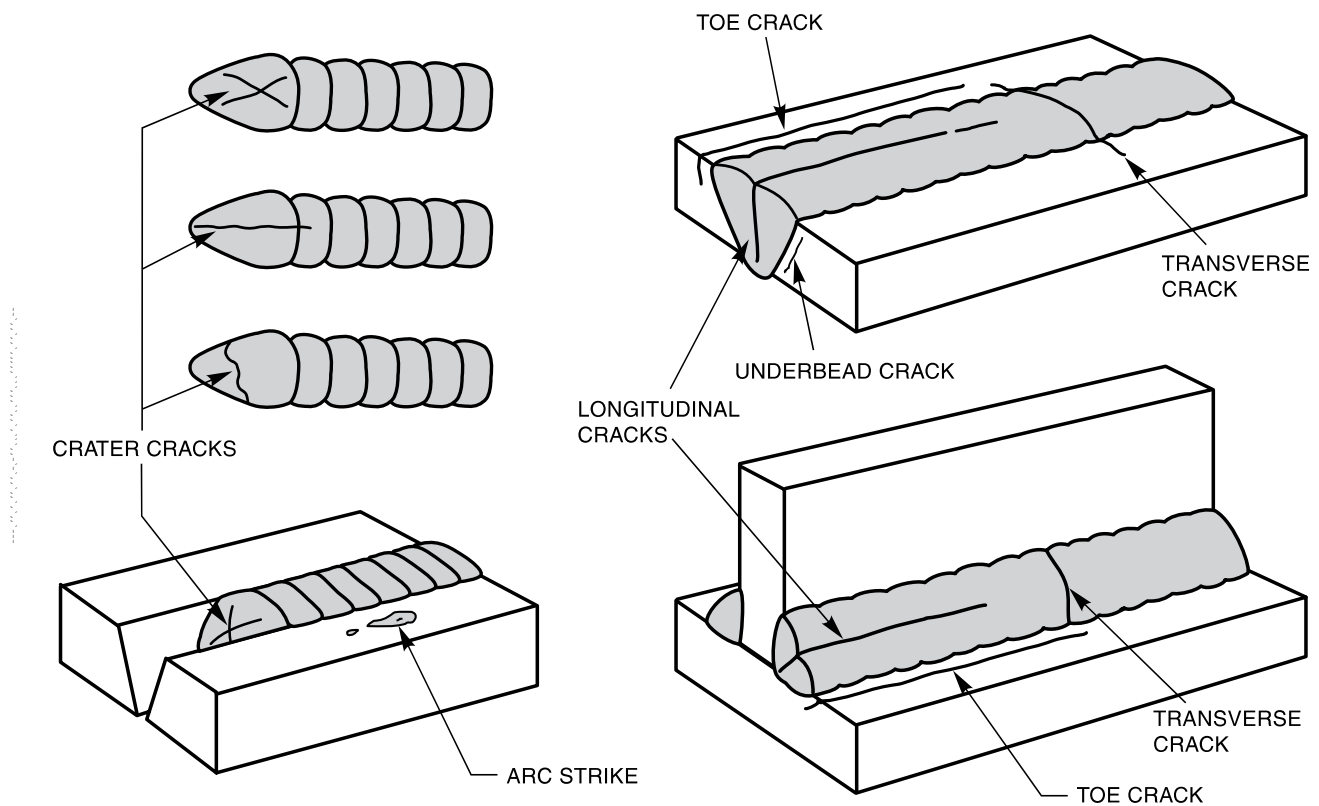


Figure 12—Cracks in Welded Joints

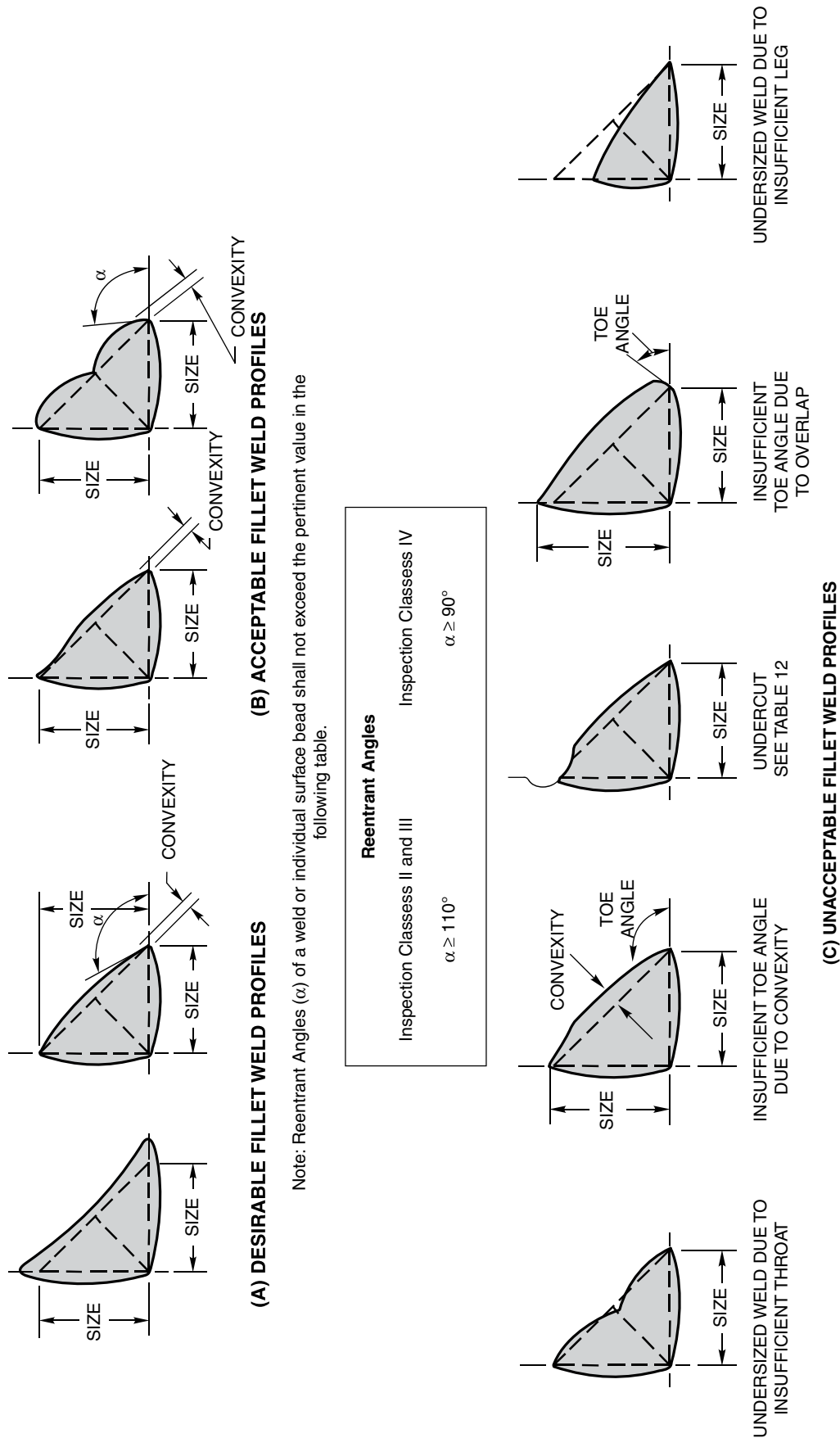


Figure 13—Acceptable and Unacceptable Weld Profiles

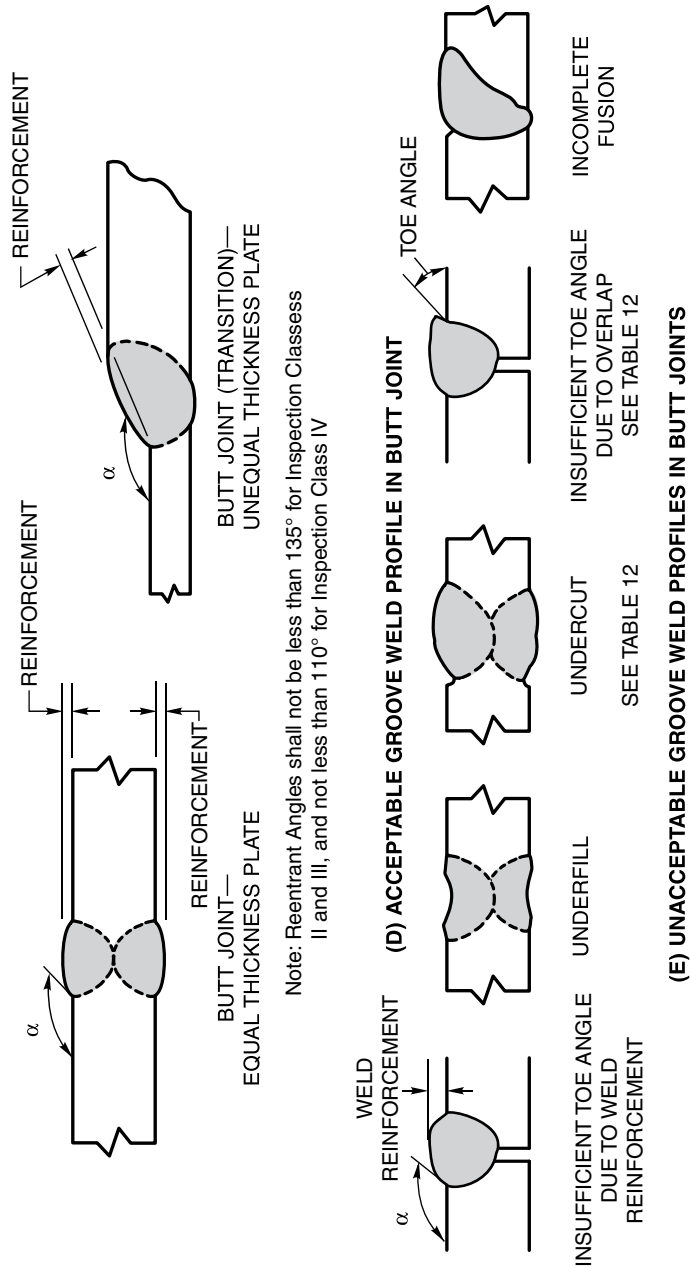


Figure 13 (Continued)—Acceptable and Unacceptable Weld Profiles

This page is intentionally blank.

Table 13
NDT and Visual Inspection Requirements^a

Inspection Class (see 4.7)	Radiographic (see 8.2) or Ultrasonic (see 8.3) Testing	Magnetic-Particle (see 8.4) or Liquid Penetrant (see 8.5) Testing	Visual Inspection (see 8.1)	
			Discontinuities (see Table 12)	Dimensions (see 8.1.7)
I	yes ^b	yes ^b	yes ^b	yes ^b
II	yes ^b (10%)	yes ^b	yes ^b	yes ^b
III	no	yes ^b	yes ^b	yes ^b
IV	no	no	yes ^b	yes ^b

^a Materials listed in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, Group 11B (i.e., A514, A517, A709) are subject to delayed cracking and shall have inspections performed not less than 48 hours after the completed weld has cooled down to ambient temperatures.

^b 100% Inspection is required unless otherwise indicated.

8.1.5.5 Surface Porosity. Surface porosity is cavity-type discontinuities formed by gas entrapment during solidification that are open to the surface.

8.1.5.6 Weld Bead Irregularities and Incorrect Profiles

(1) Weld bead irregularities and conditions of poor appearance include variations in surface layer width, non-uniformity of weld ripple, and excessive weld metal spatter.

(2) Incorrect fillet weld profiles include conditions of insufficient throat, insufficient reentrant angle at the toe of the fillet weld, underfill, excessive undercut, overlap, and insufficient leg size as defined in Figure 13C.

(3) Incorrect groove weld profiles include conditions of insufficient reentrant angle at the toe of the groove weld, excessive undercut, overlap, and incomplete fusion, as defined in Figure 13E.

(4) Machining or grinding direction shall be perpendicular to the length of Inspection Class I welds.

8.1.6 Acceptable Criteria for Weld Discontinuities. All welds shall meet the acceptance criteria listed herein and Table 12.

8.1.6.1 The faces of fillet welds may be slightly convex, flat, or slightly concave as shown in Figures 13A and 13B, with none of the unacceptable profiles shown in Figure 13C.

(1) The reentry angle at the toe of a weld or individual surface bead shall not exceed the values given in Figure 13.

(2) Except for incomplete fusion, overlap, and undercut as permitted by this specification, these profile requirements do not apply to the ends of intermittent fillet welds outside their effective length.

8.1.6.2 Groove welds shall be made with slight or minimum face reinforcement unless specified to be ground flush by design. In the case of butt and corner joints, the reentrant angle at the toe of the weld shall have gradual transition to the plane of the base metal surface (see Figure 13D.) The welds shall be free of the discontinuities shown for butt joints in Figure 13E.

8.1.6.3 Welds shall be free from overlap.

8.1.7 Description of Dimensional Defects

8.1.7.1 Incorrect Joint Geometry

(1) Incorrect joint geometry subject to visual inspection, generally before welding is started, includes out-of-tolerance welding bevel or groove dimensions, base metal misalignment, and undesirable weld joint fit-up conditions.

(2) Included in the requirements for weld joint preparation shall be inspection for removal of scale, paint, oil, etc. from the weld joint a minimum of 1/2 in [12 mm] on each side of the weld joint.

(3) Partial penetration weld joint geometry shall be visually inspected prior to welding to assure proper weld throat dimension will be achieved.

8.1.7.2 Incorrect Weld Size

(1) Incorrect weld size subject to visual inspection includes undersized fillet weld leg dimensions and underfill groove weld throat dimension as defined in Figure 13.

(2) Fillet weld size shall be determined by means of a fillet weld gage.

8.1.7.3 Incorrect Final Dimensions. Incorrect final dimensions subject to visual inspection include all conditions of dimensional inaccuracies, distortion, and lack of conformity to drawing requirements.

8.1.8 Acceptance Criteria for Dimensional Discontinuities

8.1.8.1 Incorrect Joint Geometry. Acceptance criteria for joint geometry shall be based upon the specific dimensional tolerances given in the drawing requirements. In the absence of specific weld joint geometry tolerances, any condition of the joint geometry in the opinion of the Engineer which can reasonably be expected to produce unacceptable structural discontinuities shall be considered incorrect joint geometry and unacceptable.

8.1.8.2 Incorrect Weld Size

(1) Fillet weld leg sizes shall conform to the following tolerances based on a measurement of fused leg length:

- (a) Weld sizes under 3/8 in [10 mm]: $-1/32$ in [1 mm], $+1/8$ in [3 mm];
- (b) Weld sizes 3/8 in [10 mm] and over: $-1/16$ in [2 mm], $+1/8$ in [3 mm].

The average weld size of a given length shall not be less than the weld size specified on the drawing. The average weld size is determined by the average of leg length measurements obtained at 3 in [75 mm] intervals along the weld length. For welds under 3 in [75 mm] in length, the above tolerances are applied directly.

(2) Underfill is unacceptable for groove welds in butt joints.

8.1.8.3 Incorrect Final Dimensions. Acceptability of specific dimensional conditions of the completed weldment depends upon appearance requirements and the accuracies required for subsequent machining, assembly, installation, or end use of the product.

8.1.9 Defect Removal and Repair (see Clause 9)

8.2 Radiographic Testing

8.2.1 General. The procedures and standards set forth in this clause are to govern radiographic testing of welded joints when such testing is required. The methodology shall conform to ASTM E94, *Standard Guide for Radiographic Examination*, ASTM E747, *Standard Practice Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*, and ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*.

8.2.2 Personnel performing radiographic testing shall be qualified. Acceptable qualification basis shall be the following:

- (1) Radiographic Testing Level II (RT Level II) conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A, or
- (2) Radiographic Testing Level I (RT Level I) working under an RT Level II conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A, or
- (3) For radiographic interpretation, AWS Certified Radiographic Interpreter (CRI) in conformance with AWS QC15, *Specification for the Certification of Radiographic Interpreters*.

8.2.3 Extent of Inspection

8.2.3.1 The Engineer shall identify the extent of radiographic testing to be performed by identifying the welded joints to be inspected as Class I or Class II.

(1) When welded joints with Class I Inspection are designated, the entire length of the weld shall be radiographed.

(2) When welded joints with Class II Inspection are designated, the location tested shall be a 6 in [150 mm] length of weld. The number of locations shall total 10% of the total length of the weld. When an evaluated location requires repair, two adjacent locations, one on each side, shall be tested also. If defects requiring repair are shown in either of these locations, the entire weld in that joint shall be tested.

8.2.3.2 When 100% radiography is specified, the entire length of weld in each designated joint shall be tested and evaluated in conformance to 8.2.4.1 through 8.2.4.7.

8.2.3.3 When spot radiography is specified, the selection of the spots, the testing and evaluation shall be in conformance to 8.2.5.1 through 8.2.5.4.

8.2.4 Radiographic Testing

8.2.4.1 For welded joints that are to be radiographed, the weld ripples or weld surface irregularities, inside and outside, shall be removed, where practical, by any suitable mechanical process to such a degree that the resulting radiographic contrast due to any irregularities cannot mask or be confused with the image of any indication.

8.2.4.2 The radiographic sensitivity shall be judged based on hole-type or wire image quality indicators (IQIs). (See ASTM E1025 and ASTM E747 for IQI design specifications). Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required IQIs and the essential holes or wires as described in 8.2.4.4 and Table 14, and shown in Figures 14 through 17. Identifying numbers shall show clearly in the radiograph.

8.2.4.3 When weld reinforcement or backing or both, is not removed, or wire IQI alternate placement is not used, as shown in Figures 14 through 17, shimming is required. The total thickness of steel between the IQI and the film shall be approximately equal to the average weld thickness measured through reinforcement and backing. To ensure this, steel shims shall be placed under the IQI. The shims shall extend at least 1/8 in [3 mm] beyond three sides of the IQI.

8.2.4.4 To verify the radiographic technique employed, the following requirements shall be met:

(1) Hole-type IQIs or wire IQIs shall show clearly on each radiograph. The minimum number and their required locations shall be the following:

(a) For welds joining nominally equal thickness, where a radiograph represents 10 in [250 mm] or greater of weld length, two IQIs will be placed as shown in Figure 14. Where a radiograph represents less than 10 in [250 mm] of weld length, one IQI will be placed as shown in Figure 15.

(b) For welds at transition thickness, where a radiograph represents 10 in [250 mm] or greater of weld length, two IQIs shall be placed on the thinner of the two sections and one IQI on the thicker section as shown in Figure 16. Figure 16 also permits an alternate IQI location for the use of wire IQIs. Where a radiograph represents less than 10 in [250 mm] of weld length in transition joints, IQIs will be placed as shown in Figure 17.

(c) When a radiograph does not show the outer edge of the weld area, an IQI shall be placed perpendicular to the joint with the smallest wire or hole on the outer edge of the inspection area being radiographed.

(d) For circumferential welds using a single exposure, with the source of radiation placed at the center of curvature, a minimum of three IQIs equally spaced about the circumference are required.

(2) The thickness of a hole-type IQI and the essential hole or wire shall be as specified in Table 14. A smaller essential hole or wire or a thinner hole-type IQI may be selected by the Manufacturer, provided all other provisions for radiography are met.

Thickness shall be measured as T1 or T2, or both, at the locations shown in Figures 14 through 17 and may be increased to provide for the thickness of allowable weld reinforcement, provided shims are used as specified in 8.2.4.3. Steel backing shall not be considered part of the weld or reinforcement in IQI selection.

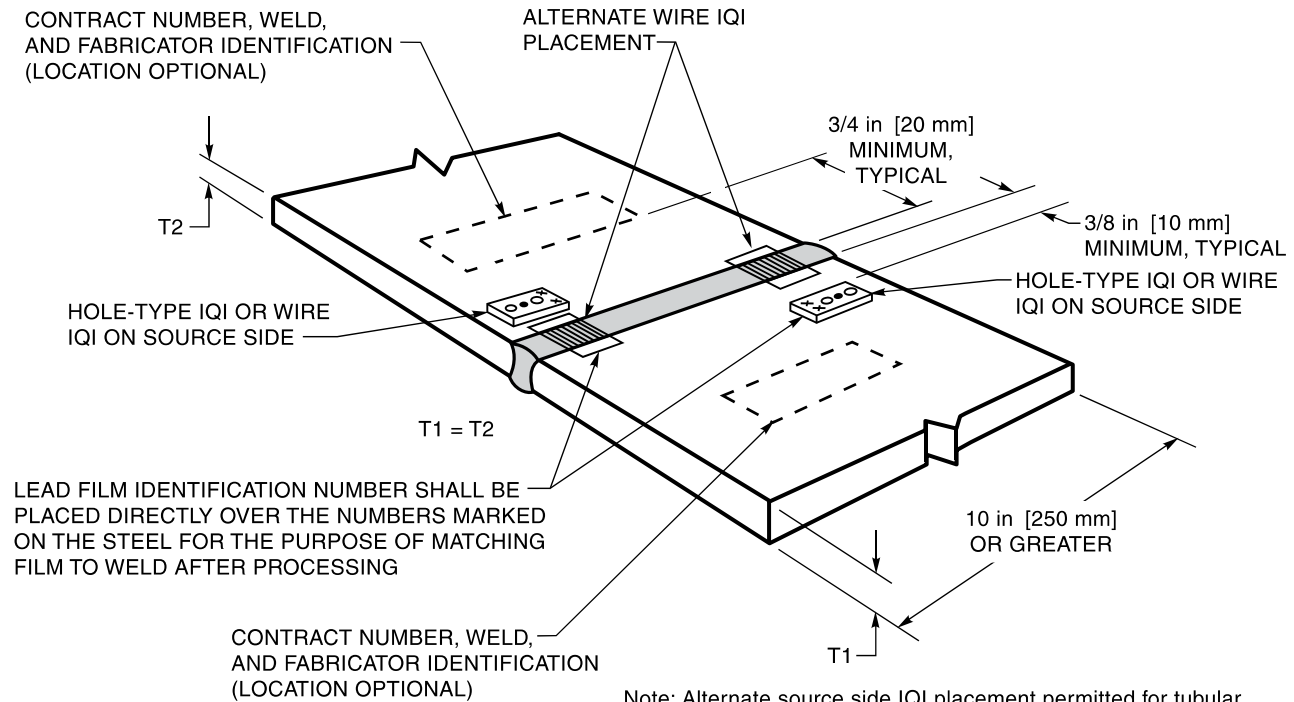
(3) Hole-type IQIs shall be manufactured from steel, preferably stainless steel, and shall conform to the requirements of ASTM E1025, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole Type Image Quality Indicators (IQI) Used for Radiology*. Each hole-type IQI shall be manufactured with three holes, one of which

Table 14
Standard Hole-Type and Wire Image Quality Indicator Requirements

Nominal Material Thickness Range ^a (T) in [mm]	Penetrameter					
	Source Side			Film Side ^b		
	Hole-Type Designation	Essential Hole	Wire Diameter, in [mm]	Hole-Type Designation	Essential Hole	Wire Diameter, in [mm]
T ≤ 0.25 [6]	12	4T	0.008 [0.20]	10	4T	0.006 [0.15]
0.25 [6] < T ≤ 0.375 [10]	15	4T	0.010 [0.25]	12	4T	0.008 [0.20]
0.375 [10] < T ≤ 0.50 [13]	17	4T	0.013 [0.33]	15	4T	0.010 [0.25]
0.5 [13] < T ≤ 0.75 [20]	20	4T	0.016 [0.41]	17	4T	0.013 [0.33]
0.75 [20] < T ≤ 1.00 [25]	25	4T	0.020 [0.51]	20	4T	0.016 [0.41]
1.00 [25] < T ≤ 1.50 [40]	30	2T	0.025 [0.64]	25	2T	0.020 [0.51]
1.50 [40] < T ≤ 2.00 [50]	35	2T	0.032 [0.81]	30	2T	0.025 [0.64]
2.00 [50] < T ≤ 2.50 [65]	40	2T	0.040 [1.02]	35	2T	0.032 [0.81]
2.50 [65] < T ≤ 4.00 [100]	50	2T	0.050 [1.27]	40	2T	0.040 [1.02]
4.00 [100] < T ≤ 6.00 [150]	60	2T	0.063 [1.60]	50	2T	0.050 [1.27]
6.00 [150] < T ≤ 8.00 [200]	80	2T	0.100 [2.54]	60	2T	0.063 [1.60]
8.00 [200] < T ≤ 10.00 [250]	100	2T	0.126 [3.20]	80	2T	0.100 [2.54]
10.00 [250] < T ≤ 12.00 [300]	120	2T	0.160 [4.06]	100	2T	0.126 [3.20]
12.00 [300] < T ≤ 16.00 [400]	160	2T	0.250 [6.35]	120	2T	0.160 [4.06]
16.00 [400] < T ≤ 20.00 [500]	200	2T	0.320 [8.13]	160	2T	0.250 [6.35]

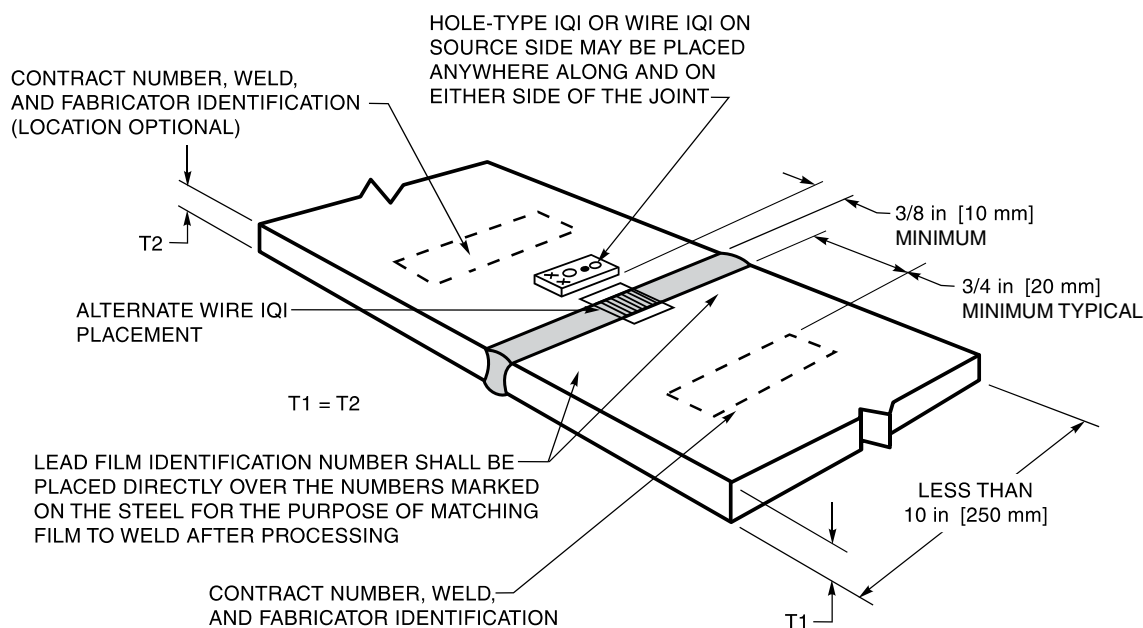
^a Single-wall radiographic thickness for tubular members.

^b Applicable to tubular members only.



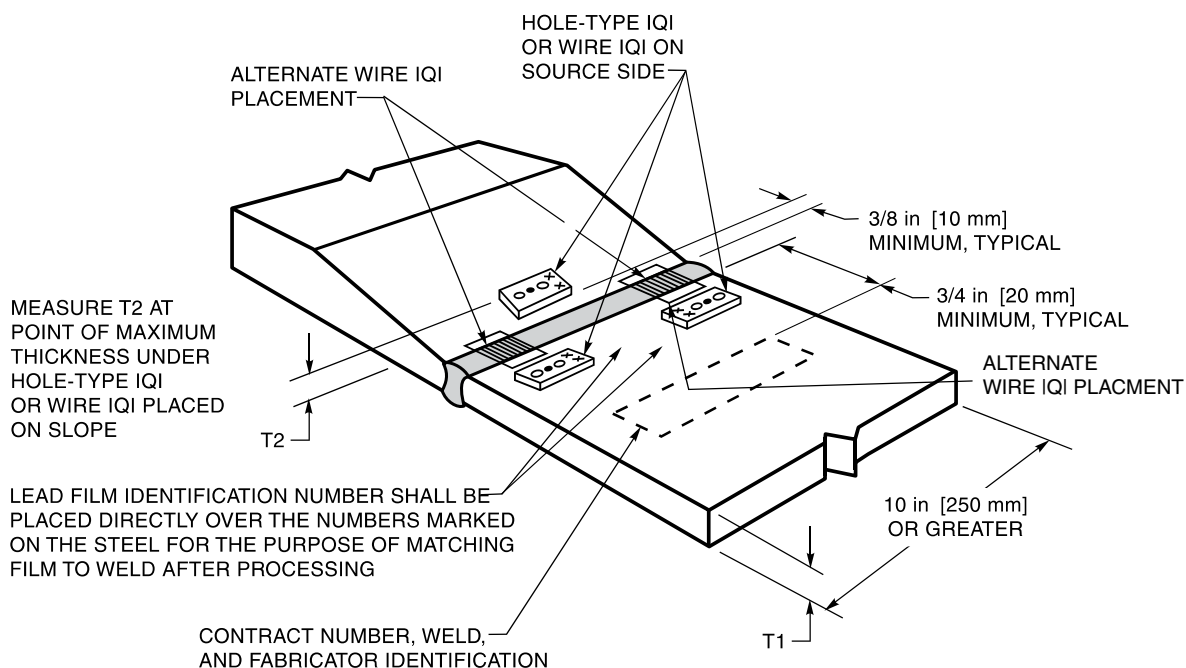
Note: Alternate source side IQI placement permitted for tubular applications and other applications when approved by the engineer.

Figure 14—Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 10 in [250 mm] and Greater in Length



Note: Alternate source side IQI placement permitted for tubular applications and other applications when approved by the engineer.

Figure 15—Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less Than 10 in [250 mm] in Length



Note: Alternate source side IQI placement permitted for tubular applications and other applications when approved by the engineer.

Figure 16—Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints 10 in [250 mm] and Greater in Length

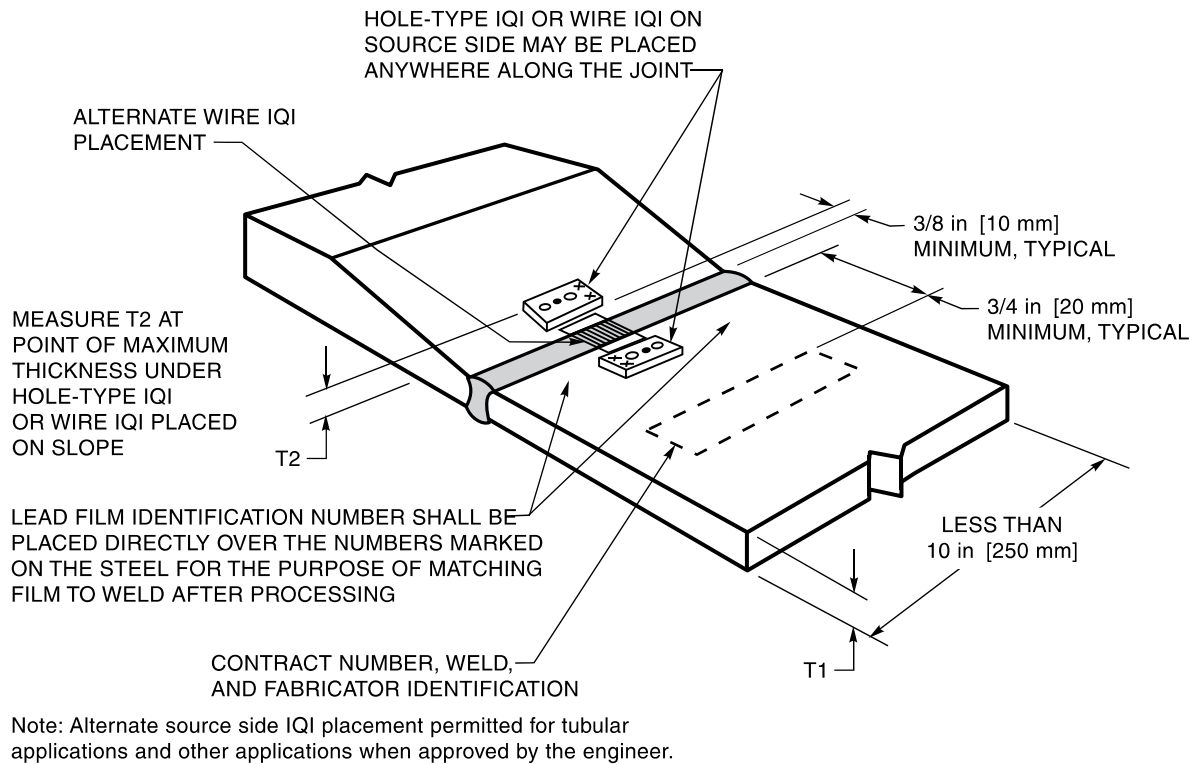


Figure 17—Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints Less Than 10 in [250 mm] in Length

shall be of a diameter equal to twice the hole-type IQI thickness (2T). The diameter of the two remaining holes shall be selected by the Manufacturer. They will ordinarily be equal to one time (1T) and four times (4T) the hole-type IQI thickness. Hole-type IQI designations 10 through 25 shall contain a 4T hole.

(4) Wire image quality indicators (IQI) shall be manufactured in accordance with ASTM E747, *Standard Practice Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*.

8.2.4.5 All radiographs shall be free from excessive artifacts, chemical or other processing defects that could interfere with proper interpretation.

8.2.4.6 Identification markers, whose images appear on the film, shall be placed adjacent to the weld on the part, not on the film; their locations shall be marked on the surface near the weld in such a manner that a defect appearing on a radiograph may be accurately located and that it is evident on the film that complete coverage of the weld has been obtained.

(1) The job identification and weld seam identification shall be indicated on each film.

(2) A complete set of radiographs for each job shall be retained by the Manufacturer and kept on file for a period of at least five years or as required by contract.

8.2.5 Spot Radiographic Examination of Welded Joints⁷

8.2.5.1 Minimum extent of spot radiography for welds not radiographed for their complete length shall be as follows:

⁷ Spot radiography, in accordance with these rules, will not ensure a predetermined quality level throughout the product fabricated. An accepted weld, according to these spot radiography rules, may still contain defects which might be disclosed on further examination.

(1) One spot shall be examined in the first 50 ft [15 m] of weld length and one spot shall be examined for each additional 50 ft [15 m] of weld length or fraction thereof. When identical welds individually less than 50 ft [15 m] of weld length, 50 ft [15 m] increments of their total weld length may be represented by one spot examination.

(2) Such additional spots as may be required shall be selected so an examination of the welding of each welding operator or welder is made. Under conditions where two or more welders or welding operators make weld layers in a joint or on the two sides of a double welded butt joint, one spot examination may represent the work of both welders and welding operators.

(3) The locations of the spots to be examined and the time after the weld is completed shall be agreed upon by the purchaser or his designated representative and by the Manufacturer.

8.2.5.2 Spot examination by radiography shall be made in conformance to 8.2.4.1 through 8.2.4.6. The minimum length of spot radiograph shall be 6 in [150 mm]. The acceptability of welds examined by spot radiography shall be judged by the following standards:

(1) Welds in which the radiographs show any type of crack or zone of incomplete fusion or penetration shall be unacceptable.

(2) Welds in which the radiographs show inclusions or cavities shall be unacceptable if the length of any such imperfection is greater than $2/3T$, where T is the thickness of the thinner plate welded. If several imperfections within these limitations exist in a line, the welds shall be judged acceptable if the sum of the longest dimensions of all such imperfections is not more than T in a length of $6T$ and if the longest imperfections considered are separated by at least $3L$ of acceptable weld metal, where L is the longest imperfection. The maximum length of acceptable imperfection shall be $3/4$ in [20 mm]. Any such imperfection shorter than $1/4$ in [6 mm] shall be acceptable for any plate thickness.

8.2.5.3 Evaluation and Retests

(1) Where spot radiography is acceptable, the entire weld length represented by the radiograph is acceptable.

(2) If a spot radiographed in conformance to these requirements discloses welding which does not comply with the minimum quality requirements, two additional spots shall be taken adjacent to the original spot, one on each side.

(a) If the additional spots examined show the welding meets the minimum quality requirements, the entire weld, represented by the three radiographs is acceptable. The defective weld found in the first radiograph shall be repaired and radiographically reinspected.

(b) If either of the two additional spots examined shows welding which does not comply with the minimum quality requirements, the entire length of weld represented shall be rejected. The entire rejected weld shall be removed and the joint shall be rewelded or, at the Manufacturer's option, the entire length of weld represented shall be completely radiographed and the defective welding corrected.

8.2.5.4 Defect Removal & Repair (see Clause 9)

8.2.6 Acceptance Standards for Radiography

8.2.6.1 Scope. The standards are applicable to ferritic steels.

8.2.6.2 Terminology

(1) **Rounded Indications.** Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any inclusion in the weld, such as porosity, slag, or tungsten.

(2) **Aligned Indications.** A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

(3) **Thickness E.** The thickness of the weld, E , is excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, E is the thinner of these two thicknesses. If a full penetration weld includes a reinforcing fillet weld, the thickness of the throat of the fillet shall be included in E .

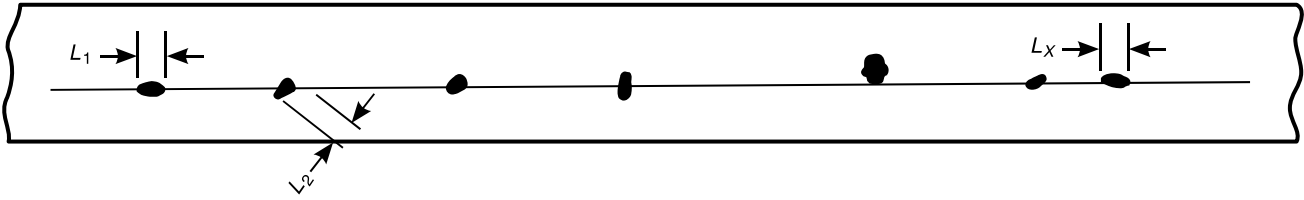
8.2.6.3 Acceptance Criteria. Sections of the weld shown by radiography to have any of the following types of imperfections shall be judged unacceptable.

- (1) Any type of crack or zone of incomplete fusion or incomplete joint penetration.
- (2) Any elongated inclusion, such as slag, which has a length greater than $1/4$ in [6 mm] for E up to $3/4$ in [20 mm], $1/3E$ for E from $3/4$ to $2-1/4$ in [20 to 60 mm], $3/4$ in [20 mm] for E over $2-1/4$ in [60 mm].
- (3) Any group of inclusions in line that has an aggregate length greater than E in a weld length $12E$, except when the distance between the successive imperfections exceeds $6L$, where L is the length of the longest imperfection in the group.
- (4) Rounded indications in excess of that specified by Table 15 and Figures 18 through 25 (ASTM E 390, *Reference Radiographs for Steel Fusion Welds* may be used in lieu of these figures).
 - (a) Maximum Size of Rounded Indication (see Table 15). An isolated indication is separated from an adjacent indication by 1 in [25 mm] or more.
 - (b) Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than E in a length of $12E$ (see Figure 18). The length of groups of aligned groups shall meet the requirements of Figure 19.
 - (c) Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.
 - (d) Rounded Indications Charts. The rounded indications as determined from the radiographic film shall not exceed that shown in the charts. The charts in Figures 20 through 25 illustrate various types of assorted randomly dispersed and clustered rounded indications for different weld thicknesses greater than $1/8$ in [3 mm]. These charts represent the maximum acceptable concentration limits for rounded indications. The chart for each thickness range represents full scale 6 in [150 mm] radiographs, and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiographs, but are typical of the concentration and size of indications permitted.
 - (e) Weld Thickness E Less than $1/8$ in [3 mm]. For E less than $1/8$ in [3 mm], the maximum number of rounded indications shall not exceed 12 in a 6 in [150 mm] length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in [150 mm] in length.

Table 15
Examples of Acceptable Indications^a

Thickness t, in [mm]	Maximum Size of Acceptable Rounded Indication, in [mm]		Maximum Size of Nonrelevant Indication, in [mm]
	Random	Isolated	
< $1/8$ [3]	$1/4t$	$1/3t$	$1/10t$
$\geq 1/8$ [3] to < $3/16$ [5]	0.031 [0.8]	0.042 [1.1]	0.015 [0.4]
$\geq 3/16$ [5] to < $1/4$ [6]	0.047 [1.2]	0.063 [1.6]	0.015 [0.4]
$\geq 1/4$ [6] to < $5/16$ [8]	0.063 [1.6]	0.083 [2.1]	0.015 [0.4]
$\geq 5/16$ [8] to < $3/8$ [10]	0.078 [2.0]	0.104 [2.6]	0.031 [0.8]
$\geq 3/8$ [10] to < $7/16$ [11]	0.091 [2.3]	0.125 [3.2]	0.031 [0.8]
$\geq 7/16$ [11] to < $1/2$ [13]	0.109 [2.8]	0.146 [3.7]	0.031 [0.8]
$\geq 1/2$ [13] to < $9/16$ [14]	0.125 [3.2]	0.168 [4.3]	0.031 [0.8]
$\geq 9/16$ [14] to < $5/8$ [16]	0.142 [3.6]	0.188 [4.8]	0.031 [0.8]
$\geq 5/8$ [16] to < $11/16$ [17]	0.156 [4.0]	0.210 [5.3]	0.031 [0.8]
$\geq 11/16$ [17] to < $3/4$ [20]	0.156 [4.0]	0.230 [5.8]	0.031 [0.8]
$\geq 3/4$ [20] to ≤ 2 [50]	0.156 [4.0]	0.250 [6.4]	0.031 [0.8]
> 2 [50]	0.156 [4.0]	0.375 [9.5]	0.063 [1.6]

^a This table contains examples only.

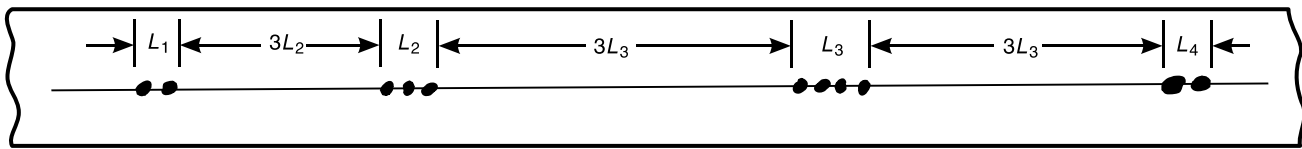


Note:

Sum of L_1 Through L_x Shall be less than t in a length of $12t$.

Adapted from ASME Boiler and Pressure Vessel Code, 2004 Section VIII, Division 1, Appendix 4, Figure 4.1 with permission from ASME.

Figure 18—Examples of Aligned Rounded Indications



NOTE: Sum of the group lengths shall be less than t in length of $12t$

Maximum Group Length

$L = 1/4$ in (6 mm) for t less than $3/4$ in (19 mm)

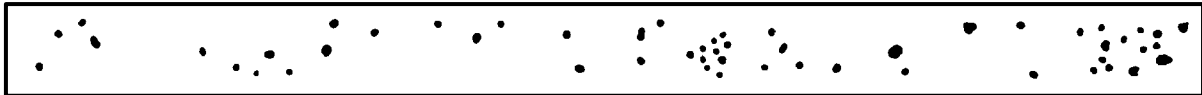
$L = 1/3t$ for t $3/4$ in (19 mm) to $2 1/4$ in (57 mm)

$L = 3/4$ in (19 mm) for t greater than $2 1/4$ in (57 mm)

Maximum Group Spacing

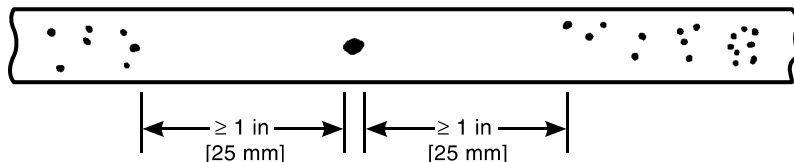
$3L$ Where L is the length of the longest adjacent group being evaluated.

Figure 19—Examples of Groups of Aligned Rounded Indications



(A) RANDOM ROUNDED INDICATIONS

TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD



(B) ISOLATED INDICATION

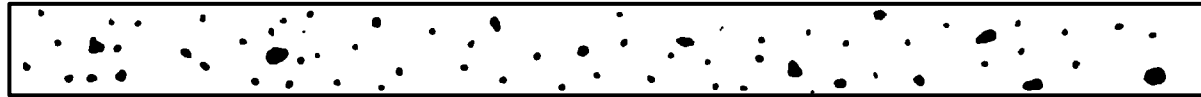


(C) CLUSTER

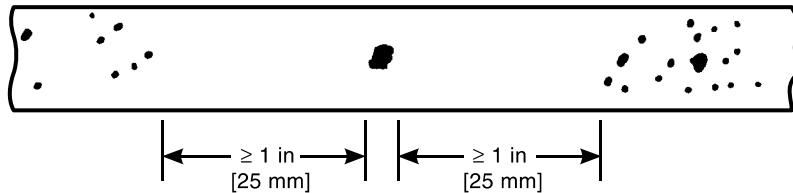
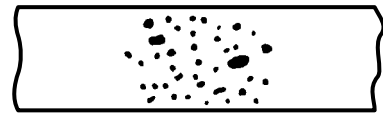
Note: Maximum size of indication per table 15 or as otherwise noted.

Adapted from ASME Boiler and Pressure Vessel Code, 2004 Section VIII, Division 1, Appendix 4, Figure 4.3 with permission from ASME.

Figure 20—Charts for Thickness Equal to $1/8$ in. [3 mm] to $1/4$ in. [6 mm], Inclusive

**(A) RANDOM ROUNDED INDICATIONS**

TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD

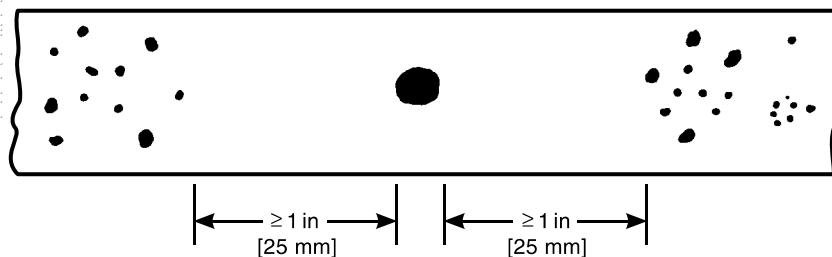
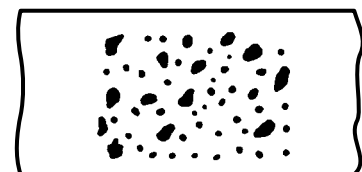
**(B) ISOLATED INDICATION****(C) CLUSTER**

Note: Maximum Size of Indication Per Table 15 or as otherwise Noted.

Adapted from ASME Boiler and Pressure Vessel Code, 2004 Section VIII, Division 1, Appendix 4, Figure 4.4 with permission from ASME.

Figure 21—Charts for Thickness Over 1/4 in. [6 mm] to 3/8 in. [10 mm], Inclusive**(A) RANDOM ROUNDED INDICATIONS**

TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD

**(B) ISOLATED INDICATION****(C) CLUSTER**

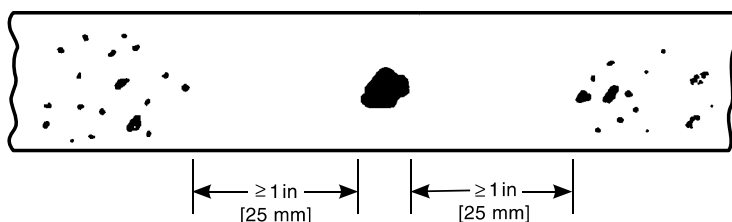
Note: Maximum size of indication per table 15 or as otherwise noted.

Adapted from ASME Boiler and Pressure Vessel Code, 2004 Section VIII, Division 1, Appendix 4, Figure 4.5 with permission from ASME.

Figure 22—Charts for Thickness Over 3/8 in [10 mm] to 3/4 in [20 mm], Inclusive

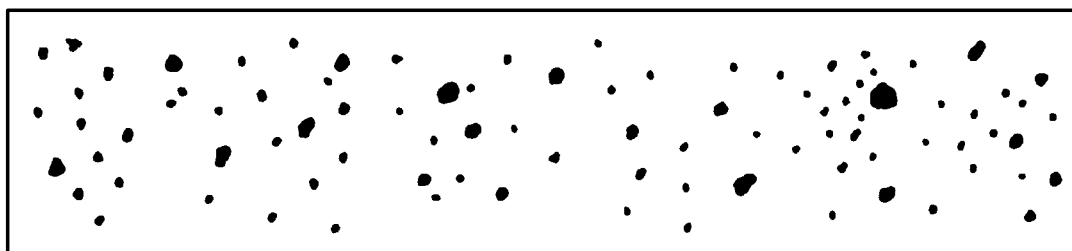
**(A) RANDOM ROUNDED INDICATIONS**

TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD

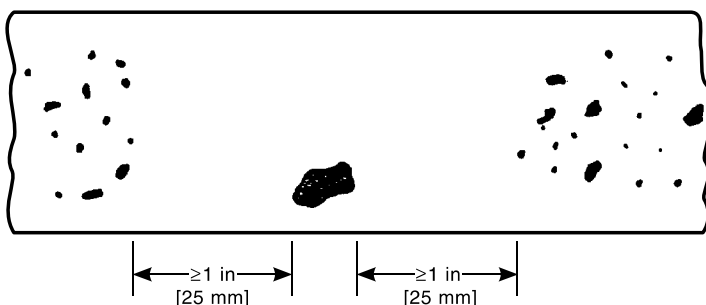
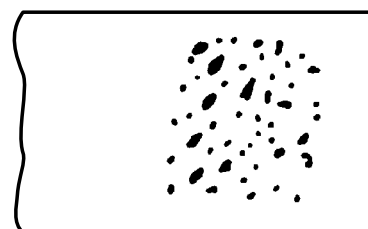
**(B) ISOLATED INDICATION****(C) CLUSTER**

Note: Maximum Size of Indication Per Table 15 or as otherwise Noted.

Adapted from ASME Boiler and Pressure Vessel Code, 2004 Section VIII, Division 1, Appendix 4, Figure 4.6 with permission from ASME.

Figure 23—Charts for Thickness Over 3/4 in [20 mm] to 2 in [50 mm], Inclusive**(A) RANDOM ROUNDED INDICATIONS**

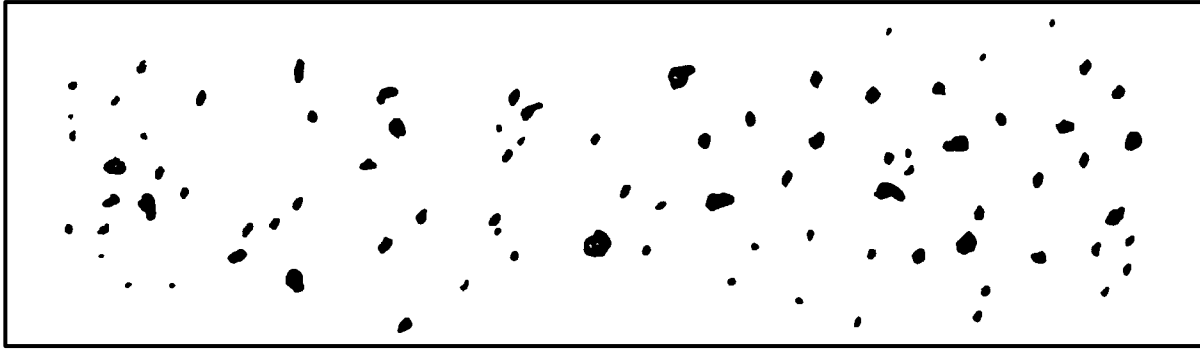
TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD

**(B) ISOLATED INDICATION****(C) CLUSTER**

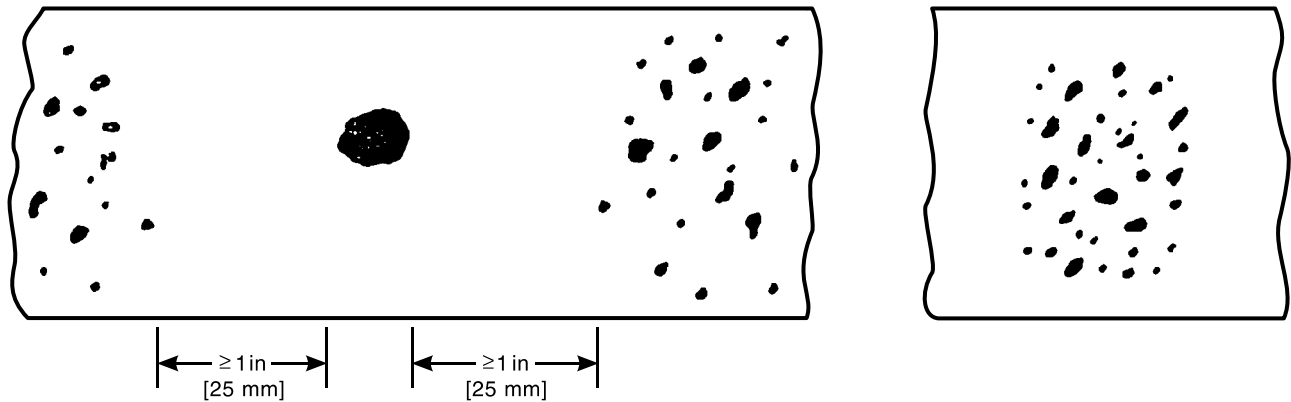
Note: Maximum size of indication per table 19 or as otherwise noted.

Adapted from ASME Boiler and Pressure Vessel Code, 2004 Section VIII, Division 1, Appendix 4, Figure 4.7 with permission from ASME.

Figure 24—Charts for Thickness Over 2 in [50 mm] to 4 in [100 mm], Inclusive

**(A) RANDOM ROUNDED INDICATIONS**

TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD

**(B) ISOLATED INDICATION****(C) CLUSTER**

Note: Maximum Size of Indication Per Table 15 or as otherwise Noted.

Adapted from ASME Boiler and Pressure Vessel Code, 2004 Section VIII, Division 1, Appendix 4, Figure 4.8 with permission from ASME.

Figure 25—Charts for Thickness Over 4 in [100 mm]

(f) Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area as that shown for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in [25 mm] or 2E. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in [25 mm] in 6 in [150 mm] length of weld.

(g) Image Density. Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

8.2.6.4 Defect Removal and Repair (see Clause 9)

8.3 Ultrasonic Testing

8.3.1 General. Ultrasonic testing of welded joints, where required, shall be conducted in conformance to the procedures specified herein, which include standards for ultrasonic acceptance or in conformance to ASME Section VIII, Division 1, Appendix 12 or Division 2, Article 9-3, ASTM E164, and ASTM E587.

8.3.2 This procedure contains the minimum requirements for the ultrasonic testing of butt, corner, and T-type welded joints by the contact method and is applicable to welds in carbon and low-alloy steels.

8.3.3 Criteria are given in Table 13 for the Ultrasonic testing of Inspection Classes I and II:

Class I for 100% testing of the weld where joint performance is equivalent to the base metal under all conditions;

Class II for welds when 10% of the length of the weld is tested after magnetic particle or liquid penetrant testing has been performed.

8.3.4 Extent of Testing

8.3.4.1 The engineer shall designate the class of ultrasonic testing to be performed by identifying the welded joints as Class I or Class II Inspection.

8.3.4.2 When welded joints with Class I Inspection are designated, the entire length of the weld shall be tested.

8.3.4.3 When welded joints with Class II Inspection are specified, the location tested shall be a 6 in [150 mm] length of weld. The number of locations shall total 10% of the total length of the weld. When an evaluated location requires repair, two adjacent locations, one on each side, shall be tested also. If defects requiring repair are shown in either of these locations, the entire weld in that joint shall be tested.

8.3.5 Requirements

8.3.5.1 Operator Qualifications and Test Specifications. Ultrasonic examination of welded joints, where required, shall be performed according to ASTM E164, *Standard Practice for Ultrasonic Contact Examination of Weldments*, and ASTM E587, *Standard Practice for Ultrasonic Angle Beam Contact Testing*.

Personnel performing ultrasonic testing shall be qualified. Acceptable qualification basis shall be the following:

(1) Ultrasonic Testing Level II (UT Level II) conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A, or

(2) Ultrasonic Testing Level I (UT Level I) working under an UT Level II conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A.

8.3.5.2 Equipment. The ultrasonic testing equipment shall consist of the instrument with scan data presentation, sweep length, calibrated sensitivity, and time corrected gain controls. The search unit and accessories shall have the following capabilities:

(1) **Search Unit.** The maximum dimension of the transducer active element shall not exceed 1 in [25 mm]. The shear wave transducer shall be fitted with a plastic wedge designed to induce shear waves into the material to be tested at an angle of 45°, 60°, or 70° within a maximum tolerance of $\pm 3^\circ$.

(2) **Calibration Standards.** Calibration standards are shown in Figures 26, 27, and 28. Calibration reference standards shall be made from material acoustically similar to the material to be tested. Standards such as IIW or ASTM may be used, provided the reference level sensitivity for instrument/search unit calibration is adjusted to be the equivalent to that achieved by the reference standard.

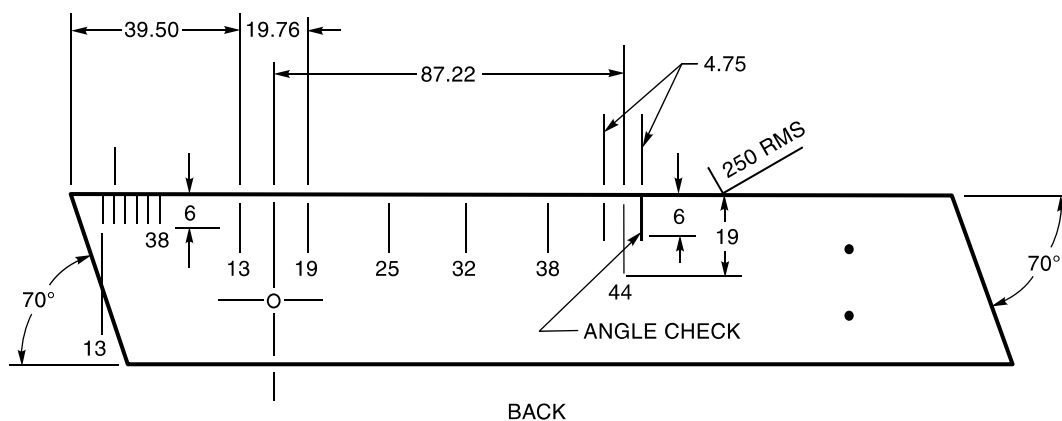
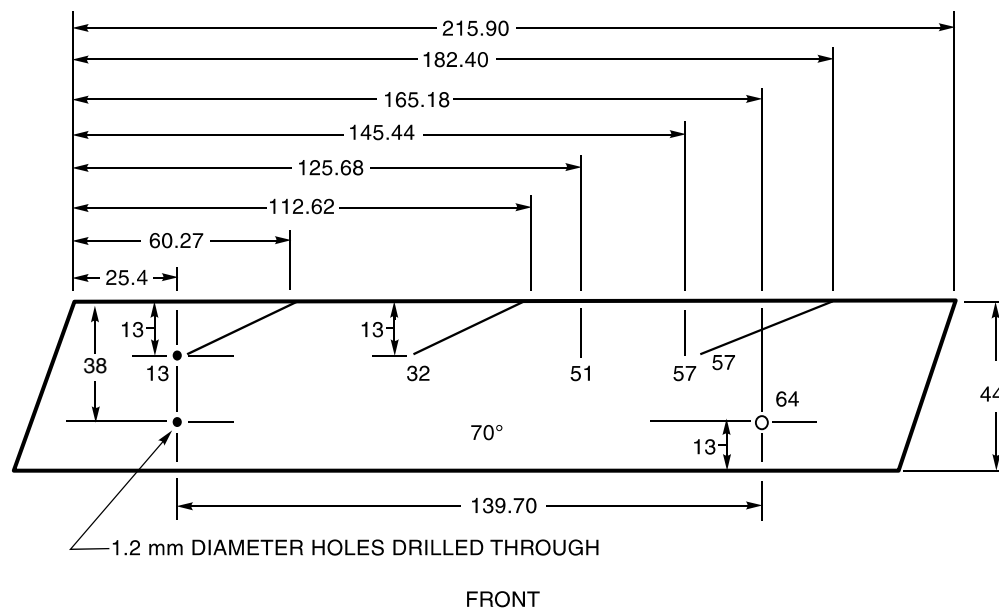
The following is a brief description of the calibration blocks:

- (a) The 3/64 in [1.2 mm] diameter holes are used in setting the test sensitivity level.
- (b) The 1/8 in [3 mm] diameter holes are used to check the accuracy of the refracted angle produced by the plastic wedge.
- (c) The diagonal lines mark the positions of the transducer to detect the 3/64 in [1.2 mm] diameter holes.
- (d) The 3/4 in [20 mm] vertical lines mark the positions of the transducer when calibrating for depth.
- (e) The 1/4 in [6 mm] vertical lines are used for measuring distance from the search unit to the hole.
- (f) The angle check area marks the position of the transducer when checking the accuracy of the refracted angle produced by the plastic wedge.

8.3.5.3 Equipment Calibration

(1) **Search Unit Angles.** Search unit angles shall be selected as follows:

- (a) For plate thicknesses 1/2 in [13 mm] to, but not including, 1-1/2 in [40 mm], a wedge angle producing a 60 or 70 degree shear wave in the material to be tested shall be used.



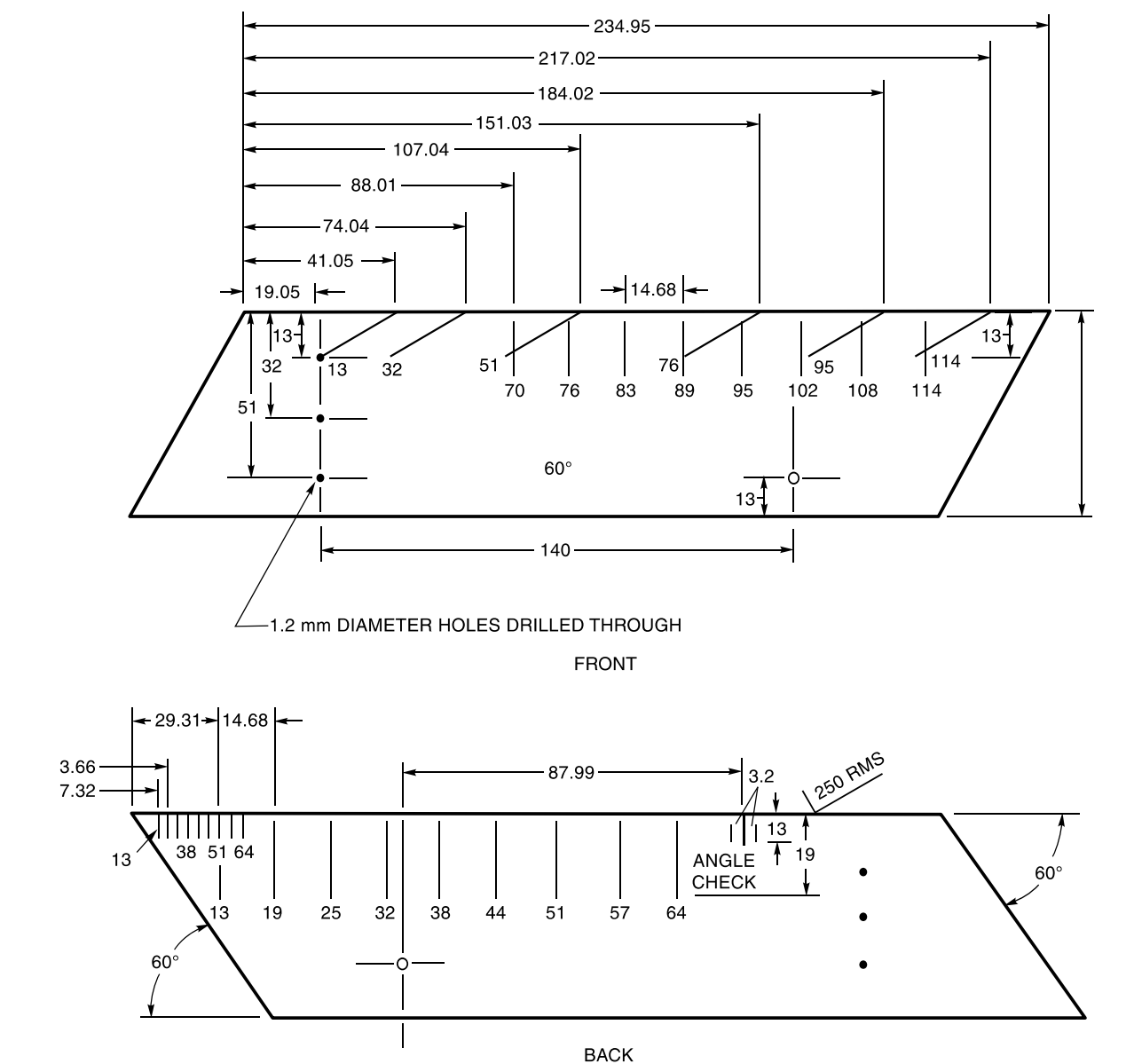
mm	in	mm	in	mm	in	mm	in
1.2	3/64	19	3/4	39.50	1.555	112.62	4.434
2.31	0.091	19.76	0.778	44	1-3/4	125.68	4.948
4.62	0.182	25	1	51	2	139.70	6.500
4.75	0.187	25.4	1.000	57	2-1/4	145.44	5.726
6	1/4	32	1-1/4	60.27	2.373	165.18	6.503
13	1/2	38	1-1/2	64	2-1/2	182.40	7.181
				87.22	3.434	215.90	8.500

All dimensions in millimeters except angles.

Notes:

1. Material is same as material to be tested.
2. Thickness = 32 mm (1-1/4 in).

Figure 26—70° Calibration Standard



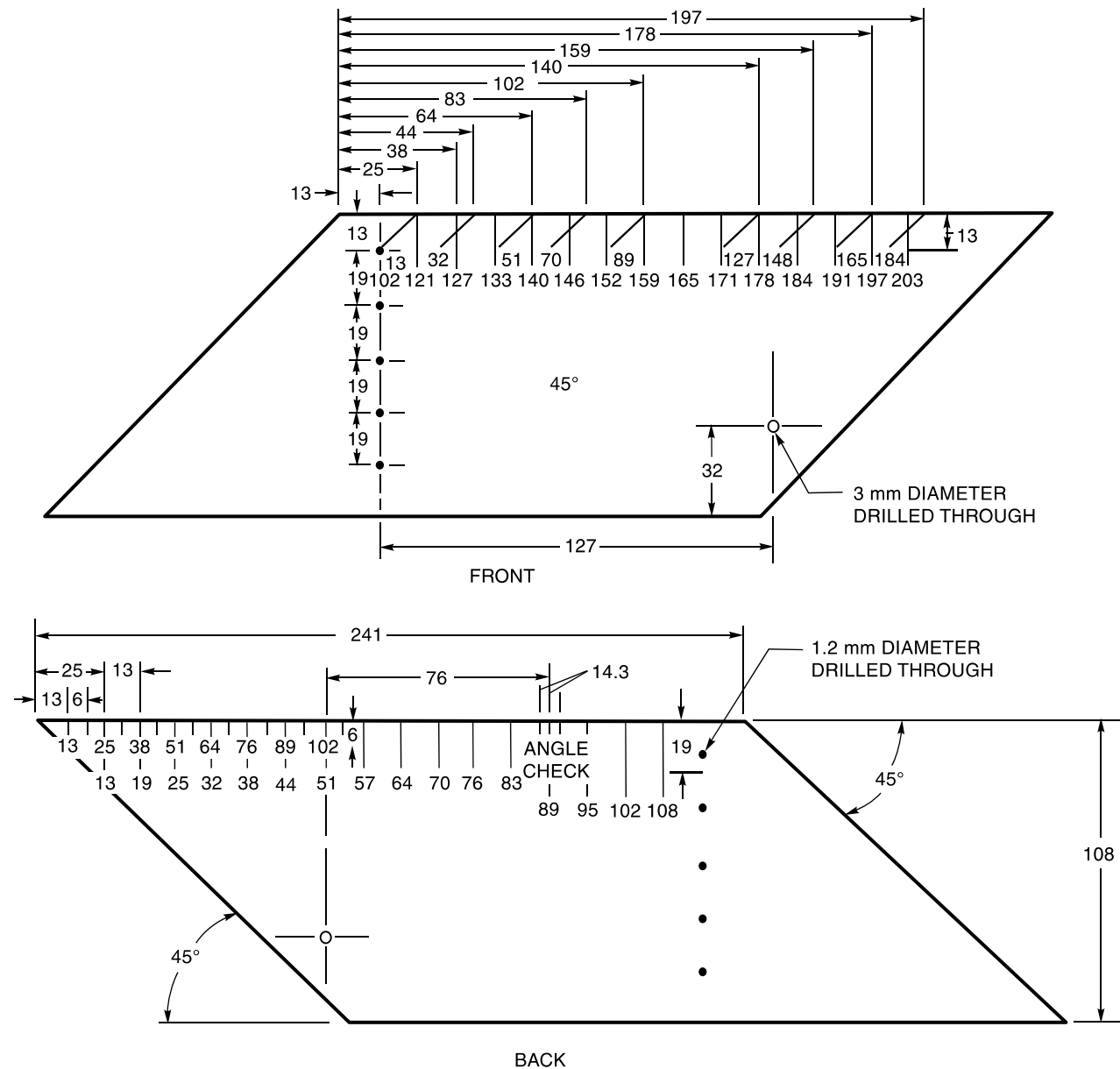
mm	in	mm	in	mm	in	mm	in
1.2	3/64	25	1	70	2-3/4	107.4	4.214
3.2	0.125	29.31	1.154	74.04	2.915	108	4-1/4
3.66	0.144	32	1-1/4	76	3	114	4-1/2
6	1/4	38	1-1/2	83	3-1/4	140	5-1/2
7.32	0.288	41.05	1.616	87.99	3.464	151.03	5.946
13	1/2	44	1-3/4	88.01	3.465	184.02	7.245
14.68	0.578	51	2	89	3-1/2	217.02	8.544
19	3/4	57	2-1/4	95	3-3/4	234.95	9.250
19.05	0.750	64	2-1/2	102	4		

All dimensions in millimeters except angles.

Notes:

1. Material is same as material to be tested.
2. Thickness = 32 mm (1-1/4 in).

Figure 27—60° Calibration Standard



All dimensions in millimeters except angles

Notes:

1. Material is same as material to be tested.
2. Thickness = 33 mm (1-1/4 in).

Figure 28—45° Calibration Standard

(b) For plate thicknesses 1-1/2 in [40 mm] to, but not including, 2-1/2 in [60 mm], a wedge angle producing a 45 or 60 degree shear wave in the material to be tested shall be used.

(c) For plate thicknesses 2-1/2 in [60 mm] and over, a wedge angle producing a 45 degree shear wave in the material to be tested shall be used.

(2) Angle Check. With the transducer positioned for maximum signal response from the 1/8 in [3 mm] diameter hole in the calibration block, the sound emission point of the transducer shall fall on or between the two lines in the angle-check area.

(3) Flaw-Locating Device Adjustment (if used). With the sound emission point of the transducer aligned with the 3/4 in [20 mm] vertical line on the calibration block representing the thickness of the weld, the flaw locating device is adjusted so that the line on the rule representing the weld thickness is in alignment with the corresponding 1/4 in [6 mm] line on the calibration block.

(4) Depth Calibration. The instrument is calibrated for the range of depth to be inspected using the large signal from the end of the block. When the emission point marked on the transducer is aligned with one of the 3/4 in [20 mm] vertical lines on the calibration standard, the signal will appear on the screen at the depth for which that line is marked. A “B” (for bottom) is marked on the screen at the depth equal to the weld thickness and a “T” (for top) is placed on the screen at the depth equal to twice the weld thickness (see Figure 29 for typical screen calibration).

(5) Test Sensitivity Calibration

(a) For the testing of Class I Inspections, weld joints, the instrument gain and attenuation correction controls shall be adjusted to peak all signals from the 3/64 in [1.2 mm] diameter holes within the range of test at a minimum of 80% and a maximum of 95% of full screen height. Minor adjustments of depth calibration should be made using the peaked signals from the holes to compensate for slight variations in search unit angles. The screen shall be divided by two horizontal lines at 20% (the disregard level or DRL) and 80% (the amplitude rejection level or ARL) or full screen height.

(b) For the testing of Class II Inspections, weld joints, the instrument gain and attenuation correction controls shall be adjusted to peak all signals from 3/64 in [1.2 mm] diameter holes within the range of test at a minimum of 80% and a maximum of 95% of full screen. Minor adjustments of depth calibration should be made using the peaked signals from the holes to compensate for slight variations in search unit angles. The screen shall be divided by two horizontal lines at 40% (the DRL) and 80% (the ARL) of full screen.

8.3.5.4 Surface Preparation. All surfaces to which a search unit is applied shall be free of loose scale, loose paint, weld spatter, grease, dirt, and any other foreign matter that might interfere with the scanning procedure. The surface must have a contour permitting intimate coupling between the search unit and the scanning surface.

8.3.5.5 Test Procedure

(1) Lamination Test

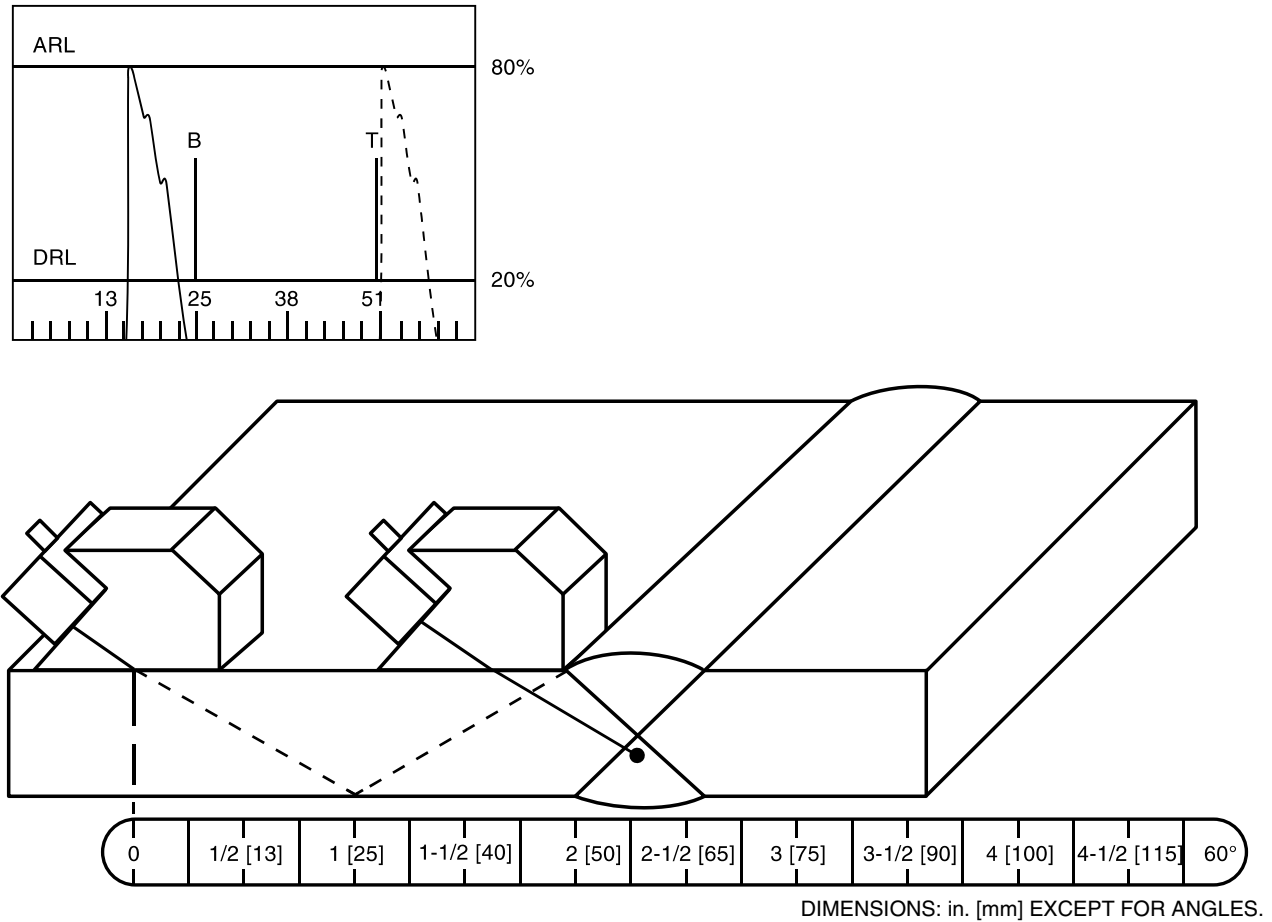
(a) Before the shear wave test is conducted on welds in carbon and low-alloy steel plates, a compressional wave test shall be performed to determine if any laminar discontinuities are present that might interfere, unless a test for lamination has been previously conducted on the plate material.

(b) The test shall be performed using a 1 in [25 mm] diameter 2.25 MHz longitudinal wave transducer. With the first back reflection from the plate adjusted to 80% of full screen height, the full width of the area to be scanned by the shear wave test shall be scanned. If a discontinuity is noted that causes a complete loss or transposition of the first back reflection, the discontinuity shall be noted on the weld inspection report. The weld in the area of the discontinuity cannot be reliably tested with shear waves from the side containing the discontinuity.

(2) CJP Groove Weld in Butt Joints

(a) The entire weld volume and heat-affected zone, excluding the weld reinforcement, shall be scanned with shear waves by directing the sound beam toward or across and along the weld axis (see Figure 30).

(b) To detect longitudinal discontinuities in welds not ground flush, the search unit shall be oscillated to the left and right with an included angle of approximately 30° while continuously scanning perpendicularly to the weld. The lateral movement advancing the search unit along the longitudinal axis of the weld shall not exceed 75% of the transducer width. The weld shall be scanned from one surface with an effective beam width on two sides or from one side on two surfaces (see Figure 31).



Notes:

1. Weld thickness = 1 in [25 mm]
2. Angle is 60°
3. Depth calibration range is 1/2 in [13 mm] to 2 in [50 mm]

Figure 29—Typical Screen Calibration

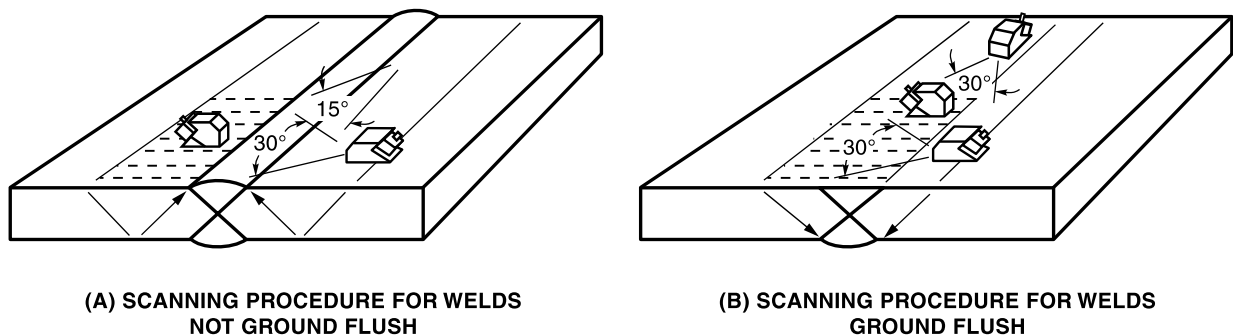


Figure 30—Test Procedure—CJP Groove Weld in Butt Joints

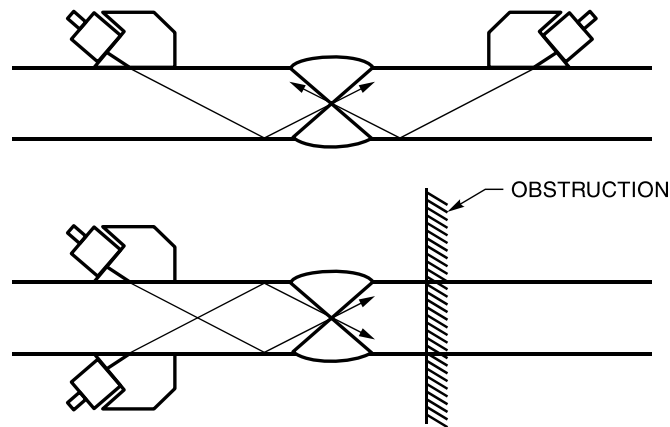


Figure 31—Method of Detecting Longitudinal Discontinuities in CJP Groove Weld in Butt Joints Not Ground Flush

The scanning area shall begin with the search unit touching the weld reinforcement and shall include an area wide enough to ensure that the entire weld and heat-affected zone are covered by the second half of the first skip distance

(c) To detect transverse discontinuities in welds not ground flush, the search unit shall be placed on the base-metal surface at the edge of the weld. The sound beam shall be directed by angling the search unit toward the weld at approximately 15° to the longitudinal axis of the weld. Scanning shall be performed by moving the search unit along the weld edge from both sides on one surface and from two opposing directions.

(d) To detect longitudinal discontinuities in welds ground flush, the search unit shall be oscillated to the left and right with an included angle of approximately 30° while continuously scanning perpendicularly across the weld. The weld shall be scanned from one surface on two sides of the weld when possible. Where this procedure is impossible, the weld may be scanned from one side on two surfaces or from one side on one surface using at least a full skip distance (see Figure 32). The lateral movement advancing the search unit along the longitudinal axis of the weld shall not exceed 75% of the transducer width per transverse scan.

(e) To detect transverse discontinuities in welds ground flush, the search unit shall be oscillated to the left and right with an included angle of approximately 30° while continuously scanning along the top of the weld from two opposing directions. If the weld width exceeds the width of the transducer, parallel scans shall be performed so that each scan overlaps the previous scan by at least 25% of the transducer width. An area wide enough to ensure coverage of the weld and heat-affected zone shall be scanned.

(3) CJP Groove Welds in Corner Joints

(a) The entire weld and heat-affected zone, excluding the weld reinforcement, shall be scanned with shear waves by directing the sound beam toward or across and along the weld axis.

(b) To detect longitudinal discontinuities, the search unit shall be oscillated to the left and right with an included angle of approximately 30° while continuously scanning perpendicularly to the weld. The lateral movement advancing the search unit along the longitudinal axis of the weld shall not exceed 75% of the transducer width per transverse scan. The weld shall be tested using the first full skip distance from surface “A” as shown in Figure 33.

(c) To detect transverse discontinuities, the search unit shall be oscillated to the left and right with an included angle of approximately 30° while continuously scanning along the top of the weld from two opposing directions. If the weld width exceeds the width of the transducer, parallel scans shall be made so that each scan overlaps the previous scan by at least 25% of the transducer width. An area wide enough to ensure complete coverage of the weld and heat-affected zone shall be scanned.

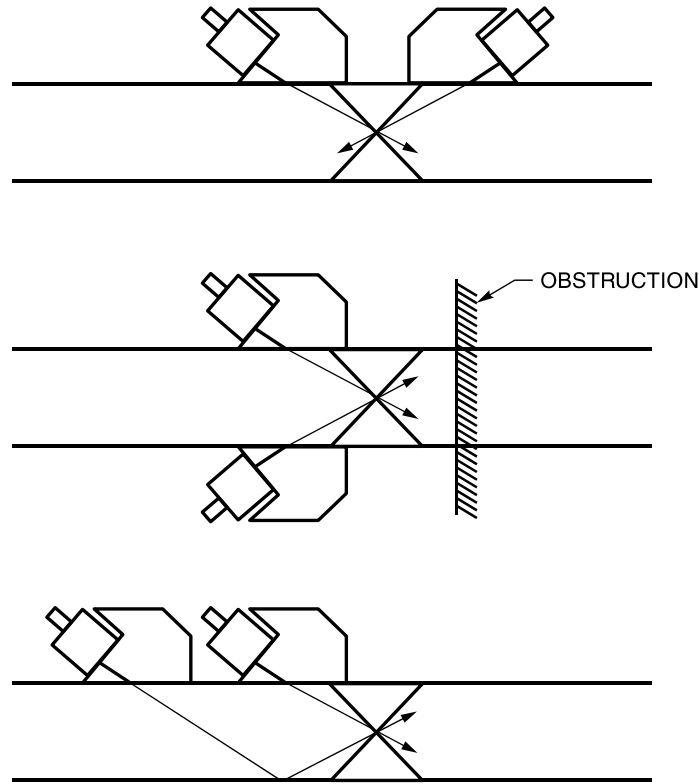


Figure 32—Method of Detecting Longitudinal Discontinuities in CJP Groove Weld in Butt Joints Ground Flush

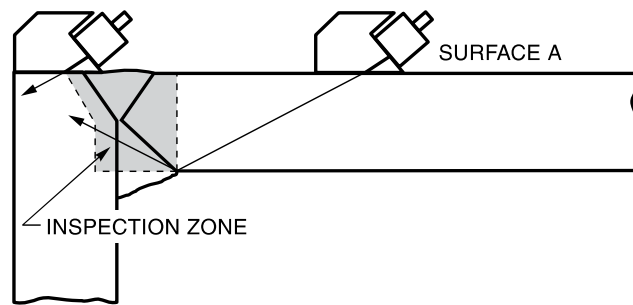


Figure 33—Method for Detecting Longitudinal Discontinuities in CJP Groove Welds in Corner Joints Not Ground Flush

(4) **CJP Groove Welds in T-Joints.** The entire weld and heat-affected zone, excluding the weld reinforcement, shall be scanned with shear waves. The search unit shall be oscillated to the left and right with an included angle of approximately 30° while continuously scanning perpendicularly to the weld. The lateral movement advancing the search unit along the longitudinal axis of the weld shall not exceed 75% of the transducer width per transverse scan. The weld shall be tested from surfaces “A” and “B” as shown in Figure 34, using the first full skip distance, or from surface “C” as shown in Figure 35, using the first half skip distance.

(5) **Discontinuities.** If discontinuities are detected, the sound beam shall be directed to maximize the signal amplitude. If the signal amplitude equals or exceeds the DRL, the maximum amplitude, location, length, depth, and zone location shall be determined.

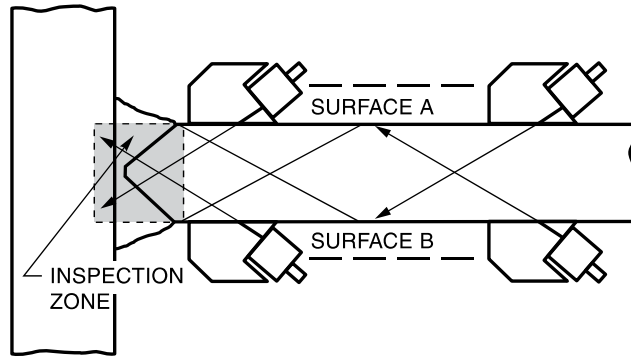


Figure 34—Procedure for Testing CJP Groove Welds in T-Joints

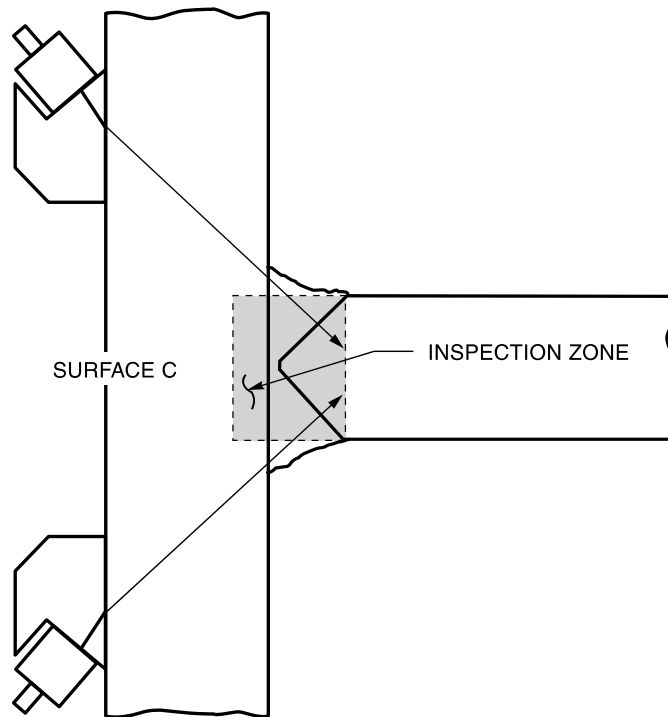


Figure 35—Method of Using Procedure for Testing CJP Groove Welds in T-Joints

(a) To determine the length of a discontinuity, the transducer shall be positioned for maximum signal response and moved parallel to the discontinuity axis until the signal drops rapidly to the base line. The transducer is then returned to the position where the indication began to drop rapidly to the base line. The plate is marked at the center of the transducer. This mark shall be defined as one extremity of the discontinuity and the procedure shall be repeated in the opposite direction to determine the other extremity.

(b) The depth of a discontinuity from the scanning surface shall be determined by the position of the signal on the viewing screen when the signal is maximized.

(c) The zone location of a discontinuity shall be determined by observing the depth of the signal on the screen and marking the weld at the corresponding depth on the material service.

8.3.5.6 Acceptance Standards

(1) Class I Inspection. Any discontinuity whose reflection exceeds 80% of full screen height shall be rejected. Discontinuities whose reflections equal 20% or greater up to and including 80% of full screen height shall be evaluated as follows:

(a) If the discontinuity length exceeds $T/2$ (where T = thickness of the thinner member), it shall be rejected. In no case shall any single discontinuity length exceed 1-1/2 in [40 mm].

(b) Any two discontinuities separated by less than $2L$ of sound metal (where L = length of the longest discontinuity), shall be considered a single discontinuity. The maximum distance between the outer extremities of any two such discontinuities or the sum of their lengths, whichever is greater, shall not exceed the length specified in 8.3.5.6(1)(a).

(c) If the total accumulative length of discontinuities in any 12 in [300 mm] of weld length exceeds $1T$, that weld length shall be rejected. When less than 12 in. [300 mm] of weld is inspected, the $1T$ criterion applies to the length inspected.

(2) Class II Inspection. Any discontinuity whose reflection exceeds 80% of full screen height and whose length exceeds 1/4 in [6 mm] shall be rejected. Adjacent discontinuities whose reflections exceed 80% of full screen, separated by less than $2L$ of sound metal (where L = length of longest discontinuity), shall be considered a single discontinuity. Discontinuities whose reflections equal 40% of full screen height, up to and including 80%, shall be evaluated as follows:

(a) If the discontinuity length exceeds $1T$ (where T = thickness of the thinner member), it shall be rejected. In no case shall any single discontinuity length exceed 2 in [50 mm].

(b) Any two discontinuities separated by less than $2L$ of sound metal (where L = length of longest discontinuity) shall be considered as a single discontinuity. The maximum distance between the outer extremities of any two such adjacent discontinuities or the sum of their lengths, whichever is greater, shall not exceed the length specified in 8.3.5.6(2)(a).

(c) If the cumulative length of discontinuities in any 12 in [300 mm] of weld exceeds $2T$, that weld length shall be rejected. When less than 12 in [300 mm] of weld is inspected, the $2T$ criterion applies to the length inspected.

8.3.5.7 Test Results

(1) Recording and Reporting Discontinuities

(a) The location, length, depth, maximum amplitude, and zone location of discontinuities having a signal amplitude that equals or exceeds the DRL shall be recorded and reported.

(b) Indications less than the DRL shall be disregarded.

(2) Record Data and Report Sheets. The ultrasonic test data and report sheets for inspection results of welds shall contain, as a minimum, the following information:

- (a) Weld identification
- (b) Location
- (c) Type of weld
- (d) Type of material
- (e) Thickness of material
- (f) Joint identification
- (g) Segment number
- (h) Length of weld inspected
- (i) Operational procedure identification
- (j) Equipment used for inspection and its record of calibration {see 8.3.5.8(3)}

- (k) Reference block identification
- (l) Inspection results
- (m) Acceptance or rejection
- (n) Signature of inspection personnel
- (o) Date of test

8.3.5.8 Special Notes

- (1) Supplemental ultrasonic inspection techniques that contribute to the final inspection result shall be recorded, if used.
- (2) All repaired areas, plus an additional 3 in [75 mm] beyond each end of repair, shall be retested as original welds and the test results shall be recorded in conformance to 8.3.5.7.
- (3) The instrument shall be allowed to warm up before calibration is attempted. The equipment shall be calibrated with the reference calibration standard each time it is used and shall be recalibrated at least once every four hours during continuous use, whenever the electric power to the instrument has been interrupted or whenever the calibration of the equipment is suspected of being in error.

8.3.5.9 Defect Removal and Repair (see Clause 9)

8.4 Magnetic Particle Testing

8.4.1 General. Magnetic particle testing of welded joints, where required, shall be conducted in conformance to the procedures specified herein, which include standards for acceptance.

8.4.2 Personnel performing magnetic particle testing shall be qualified. Acceptable qualification basis shall be the following:

- (1) Magnetic Particle Testing Level II (MT Level II) conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A, or
- (2) Magnetic Particle Testing Level I (MT Level I) working under an MT Level II conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A.

8.4.3 Extent of Inspection

8.4.3.1 Information furnished to the bidder shall clearly identify the extent of magnetic particle inspection to be performed in excess of Table 13.

8.4.4 Equipment

8.4.4.1 Source of Magnetic Fields. The following magnetizing equipment shall be capable of inducing a magnetic flux of suitable intensity in the desired direction:

(1) Prod Method

- (a) Portable prod-type electrical contacts shall be spaced 3 to 8 in [75 to 200 mm] apart using direct current at 100 to 125 Amperes per 1 in [25 mm] of spacing.
- (b) At least two separate examinations shall be carried out using the dry particle medium. Prods shall be placed so that the magnetizing flux during one examination is perpendicular to the other examination direction.

(2) Coil Method

- (a) Multiple coils shall be looped around the part and shall be capable of producing a magnetic field strength of 3000 to 10,000 Ampere turns using direct current.
- (b) At least two separate examinations shall be carried out using dry or wet particle medium. The second examination shall be with magnetic flux at right angles to the first examination or a different magnetic source may be used.
- (c) Examination of welds by the magnetic particle method shall be made over an area including the weld and base metal and extending at least 1/2 in [13 mm] on each side of the weld.

(3) Yoke Method

(a) Either alternating current or permanent yokes shall be used, equivalent to a prod method of 25 to 30 Amperes per 1 in [25 mm] of prod spacing.

(b) At least two separate examinations shall be done using dry or wet particle medium. The second examination shall be with the magnetic flux at right angles to the first examination.

8.4.4.2 Particle Application and Removal

(1) **Dry Particles.** Dry particles may be applied by means of mechanical shakers, bulb blowers, or mechanical blowers. Excess particles shall be removed by means of a dry air current of sufficient force to remove the excess particles which are not indicative of discontinuities. Extreme care should be taken when removing the magnetic particles so that any particles indicative of subsurface indications are not removed.

(2) **Wet Particles.** Wet particles may be applied by means of spraying or dipping per ASTM E709, *Standard Guide for Magnetic Particle Testing*.

8.4.4.3 Lighting. The weld areas shall be adequately illuminated for proper evaluation of the indications revealed on the weld surface.

8.4.4.4 Examination Medium. The magnetic particles used for detection of defects shall be as follows:

(1) **Dry Particles.** Dry particles used shall be of high permeability and low retentivity and of such size and shape as will produce suitable indications. It is desirable that the color be such as to provide adequate contrast with the background of the surface being examined.

(2) **Wet Particles.** Wet particles used shall be red or black or, alternatively, may be fluorescent when viewed under ultraviolet illumination. The particles shall be suspended in a suitable liquid medium in the concentration recommended by the manufacturer of the particles. Amplified details on the use of wet particles are given in ASTM E709, *Standard Guide for Magnetic Particle Testing*.

8.4.5 Surface Preparation

8.4.5.1 Surface Finish – Completed Surfaces. As-welded surfaces shall be considered suitable for inspection without any grinding, provided the following conditions are met:

(1) There shall be no roll-over or undercutting, and the deposited metal shall be fused smoothly and uniformly into the plate surfaces.

(2) The finished weld shall be reasonably smooth and free from irregularities, grooves, or depressions.

8.4.5.2 Precleaning. The materials or parts to be examined shall be dry and free of oil or other foreign matter which might interfere with the formation or interpretation of magnetic particle patterns or indications. Oil or grease shall be removed with petroleum distillate or alcohol.

8.4.5.3 Application of Magnetic Field

(1) **Direction.** The magnetic field shall be induced in more than one direction to insure detection of discontinuities having axes in any direction.

(2) **Direct Magnetization.** When using direct magnetization, direct current, or half-wave rectified alternating current, current shall be passed through the part being tested for a minimum of 1/5 second.

(3) **Indirect Magnetization.** Indirect magnetization shall be accomplished by passing magnetizing current through an auxiliary conductor for a minimum of 1/5 second.

(4) **Precaution.** Care shall be taken to prevent local overheating, arcing, or burning the surface being inspected. The magnetizing current shall not be turned on until after the prods have been properly positioned in contact with the surface and current shall be turned off before the prods are removed.

(5) **Demagnetization.** When necessary, demagnetization shall be performed.

8.4.6 Acceptance Standard

8.4.6.1 Surfaces examined by the magnetic particle method shall be free of laps, fissures, cracks, or other defects. In-line porosity which appears as a linear accumulation of magnetic powder shall also be removed.

8.4.6.2 Only such defects need be removed as to render the surface acceptable to the requirements of this specification. Areas containing defects shall be ground out to remove the defects. The ground out areas shall be reinspected to verify the complete removal of the defect. Minor cavities resulting from the removal of shallow discontinuities shall be blended into the surrounding area. They need not be repair welded if they do not reduce wall thickness or drawing requirements or affect machined or gasket fits. Other defects may be repair welded by means of the original welding procedure or an approved repair welding process. Completed repairs shall be reinspected by the method originally used.

8.4.6.3 Defect Removal and Repair (see Clause 9)

8.5 Liquid Penetrant Testing

8.5.1 Liquid penetrant testing of welded joints, where required, shall be conducted in conformance to the procedures specified herein, which include standards for acceptance.

8.5.2 Personnel performing dye penetrant testing shall be qualified. Acceptable qualification basis shall be the following:

- (1) Dye Penetrant Testing Level II (PT Level II) conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A, or
- (2) Dye Penetrant Testing Level I (PT Level I) working under an PT Level II conforming with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A.

8.5.3 Extent of Testing. Information furnished to the bidder shall identify the extent of liquid penetrant testing to be performed.

8.5.4 Equipment

8.5.4.1 Penetrant Equipment. Aerosol cans, air or CO₂, powder spray guns, paint brushes, spraying, or dipping may be used to apply the liquids.

8.5.4.2 Drying Equipment. Paper towels, lint-free cloths, or vacuum equipment may be used for drying.

8.5.4.3 Lighting. The test area shall be adequately illuminated for proper evaluation of the visual indications revealed on the test surface.

8.5.4.4 Fluorescent Penetrants. A darkened area for black light use is necessary. The black light intensity should be 90 to 100 foot-candles [8 to 9 lux] in the 3650 Angstrom wave length band. Allow 5 minutes for the black light source to warm up to achieve the desired intensity.

8.5.5 Procedure

8.5.5.1 Temperature. The temperature of the penetrant and the part to be tested shall be 40° to 125°F [5° to 50°C] before application of the penetrant. When testing is necessary under conditions where the temperature of the penetrant or the test surface is outside the 40° to 125°F [5° to 50°C] range, the temperatures shall be adjusted to bring them within this range or the procedure shall be qualified or demonstrated to the satisfaction of the customer to be effective at other temperatures.

8.5.5.2 Surface Finish—Completed Surfaces. As-welded surfaces shall be considered suitable for testing without any grinding, provided all of the following conditions are met:

- (1) There shall be no roll-over or undercutting, valleys or grooves along the axis of, or within, the weld.
- (2) The deposited metal shall be fused smoothly and uniformly into the plate surfaces.
- (3) The finished weld shall be reasonably smooth and free from irregularities, grooves, or depressions.

8.5.5.3 Precleaning

(1) Rust, scale, slag, weld spatter, or other hard tenacious materials shall be removed by wire brushing, grinding, or machining.

(2) All types of grinding wheels are permitted on steel.

(3) All oil and grease shall be removed with petroleum distillate or alcohol using paper towels or lint-free cloth.

8.5.5.4 Application of Penetrant. The surface to be tested shall be thoroughly dry before application of the liquid penetrant. The penetrant may be applied by spraying, brushing, or immersion. The area to be tested shall be completely covered. The surface shall be kept wet for a minimum of six minutes and during this period additional penetrant should

be added, if necessary, to prevent drying. Precautions should be taken to prevent test materials from entering inaccessible areas. It is permissible to remove excess penetrant prior to application of the emulsifier by wiping with paper towels or lint-free cloth.

8.5.5.5 Application of Remover. The remover shall be applied by spraying or brushing.

8.5.5.6 Removal of Excess Penetrant

(1) Wet Removal (Water Washable). After an emulsification time to exceed two minutes, the penetrant-emulsified film shall be removed by a water spray. The water pressure shall not exceed 50 psi [345 kPa] and the water temperature shall not be less than 40°F [5°C] nor more than 110°F [45°C]. The spray shall be applied at a distance of 10 to 15 in [250 to 400 mm] from the surface. Washing should be continued until all traces of surface penetrant have disappeared. Where restricted areas prevent the use of a water spray, the penetrant-emulsified film may be removed by repeated applications of dry or water-soaked paper towels or lint-free cloths.

(2) Dry Removal (Solvent)

(a) As much penetrant as possible shall be removed by first wiping the surface thoroughly with a clean dry cloth or absorbent paper.

(b) The remaining excess penetrant shall be removed by wiping the surface with a clean cloth or absorbent paper dampened with remover. Flushing of the surface with any liquid, following application of the penetrant and prior to developing, is prohibited.

(3) Postemulsifier Removal. With postemulsifier penetrants, an additional step is required. This step is the application of a liquid emulsifier prior to the rinsing operation. The emulsifier may be applied by brushing, spraying, or dipping. Emulsifying times of ten seconds to five minutes can be used, depending upon prevailing conditions, such as surface roughness or the type of defect sought. The emulsifying time is critical. Once the emulsifying time has been set for a particular test, it should not vary more than $\pm 10\%$. After emulsification, the mixture is removed by a water spray, using the same procedure as for water-washable liquid penetrants.

8.5.5.7 Application of Developer

(1) Dry. After the surface has been thoroughly dried, the developer shall be applied by dipping, spraying, or brushing. Application of the developer by spraying is preferable. The surface shall be completely covered with developer. It is suggested that the aerosol can or sprayer be held 10 in [250 mm] from the work and be applied in short dusting strokes. The application of excessive developer should be avoided, since it is possible for a thick coating of developer to mask indications.

(2) Liquid. The liquid developer is a suspension of powder in water or a volatile solvent. It is applied by dipping, spraying, or brushing. In any case, a film of powder is left on the surface when the developer dries. Where a water suspension developer is used, drying time may be decreased by the use of warm air.

8.5.5.8 Examination. Visual examination of the surface being inspected shall be made after a minimum of seven minutes and a maximum of thirty minutes after developer has dried. Interpretation and acceptance shall be made according to 8.5.6.

8.5.5.9 Final Cleaning. When the inspection is concluded, the penetrant materials shall be removed as soon as possible by means of brushing, flushing, or wiping with paper towels or lint-free cloth.

8.5.6 Acceptance Standards. All surfaces examined shall be free of linear indications in excess of 1/8 in [3 mm]. These surfaces may have four or fewer, rounded indications in a line, edge to edge, separated by 1/16 in [2 mm], except where the specification for the material establishes different requirements for acceptance.

8.5.6.1 Linear indications are those indications in which the length is more than twice the width.

8.5.6.2 Defect Removal and Repair. See Clause 9.

9. Repair

9.1 Weld Repairs

9.1.1 Overlap or Insufficient Reentrant Angle. The objection to overlap or insufficient reentrant angle is not the height of the center of the weld bead, but the stress concentration resulting from the normally sharper than usual angle at

the toes of the weld. For this reason, simply grinding off the excessive crown height of the weld may not be sufficient. The toes of the weld should be blended in with the base metal and care must be exercised so as not to gouge the base metal.

9.1.2 Excessive Concavity of Weld or Crater and Undersize Welds. Surfaces shall be prepared and additional weld metal deposited with the original weld procedure. All slag shall be removed and the adjacent base metal shall be clean before additional welding.

9.1.3 Cracks in Weld or Base Metal. All cracks shall be removed (see 9.3) and the area rewelded with the original weld procedure or a qualified repair procedure.

9.1.4 Undercutting

9.1.4.1 Undercutting may be repaired by grinding and blending or by welding using a qualified welding procedure. It is preferably done by careful grinding and blending. Grinding should be performed with a pencil-type grinder. The grinding marks should be transverse to the length of the weld, and have a 250 RMS [6.4 Ra] finish or better.

9.1.4.2 Blending shall be done with a slope not to exceed 1 in 2.5. On plates of 1/2 in [13 mm] thickness and above, up to 7% reduction of base material thickness is permitted. Repair of undercut areas by grinding and blending in excess of this amount may be permitted with the approval of the Engineer.

9.1.4.3 When undercut is to be repaired by welding, the surfaces shall be prepared and then additional weld metal shall be deposit using the original weld procedure.

9.1.5 Incomplete Fusion, Excessive Weld Porosity, or Slag Inclusions. Defective portions shall be removed (see 9.2.3) and rewelded with the original weld procedure or a qualified repair procedure.

9.2 Base-Metal Repairs

9.2.1 Defects in Cut Edges of Plate. If a defect is found in a cut edge that exceeds the limits imposed in Table 16, it shall be removed and repaired in accordance with 9.3.

9.2.2 Arc Strikes and Temporary Attachment Areas. Arc strikes and temporary welds in critical locations, as defined by the Engineer, shall be removed and ground smooth to assure that no abrupt change in section exists. The smoothed area shall be inspected by an appropriate nondestructive testing method to assure that there are no existing cracks or similar discontinuities. Any cracks or similar discontinuities shall be repaired in accordance with 9.3.

Table 16
Limits on Acceptability and Repair of Cut Edge Discontinuities of Plate

Description of Discontinuity	Repair Required
Any discontinuity 1 in [25 mm] in length or less.	None, need not be explored
Any discontinuity over 1 in [25 mm] in length with depth over 1/8 in [3 mm] maximum depth.	None, but the depth should be explored. ^a
Any discontinuity over 1 in [25 mm] in length with depth over 1/8 in [3 mm] but not greater than 1/4 in. [6 mm].	Remove, no need to reweld
Any discontinuity over 1 in [25 mm] in length with depth over 1/4 in [6 mm] but not greater than 1 in [25 mm].	Completely remove and reweld with the original weld procedure or a qualified repair procedure. Aggregate length of welding shall not exceed 20% of the length of the plate edge being repaired.
Any discontinuity over 1 in [25 mm] in length with depth greater than 1 in [25 mm].	Completely remove and reweld with the original weld procedure or a qualified repair procedure. Aggregate length of welding shall not exceed 20% of the length of the plate edge being repaired.

^a A spot check of 10% of the discontinuities on the oxygen-cut edge in question should be explored by grinding to determine depth. If the depth of any one of the discontinuities explored exceeds 1/8 in [3 mm], then all of the discontinuities remaining on that edge shall be explored by grinding to determine depth. If none of the discontinuities explored in the 10% spot check have a depth exceeding 1/8 in [3 mm], then the remainder of the discontinuities on that edge need not be explored.

9.2.3 Removal of Defective Areas. The removal of weld metal or portions of the base metal may be done by machining, grinding, chipping, oxygen gouging, or air carbon arc gouging. It shall be done in such a manner that the remaining weld metal or base metal is not nicked or undercut.

9.2.3.1 Oxygen gouging shall not be used on quenched-and-tempered steel.

9.2.3.2 Defective portions of the weld shall be removed without substantial removal of the base metal.

9.2.3.3 The surfaces shall be cleaned thoroughly before welding. Defects that occur in material handling that do not affect the structural integrity of the design can be repaired by grinding.

9.2.3.4 Additional weld metal, when required, to compensate for any deficiency in size, shall be deposited using a low-hydrogen process with the original weld procedure or a qualified repair procedure.

9.2.4 Distortion and Camber. Members distorted by welding may be straightened by mechanical means, in combination with, or by careful application of localized heat. The temperature of the heated area shall be measured by approved methods such as temperature indicating crayons or contact pyrometers, and limited to that permitted by the material being straightened. For quenched and tempered, or normalized and tempered steels, the temperature shall not exceed the tempering temperature minus 100°F [55°C], or 1200°F [650°C] for other steels.

9.2.5 Correction of Improperly Fitted and Welded Members. If a weld is found to be unacceptable after additional work, or new conditions make correction of the unacceptable weld dangerous or ineffectual, the original conditions shall be restored by removing welds or members, or both, before the corrections are made. If this is not done, the deficiency shall be compensated for by additional work performed according to an approved revised design. Improperly fitted and welded members require design engineer approval prior to cutting apart. Cutting is to be handled by methods similar to those in 9.3.

9.2.5.1 Where discontinuities such as (W), (Y), or (X) in Figure 36 are observed prior to completing the joint, the size and shape of the discontinuity shall be determined by ultrasonic testing. The area of the discontinuity shall be determined as the area of total loss of back reflection, when tested in conformance to the procedure of ASTM A435/435M, *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*.

9.2.5.2 For acceptance, the area of the discontinuity (or the aggregate area of multiple discontinuities) shall not exceed 4% of the cut material area (length × width) with the following exception: if the length of discontinuities on any transverse section, as measured perpendicular to the cut material length, exceeds 20% of the cut material width, the 4% cut material area shall be reduced by the percentage amount of the width exceeding 20%. (For example, if a discontinuity

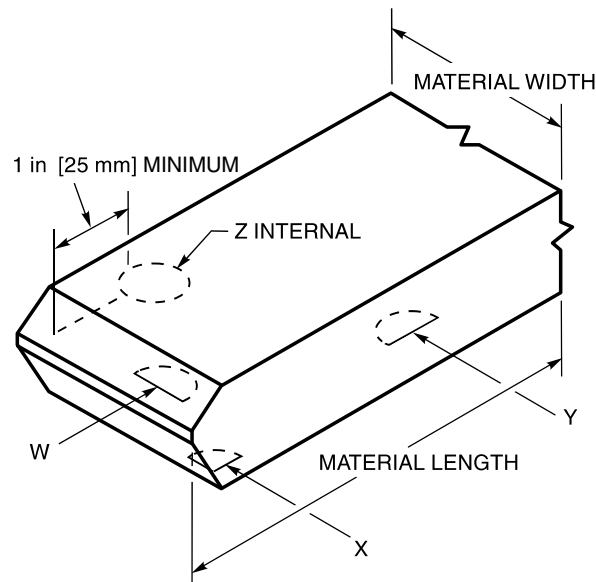


Figure 36—Edge Discontinuities in Cut Material

is 30% of the cut material width, the area of discontinuity cannot exceed 3.6% of the cut material area). The discontinuity on the cut edge of the cut material shall be gouged out to a depth of 1 in [25 mm] beyond its intersection with the surface by chipping, air carbon arc gouging, or grinding, and blocked off by welding with a low hydrogen process in layers not exceeding 1/8 in [3 mm] in thickness.

9.2.5.3 If a discontinuity (Z), not exceeding the allowable area in 9.2.5.2 is discovered after the joint has been completed and is determined to be 1 in [25 mm] or more away from the face of the weld, as measured on the cut material surface, no repair of the discontinuity is required. If the discontinuity (Z) is less than 1 in [25 mm] away from the face of the weld, it shall be gouged out to a distance of 1 in [25 mm] from the fusion zone of the weld by chipping, air carbon arc back gouging, or grinding. It shall then be blocked off by welding with a low-hydrogen process for at least four layers not exceeding 1/8 in [3 mm] in thickness per layer.

9.2.5.4 If the area of the discontinuity (W), (X), (Y), or (Z) exceeds the allowable area in 9.2.5.2, the cut material or subcomponent shall be rejected and replaced, or repaired at the discretion of the Engineer.

9.2.5.5 The aggregate length of weld repair shall not exceed 20% of the length of the material edge without approval of the Engineer.

9.2.5.6 All repairs shall be in conformance to this specification. Backgouging of the discontinuity may be done from either surface or edge.

9.3 Repair Procedure

9.3.1 The size of surface or subsurface defects shall be determined and documented by means of suitable nondestructive testing. The defects shall be completely removed.

9.3.2 Prior to rewelding, these areas shall be checked by an appropriate testing method, such as magnetic particle or dye penetrant, to insure complete removal of defective material.

9.3.3 After rewelding in accordance with an approved repair welding procedure, the repaired areas are to be reinspected per Clause 8.

10. Postweld Treatments

10.1 Introduction

10.1.1 This section describes various postweld treatments to condition the weldment prior to its introduction into service. These treatments are designed to do one or more of the following:

- (1) maintain dimensional stability;
- (2) reduce or redistribute residual stress;
- (3) improve the microstructure;
- (4) improve fatigue life; or
- (5) improve mechanical properties.

10.1.2 The residual stress reduction methods discussed in this section are thermal, peening, and vibratory. The use of vibratory conditioning or other postweld treatments not listed in Clause 10 may be applied only with the approval of the Engineer.

10.1.3 Residual stress reduction methods used to minimize distortion of welded components will include, but not be limited to, those described in this section.

10.2 Thermal Residual Stress Reduction. Stresses created during the manufacture of the welded components or which were residual in the base material may be reduced by thermal stress reduction methods such as furnaces, portable electric resistance heaters, and other controlled heat sources. Thermal stress reduction is a process which:

- (1) raises the temperature of a metal at a controlled rate to an appropriate level for the metal (heating cycle);
- (2) maintains that elevated temperature for a specified time period (holding cycle); and
- (3) lowers the temperature at a controlled rate (cooling cycle).

10.2.1 The weldment shall be adequately supported to prevent sagging during stress reduction.

10.2.2 When two or more items are heated in a furnace at the same time, they shall be spaced so that all pieces will heat uniformly.

10.2.3 Baffles or insulating material, when needed, should be placed to protect the work from direct impingement of heat source.

10.2.4 The temperature shall be controlled and recorded from a thermocouple(s) that have surface contact with the welded component and are shielded from direct impingement of the heat source. Records shall include the location and calibration, of each thermocouple, along with traceable weldment identification such as weldment name, part number, or serial number. The records and data shall become part of the weldment documentation.

10.2.5 Heating Cycle. The postweld heat treatment temperature shall be as specified by the Engineer. The furnace shall not exceed 400°F [205°C] at the time the weldment is placed in it. After the temperature of the weldment reaches 400°F [205°C], the rate of heating shall not exceed 100°F [55°C] per hour until the weldment reaches the holding temperature. For other heat source methods, such as portable electric pads, the rate of temperature rise shall not exceed 100°F [55°C] per hour.

10.2.6 Hold Cycle. Hold time and temperature shall be approved by the Engineer.

10.2.7 Cooling Cycle. The weldment should be cooled at a rate not exceeding 100°F [55°C] per hour until the component reaches 300°F [150°C]. Blowers or fans shall not be used to increase the cooling rate during the cooling cycle.

10.2.8 Steels Not Recommended for Postweld Heat Treatment (PWHT). Stress relieving of weldments of A 514, A 517, A 709 Grades 100 and 100W, and A710 steels is generally not recommended. Stress relieving may be necessary for those applications where weldments must retain dimensional stability during machining or where stress corrosion may be involved, neither condition being unique to weldments involving A 514, A 517, A 709 Grades 100 and 100W and A710 steels. However, the results of notch toughness tests have shown that a PWHT may actually impair weld metal and heat-affected zone toughness, and intergranular cracking may sometimes occur in the grain-coarsened region of the weld heat-affected zone.

10.3 Peening

10.3.1 Shot Peening. Controlled shot peening may be employed to reduce surface tensile stresses. Controlled shot peening specifications shall apply.

10.3.2 Mechanical Peening. Hammer or needle peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking. No peening shall be done on the root pass. Mechanical peening of the surface layer of the weld and the base metal at the edges of the weld is permitted for fatigue strength improvement. Controlled peening procedures should be used to prevent overlapping or cracking of the weld or base metal. All slag should be removed prior to hammer peening. The use of manual slag hammers, chisels and lightweight vibrating tools for the removal of slag and spatter is permitted, but is not considered peening.

10.3.3 Peening for Fatigue Strength Improvement. Under controlled conditions, both shot and mechanical peening places the surface material in compression which reduces residual tensile stresses at the weld surface, the toe of the weld and the base metal adjacent to the weld. Both shot and mechanical peening provide for improved fatigue life in the weld joint as a result of the surface material being placed in compression.^{8,9,10}

10.4 Vibratory Conditioning

10.4.1 Vibrational conditioning has been used successfully to provide dimensional stability on some structures; however, the dimensional geometry, structural complexity and rigidity have a marked effect on the success of the method

⁸ Bremen, U., Smith, I.F.C., and Hirt, M.A., 1987, Crack Growth Behavior in a Welded Joint Improved by Residual Stress Method, International Conference: Fatigue of Welded Construction, ed. Maddos, S. J. Abington, Cambridge: The Welding Institute.

⁹ Booth, G. S., ed. 1983, *Improving the Fatigue Performance of Welded Joints*. Abington, Cambridge: The Welding Institute.

¹⁰ Metal Improvement Company, Inc., *Shot Peening Application*, Eighth Edition.

employed. Vibrational conditioning after welding is minimally effective (approximately up to 15% reduction) in reducing residual stress; but has been found to be moderately effective during welding, to minimize distortion in mild steel weldments.

10.4.2 Vibrational conditioning of welded structures to obtain dimensional stability for machining of the weldment may be employed with the approval of the Engineer.

10.4.3 Vibrational conditioning is not to be substituted for thermal stress relief.

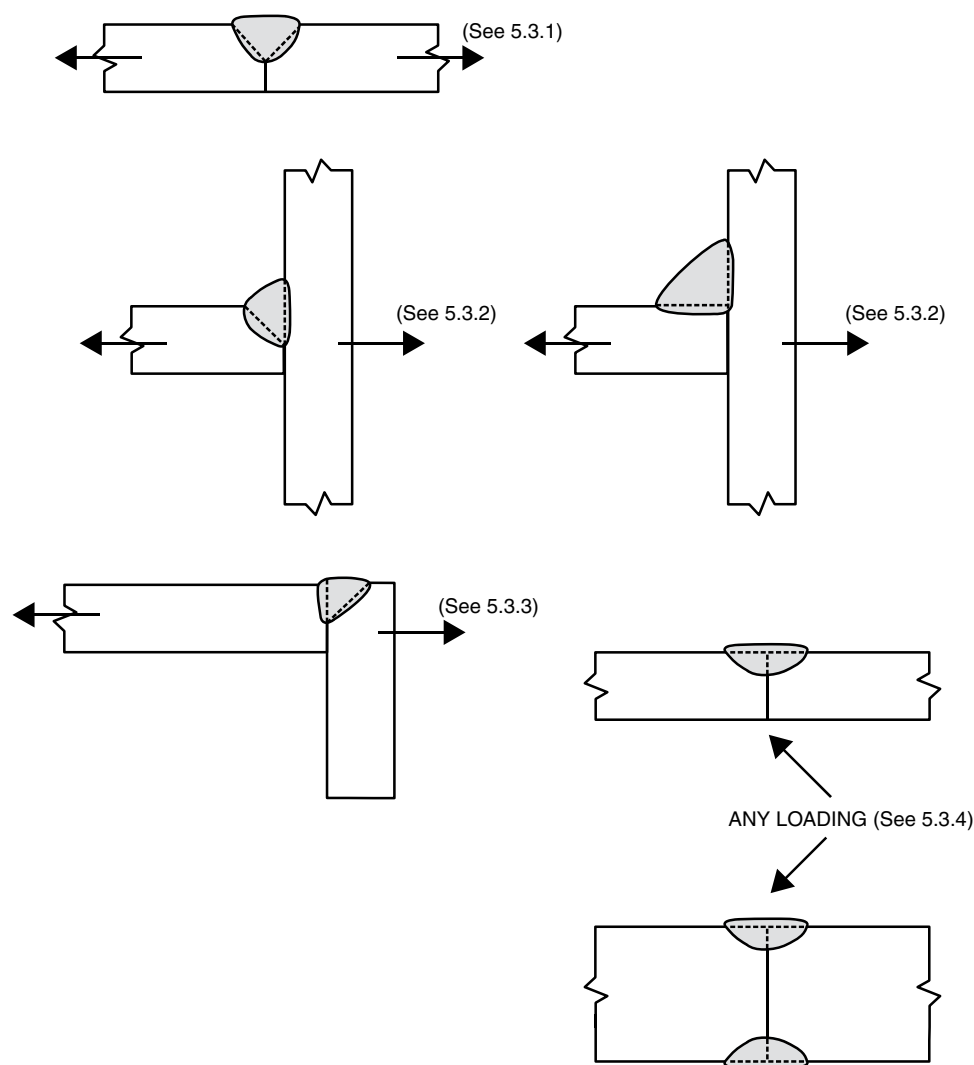
This page is intentionally blank.

Annex A (Normative)

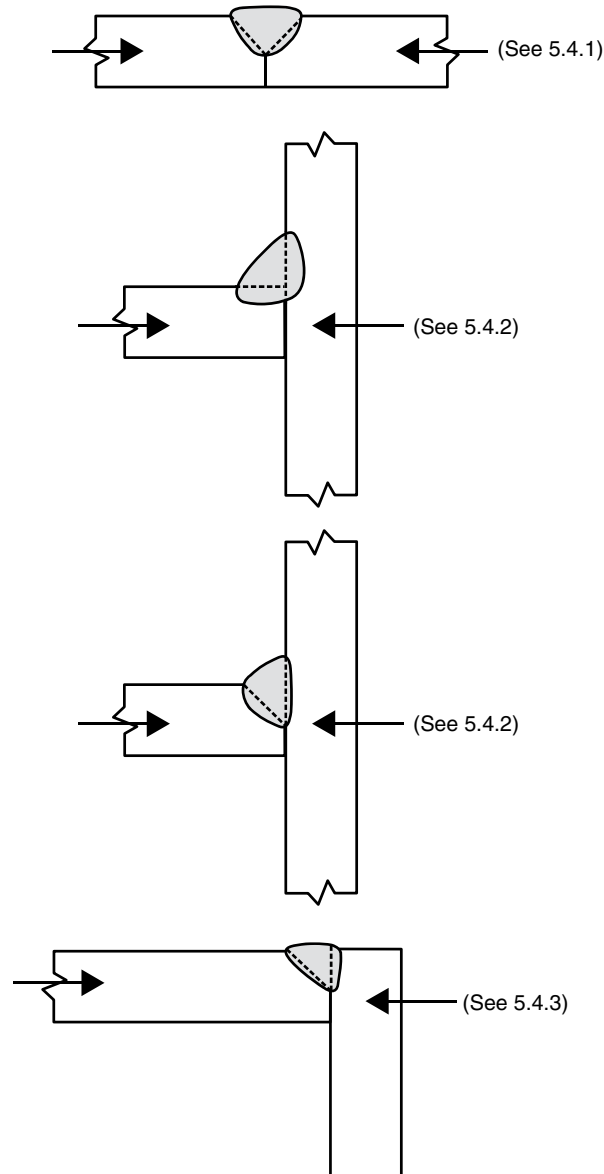
Illustrative Examples of Prohibited Joints and Welds

This annex is part of AWS D14.4/D14.4M:2012, *Specification for the Design of Welded Joints in Machinery and Equipment*, and includes mandatory elements for use with this standard.

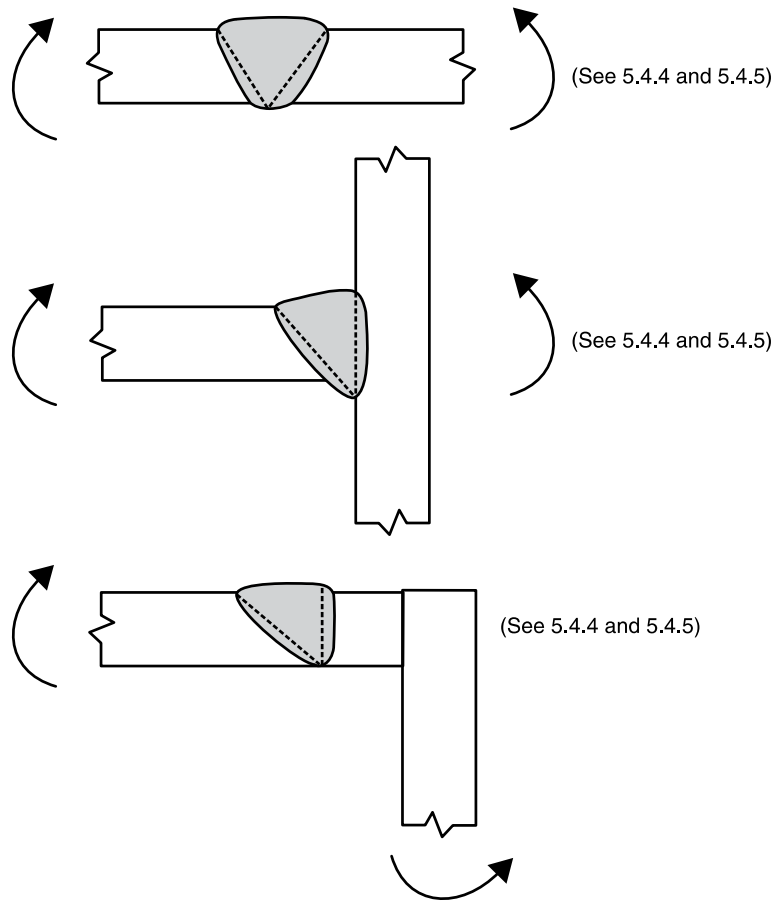
The figures shown below are intended to be illustrative examples of the prohibited joints and welds as listed in clauses 5.3 and 5.4. This annex is not intended to be an exhaustive list of examples.



Prohibited Joints and Welds on Principle Structural Weldments (See 5.3)



Prohibited Joints and Welds – Cyclically Loaded – on Principle Structural Weldment (See 5.4)



Note: Welds made without backing and without root NDT, or welds made with removeable backing without root NDT.

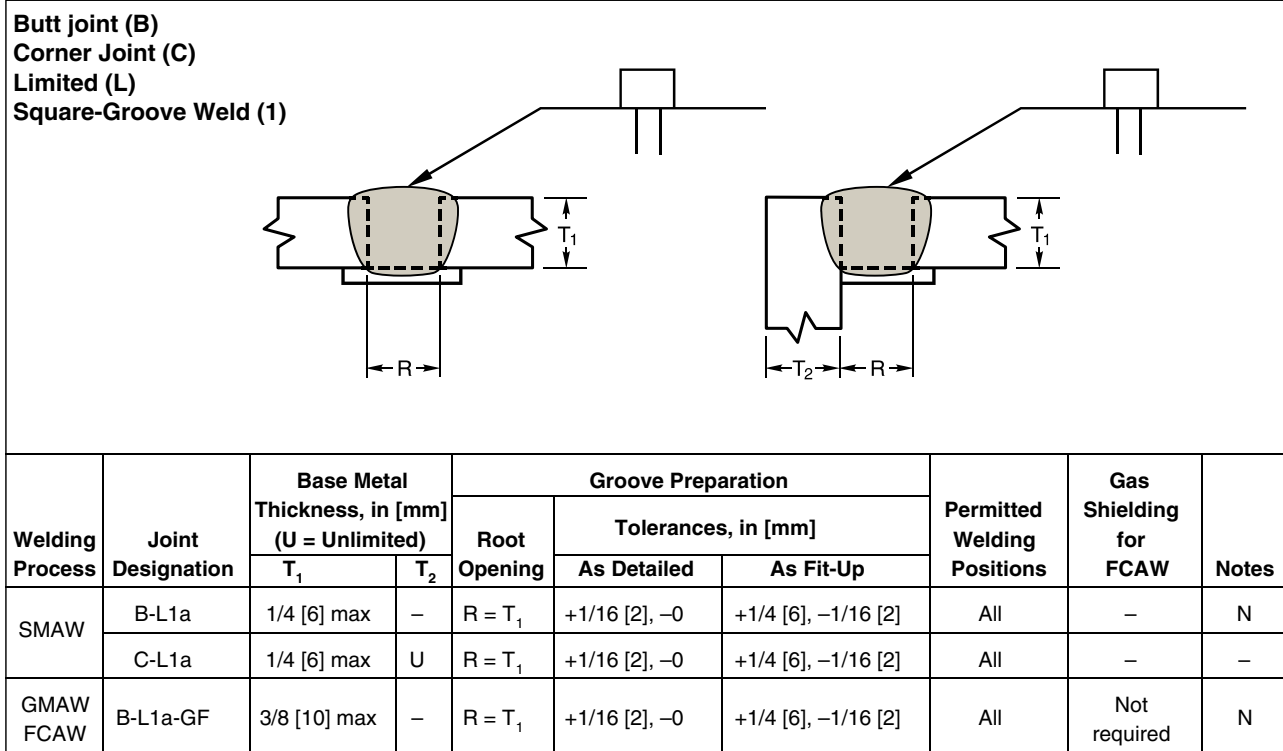
Prohibited Joints and Welds – Cyclically Loaded – on Principle Structural Weldment (See 5.4)

This page is intentionally blank.

Annex B (Informative)

Typical Weld Joints Details

This annex is not part of AWS D14.4/D14.4M:2012, *Specification for the Design of Welded Joints in Machinery and Equipment*, but is included for informational purposes only.

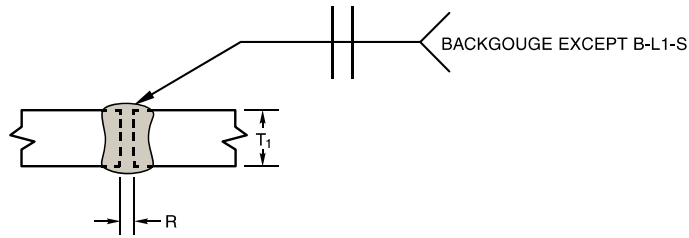


(A)

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Figure B.1—Typical Complete Joint Penetration Groove Welded Joints

Butt joint (B)
Limited (L)
Square-Groove Weld (1)



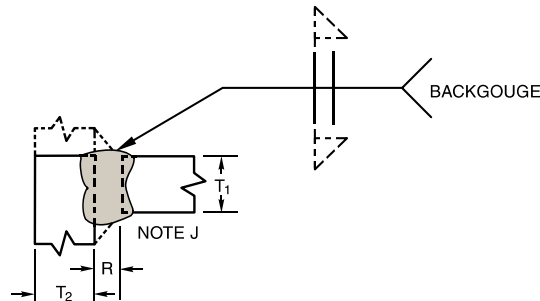
Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening in [mm]	Tolerances, in [mm]				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	B-L 1b	1/4 [6] max	—	R = T _r /2	+1/16 [2], -0	+1/16 [2], -1/8 [3]	All	—	C, N
GMAW FCAW	B-L1b-GF	3/8 [10] max	—	R = 0 to 1/8 [3]	+1/16 [2], -0	+1/16 [2], -1/8 [3]	All	Not required	C, N
SAW	B-L1-S	3/8 [10] max	—	R = 0	±0	+1/16 [2], -0	Flat	—	N
SAW	B-L1a-S	5/8 [16] max	—	R = 0	±0	+1/16 [2], -0	Flat	—	C, N

(B)

Note C: Backgouge root to sound metal before welding second side.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

T- or Corner joint (TC)
Limited (L)
Square-Groove Weld (1)



Welding Process	Joint Designation	Base Metal		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		Thickness, in [mm] (U = Unlimited)		Root Opening in [mm]	Tolerances, in [mm]				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	TC-L1b	1/4 [6] max	U	R = T ₁ /2	+1/16 [2], −0	+1/16 [2], −1/8 [3]	All	—	C, J
GMAW FCAW	TC-L1a-GF	3/8 [10] max	U	R = 0 to 1/8 [3]	+1/16 [2], −0	+1/16 [2], −1/8 [3]	All	Not required	C, J
SAW	TC-L1-S	3/8 [10] max	U	R = 0	±0	+1/16 [2], −0	Flat	—	C, J

(C)

Note C: Backgouge root to sound metal before welding second side.

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed 3/8 in. [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed 3/8 in. [10 mm].

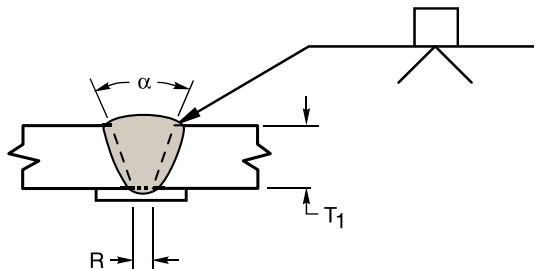
Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B)

Unlimited (U) or

Limited (L)

Single V-Groove Weld (2)



Tolerances,
in [mm] for R; ° for α

As Detailed	As Fit-Up
R = +1/16 [2], -0	+1/4 [6], -1/16 [2]
α = +10°, -0°	+10°, -5°

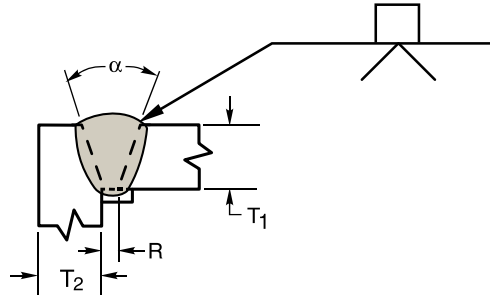
Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening in [mm]	Groove Angle			
SMAW	B-U2a	U	—	R = 1/4 [6]	α = 45°	All	—	N
				R = 3/8 [10]	α = 30°	F, V, OH	—	
				R = 1/2 [13]	α = 20°	F, V, OH	—	
GMAW FCAW	B-U2a-GF	U	—	R = 3/16 [5]	α = 30°	F, V, OH	Required	N
				R = 1/4 [6]	α = 30°	F, V, OH	Not Req.	
				R = 3/8 [10]	α = 45°	F, V, OH	Not Req.	
SAW	B-L2a-S	2 [50] max	—	R = 1/4 [6]	α = 30°	F	—	N
SAW	B-U2-S	U	—	R = 5/8 [16]	α = 20°	F	—	

(D)

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Corner Joint (C)
Unlimited (U) or Limited (L)
Single V-Groove Weld (2)



Tolerances, in [mm] for R; ° for α	
As Detailed	As Fit-Up
R = +1/16 [2], -0	+1/4 [6], -1/16 [2]
α = +10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation		Permitted Welding Positions*	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening, in [mm]	Groove Angle			
SMAW	C-U2a	U	U	R = 1/4 [6]	α = 45°	All	—	Q
				R = 3/8 [10]	α = 30°	F, V, OH	—	
				R = 1/2 [13]	α = 20°	F, V, OH	—	
GMAW FCAW	C-U2a-GF	U	U	R = 3/16 [5]	α = 30°	F, V, OH	Required	Q
				R = 3/8 [10]	α = 30°	F, V, OH	Not Req.	
				R = 1/4 [6]	α = 45°	F, V, OH	Not Req.	
SAW	C-L2a-S	2 [50] max	U	R = 1/4 [6]	α = 30°	F	—	Q
SAW	C-U2-S	U	U	R = 5/8 [16]	α = 20°	F	—	

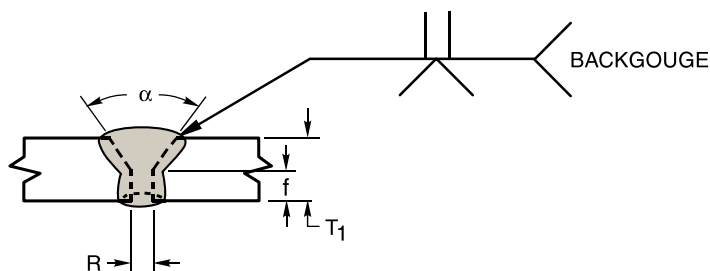
(E)

Note Q: For corner and T-joints, the member orientation may be changed provided the groove angle is maintained as specified.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

**Butt joint (B)
Unlimited (U) or
Limited (L)
Single V-Groove Weld (2)**



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions*	Gas Shielding for FCAW	Notes
				Root Opening Root Face in [mm]	Tolerances, in [mm] for R & f; ° for α				
		T ₁	T ₂	Groove Angle	As Detailed	As Fit-Up			
SMAW	B-U2	U	—	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 60°	R = +1/16 [2], -0 f = +1/16 [2], -0 α = +10°, -0°	R = +1/16 [2], -1/8 [3] f = Not Limited α = +10°, -5°	All	—	C, N
GMAW FCAW	B-U2-GF	U	—	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 60°			All	Not required	C, N
SAW	B-L2c-S	Over 1/2 [13] to 1 [25]	—	R = 0 f = 1/4 [6] max α = 60°	R = ±0 f = +0, -f α = +10°, -0°	R =+1/16 [2], -0 f = ±1/16 [2] α = +10°, -5°	Flat	—	C, N
		Over 1 [25] to 1 1/2 [40]	—	R = 0 f = 1/2 [13] max α = 60°					
		Over 1 1/2 [40] to 2 [50]	—	R = 0 f = 5/8 [16] max α = 60°					

(F)

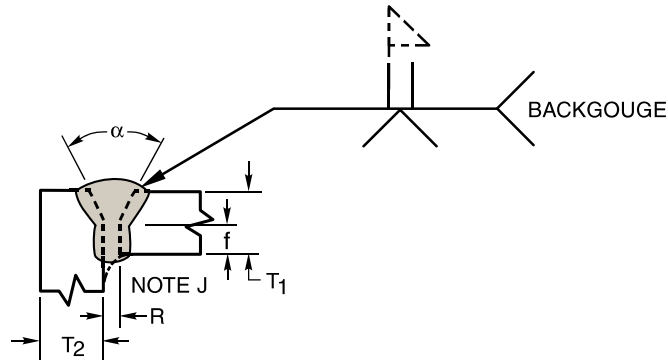
Note C: Backgouge root to sound metal before welding second side.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Corner joint (C)
Unlimited (U)
Single V-Groove Weld (2)



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face in [mm]	Tolerances, in [mm] for R & f; ° for α				
		T ₁	T ₂	Groove Angle	As Detailed	As Fit-Up			
SMAW	C-U2	U	U	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 60°	+1/16 [2], −0 +1/16 [2], −0 +10°, −0°	+1/16 [2], −1/8 [3] Not Limited +10°, −5°	All	—	C, J, R
GMAW FCAW	C-U2-GF	U	U	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 60°	+1/16 [2], −0 +1/16 [2], −0 +10°, −0°	+1/16 [2], −1/8 [3] Not Limited +10°, −5°	All	Not required	C, J, R
SAW	C-U2b-S	U	U	R = 0 f = 1/4 [6] max α = 60°	± 0 +0, −1/4 [6] +10°, −0°	+1/16 [2], −0 ±1/16 [2] +10°, −5°	Flat	—	C, J, R

(G)

Note C: Backgouge root to sound metal before welding second side.

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm].

Note R: The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B) Unlimited (U) Double V-Groove Weld (3)				Tolerances, in [mm] for R, f, or Spacer; ° for α					
				As Detailed		As Fit-Up			
				$R = \pm 0$		$+1/4 [6], -0$			
				$f = \pm 0$		$+1/16 [2], -0$			
				$\alpha = +10^\circ, -0^\circ$		$+10^\circ, -5^\circ$			
				SAW Spacer = ± 0		$+1/16 [2], -0$			
				SMAW Spacer = ± 0		$+1/8 [3], -0$			

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions*	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening (R) in [mm]	Root Face (f) in [mm]	Groove Angle			
SMAW	B-U3a	U Spacer = $1/8R$	—	$1/4 [6]$	$0 \text{ to } 1/8 [3]$	$\alpha = 45^\circ$	All	—	C, M, N
				$3/8 [10]$	$0 \text{ to } 1/8 [3]$	$\alpha = 30^\circ$	F, V, OH	—	
				$1/2 [13]$	$0 \text{ to } 1/8 [3]$	$\alpha = 20^\circ$	F, V, OH	—	
SAW	B-U3a-S	U Spacer = $1/4R$	—	$5/8 [16]$	$0 \text{ to } 1/4 [6]$	$a = 20^\circ$	F	—	C, M, N

(H)

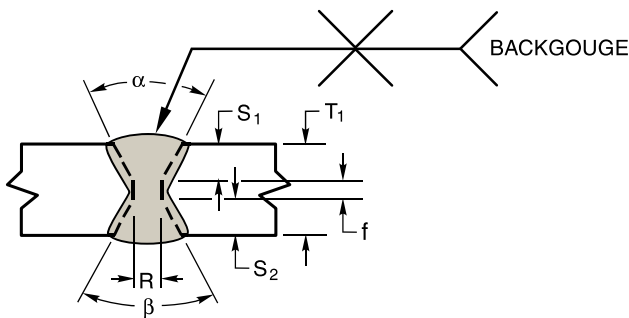
Note C: Backgouge root to sound metal before welding second side.

Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B) Unlimited (U) Double V-Groove Weld (3) 				For B-U3c-S only in [mm]					
				T1	S1				
				>2 [50] to ≤ 2 1/2 [60]	1 3/8 [35]				
				>2 1/2 [60] to ≤ 3 [75]	1 3/4 [45]				
				>3 [75] to ≤ 3 5/8 [90]	2 1/8 [55]				
				>3 5/8 [90] to ≤ 4 [100]	2 3/8 [60]				
				>4 [100] to ≤ 4 3/4 [120]	2 3/4 [70]				
				>4 3/4 [120] to ≤ 5 1/2 [140]	3 1/4 [80]				
				>5 1/2 [140] to ≤ 6 1/4 [160]	3 3/4 [95]				
				For T1 > 6 1/4 [160], or T1 ≤ 2 [50] S1 = 2/3(T1 - 1/4 [6])					
Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face in [mm] Groove Angle	Tolerances, in [mm] for R & f; ° for α				
	As Detailed	As Fit-Up							
	SMAW	B-U3b	U	—	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = β = 60°	+1/16 [2], -0			
GMAW FCAW	B-U3-GF	+1/16 [2], -0				Not Limited	All	Not Required	C, M, N
SAW	B-U3c-S	U	—	R = 0 f = 1/4 [6] min α = β = 60°	+1/16 [2], -0	+1/16 [2], -0	Flat	—	C, M, N
					+1/4 [6], -0	+1/4 [6], -0			
				To find S1 see table above; S2 = T1 - (S1 + f)					

(I)

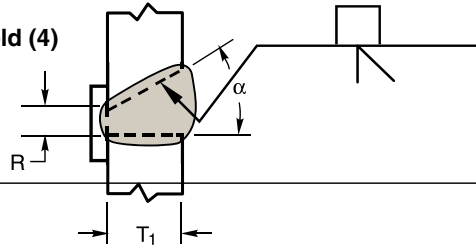
Note C: Backgouge root to sound metal before welding second side.

Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

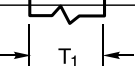
Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B)
Unlimited (U)
Single-Bevel-Groove Weld (4)



Tolerances, in [mm] for R; ° for α	
As Detailed	As Fit-Up
$R = +1/16 [2] -0 [0]$	$+1/4 [6], -1/16 [2]$
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$

								
Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation		Permitted Welding Positions*	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening in [mm]	Groove Angle			
SMAW	B-U4a	U	—	R = 1/4 [6]	$\alpha = 45^\circ$	All	—	Br, N
				R = 3/8 [10]	$\alpha = 30^\circ$	All	—	
GMAW FCAW	B-U4a-GF	U	—	R = 3/16 [5]	$\alpha = 30^\circ$	All	Required	Br, N
				R = 1/4 [6]	$\alpha = 45^\circ$	All	Not Req.	
				R = 3/8 [10]	$\alpha = 30^\circ$	F	Not Req.	

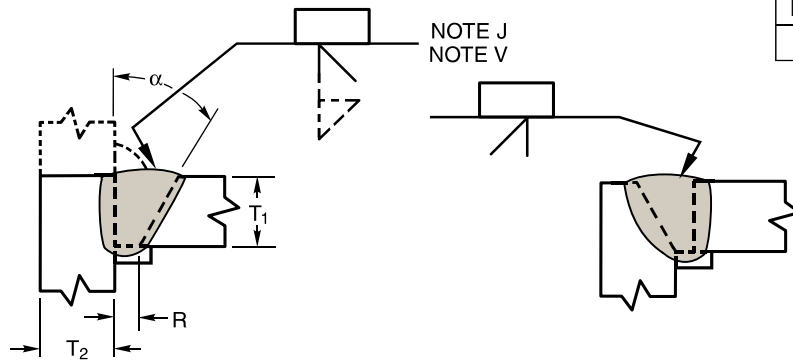
(J)

Note Br: Cyclic load application limits these joints to the horizontal welding position.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

T- or Corner Joint (TC)**Unlimited (U)****Single-Bevel-Groove Weld (4)**

Tolerances in [mm] for R; ° for α	
As Detailed	As Fit-Up
$R = +1/16 [2] -0$	$+1/4 [6], -1/16 [2]$
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation		Permitted Welding Positions*	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening in [mm]	Groove Angle			
SMAW	TC-U4a	U	U	$R = 1/4 [6]$	$\alpha = 45^\circ$	All	—	J, Q, V
				$R = 3/8 [10]$	$\alpha = 30^\circ$	F, V, OH	—	
GMAW FCAW	TC-U4a-GF	U	U	$R = 3/16 [5]$	$\alpha = 30^\circ$	All	Required	J, Q, V
				$R = 3/8 [10]$	$\alpha = 30^\circ$	F	Not Req.	
				$R = 1/4 [6]$	$\alpha = 45^\circ$	All	Not Req.	
SAW	TC-U4a-S	U	U	$R = 3/8 [10]$	$\alpha = 30^\circ$	F	—	J, Q, V
				$R = 1/4 [6]$	$\alpha = 45^\circ$			

(K)

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm].

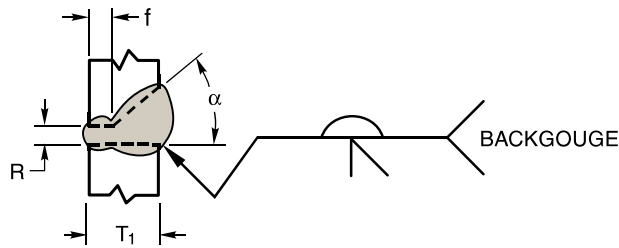
Note Q: For corner and T-joints, the member orientation may be changed provided the groove angle is maintained as specified.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

**Butt joint (B)
Unlimited (U)
Single-Bevel-Groove Weld (4)**



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening	Tolerances,				
		Root Face in [mm]	in [mm] for R & f; ° for α						
		Groove Angle	As Detailed	As Fit-Up					
SMAW	B-U4b	U	—	R = 0 to 1/8 [3]	+1/16 [2], -0	+1/16 [2], -1/8 [3]	All	—	Br, C, N
GMAW FCAW	B-U4b-GF	U	—	f = 0 to 1/8 [3] α = 45°	+1/16 [2], -0 +10°, -0°	Not Limited +10°, -5°	All	Not required	Br, C, N

(L)

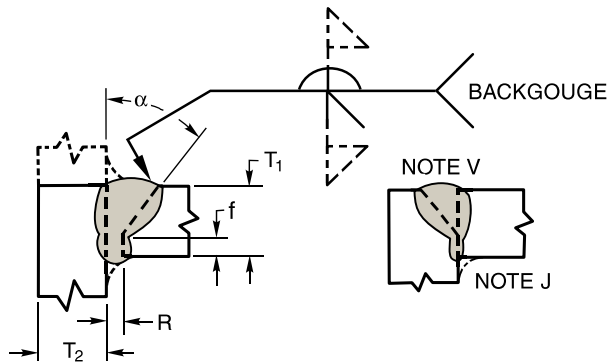
Note Br: Cyclic load application limits these joints to the horizontal welding position.

Note C: Backgouge root to sound metal before welding second side.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

T- or Corner joint (TC)
Unlimited (U)
Single-Bevel-Groove Weld (4)



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face (f), in [mm] Groove Angle	Tolerances, in [mm] for R & f; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	TC-U4b	U	U	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 45°	+1/16 [2], −0	+1/16 [2], −1/8 [3]	All	—	C, J, R, V
GMAW FCAW	TC-U4b-GF	U	U		+1/16 [2], −0 +10°, −0°	Not Limited +10°, −5°	All	Not required	C, J, R, V
SAW	TC-U4b-S	U	U	R = 0 f = 1/4 [6] max α = 60°	±0 +0, −1/8 [3] +10°, −0°	+1/4 [6], −0 ±1/16 [2] +10°, −5°	Flat	—	C, J, R, V

(M)

Note C: Backgouge root to sound metal before welding second side.

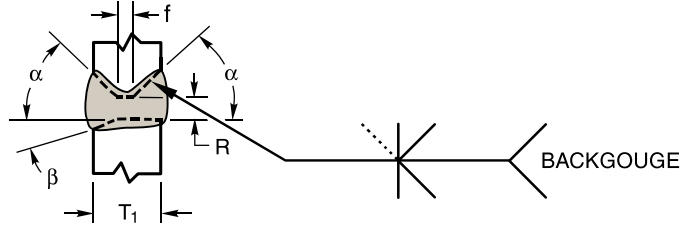
Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm].

Note R: The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B)
Unlimited (U)
Double-Bevel-Groove Weld (5)



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening, Root Face (f), in [mm] Groove Angle	Tolerances, in [mm] for R & f; ° for α & β				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	B-U5a	U	—	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 45° β = 0° to 15°	+1/16 [2], −0 +1/16 [2], −0 α + β: +10°, −0°	+1/16 [2], −1/8 [3] Not Limited α + β: +10°, −5°	All	—	Br, C, M, N
GMAW FCAW	B-U5-GF	U	—	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 45° β = 0° to 15°	+1/16 [2], −0 +1/16 [2], −0 α + β: +10°, −0°	+1/16 [2], −0 +1/16 [2], −0 α + β: +10°, −5°	All	Not required	Br, C, M, N

(N)

Note Br: Cyclic load application limits these joints to the horizontal welding position.

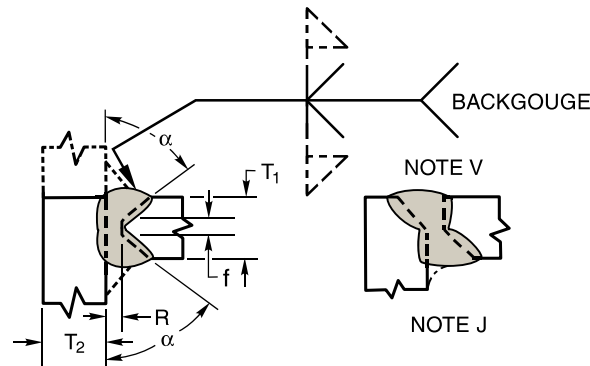
Note C: Backgouge root to sound metal before welding second side.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

T- or Corner joint (TC)
Unlimited (U)
Double-Bevel-Groove Weld (5)



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening, Root Face (f), in [mm] Groove Angle	Tolerances, in [mm] for R & f; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	TC-U5b	U	U	R = 0 to 1/8 [3] f = 0 to 1/8 [3] α = 45°	+1/16 [2], -0 +1/16 [2], -0 +10°, -0°	+1/16 [2], -1/8 [3] Not Limited +10°, -5°	All	—	C, J, M, R, V
GMAW FCAW	TC-U5-GF	U	U		All	Not required	C, J, M, R, V		
SAW	TC-U5-S	U	U	R = 0 f = 3/16 [5] max α = 60°	±0 +0, -3/16 [5] +10°, -0°	+1/16 [2], -0 ±1/16 [2] +10°, -5°	Flat		C, J, M, R, V

(O)

Note C: Backgouge root to sound metal before welding second side.

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm].

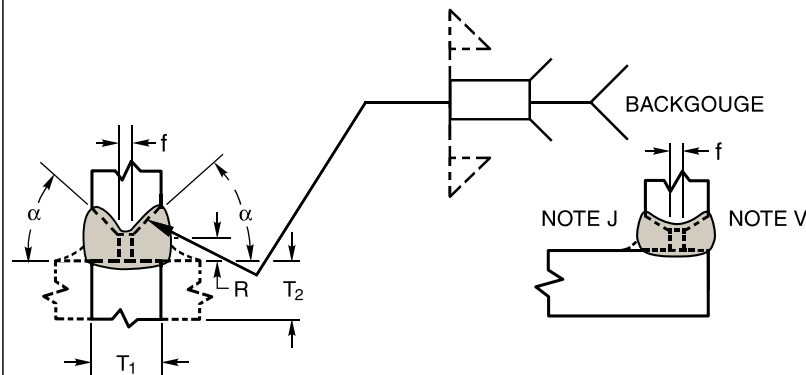
Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note R: The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

**Butt Joint (B),
T- or Corner Joint (TC)
Unlimited (U)
Double-bevel-Groove Weld (5)**



Tolerances,
in [mm] for R, f, & Spacer; ° for α

As Detailed	As Fit-Up
R: ± 0	+1/4 [6], -0
f: +1/16 [2], -0	$\pm 1/16$ [2]
α : +10°, -0°	+10°, -5°
Spacer: +1/16 [2], -0	+1/8 [3], -0

Spacer same steel as base metal.

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening (R), in [mm]	Root Face (f), in [mm]	Groove Angle			
SMAW	B-U5b	U Spacer = 1/8 × R	—	1/4 [6]	0 to 1/8 [3]	α = 45 °	All	—	Br, C, M, N
	TC-U5a	U Spacer = 1/4 × R	U	1/4 [6]	0 to 1/8 [3]	α = 45 °	All	—	C, J, M, R, V
				3/8 [10]	0 to 1/8 [3]	α = 30 °	Flat, Overhead	—	C, J, M, R, V

(P)

Note Br: Cyclic load application limits these joints to the horizontal welding position.

Note C: Backgouge root to sound metal before welding second side.

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed 3/8 in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed 3/8 in [10 mm].

Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note R: The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B), Corner Joint (C) Unlimited (U) Single U-Groove Weld (6)				Tolerances, in [mm] for R, f, & r; ° for α	
				As Detailed	As Fit-Up
				R: +1/16 [2], -0	+1/16 [2], -1/8 [3]
				f: $\pm 1/16$ [2]	Not Limited
				α : +10°, -0°	+10°, -5°
				r: +1/8 [3], -0	+1/8 [3], -0

Groove Radius (r) = 1/4 in [6 mm] for all

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions*	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening (R), in [mm]	Root Face (f), in [mm]	Groove Angle			
SMAW	B-U6	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 45^\circ$	All	—	C, N
				0 to 1/8 [3]	1/8 [3]	$\alpha = 20^\circ$	F, OH	—	
	C-U6	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 45^\circ$	All	—	C, J, R
				0 to 1/8 [3]	1/8 [3]	$\alpha = 20^\circ$	F, OH	—	
GMAW FCAW	B-U6-GF	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 20^\circ$	All	Not Req.	C, N
	C-U6-GF	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 20^\circ$	All	Not Req.	C, J, R

(Q)

Note C: Backgouge root to sound metal before welding second side.

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed $3/8$ in [10 mm].

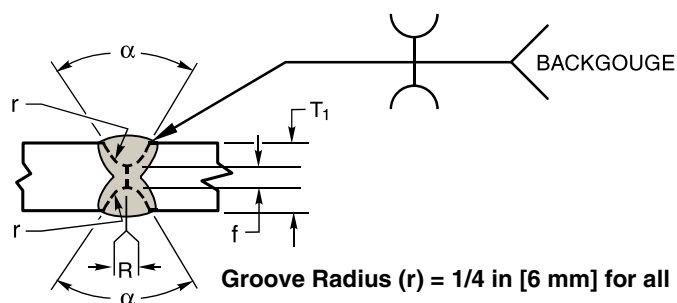
Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Note R: The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B)
Unlimited (U)
Double U-Groove Weld (7)



Tolerances,
in [mm] for R , f , & r ; ° for α

As Detailed	As Fit-Up
-------------	-----------

For B-U7 and B-U7-GF

R : +1/16 [2], -0	+1/16 [2], -1/8 [3]
---------------------	---------------------

f : ±1/16 [2]	Not Limited
-----------------	-------------

α : +10°, -0°	+10°, -5°
----------------------	-----------

r : +1/4 [6], -0	±1/16 [2]
--------------------	-----------

For B-U7-S

R : ±0	+1/16 [2], -0
----------	---------------

f : +0, -1/4 [6]	±1/16 [2]
--------------------	-----------

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions*	Gas Shielding for FCAW	Notes
				Root Opening (R), in [mm]	Root Face (f), in [mm]	Groove Angle			
		T_1	T_2						
SMAW	B-U7	U	—	0 to 1/8 [3]	1/8 [3]	$\alpha = 45^\circ$	All	—	C, M, N
			—	0 to 1/8 [3]	1/8 [3]	$\alpha = 20^\circ$	F, OH	—	C, M, N
GMAW FCAW	B-U7-GF	U	—	0 to 1/8 [3]	1/8 [3]	$\alpha = 20^\circ$	All	Not Required	C, M, N
SAW	B-U7-S	U	—	0	1/4 [6] max.	$\alpha = 20^\circ$	F	—	C, M, N

(R)

Note C: Backgouge root to sound metal before welding second side.

Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B)
Unlimited (U)
Single J-Groove Weld (8)

Groove Radius (r) = 3/8 in [10 mm] for all

Tolerances, in [mm] for R, f, & r; ° for α	
As Detailed	As Fit-Up
R: +1/16 [2], -0	+1/16 [2], -1/8 [3]
f: +1/16 [2], -0	Not Limited
α : +10°, -0°	+10°, -5°
r: +1/4 [6], -0	±1/16 [2]

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening (R), in [mm]	Root Face (f), in [mm]	Groove Angle			
		T ₁	T ₂						
SMAW	B-U8	U	—	0 to 1/8 [3]	1/8 [3]	$\alpha = 45^\circ$	All	—	Br, C, N
GMAW FCAW	B-U8-GF	U	—	0 to 1/8 [3]	1/8 [3]	$\alpha = 30^\circ$	All	Not Req.	Br, C, N

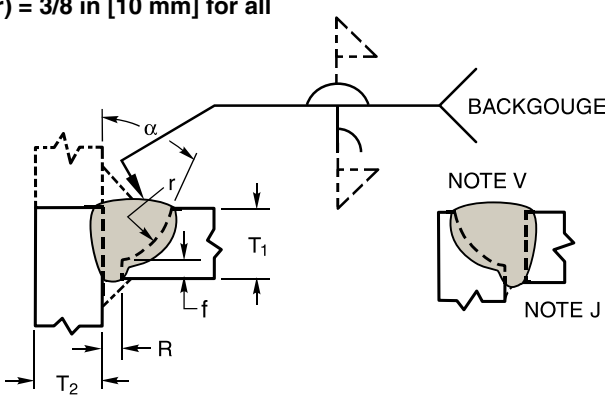
(S)

Note Br: Cyclic load application limits these joints to the horizontal welding position.

Note C: Backgouge root to sound metal before welding second side.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

T- or Corner Joint (TC) Unlimited (U) Single J-Groove Weld (8) Groove Radius (r) = 3/8 in [10 mm] for all				Tolerances, in [mm] for R, f, & r; ° for α					
				As Detailed	As Fit-Up				
				R: +1/16 [2], -0	+1/16 [2], -1/8 [3]				
				f: +1/16 [2], -0	Not Limited				
				α : +10°, -0°	+10°, -5°				
				r: +1/4 [6], -0	±1/16 [2]				
Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation		Groove Angle	Permitted Welding Positions*	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening (R), in [mm]	Root Face (f), in [mm]				
SMAW	TC-U8a	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 45^\circ$	All	—	C, J, R, V
				0 to 1/8 [3]	1/8 [3]	$\alpha = 30^\circ$	F, OH	—	
GMAW FCAW	TC-U8a-GF	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 30^\circ$	All	Not Required	C, J, R, V

(T)

Note C: Backgouge root to sound metal before welding second side.

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed 3/8 in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed 3/8 in [10 mm].

Note R: The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

* F = Flat, OH = Overhead, V = Vertical

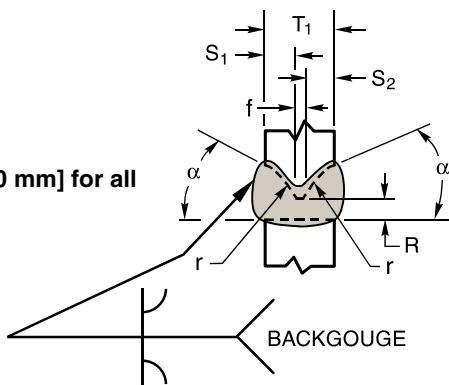
Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B)

Unlimited (U)

Double J-Groove Weld (9)

Groove Radius (r) = 3/8 in [10 mm] for all



Tolerances,
in [mm] for R, f, & r; ° for α

As Detailed	As Fit-Up
R: +1/16 [2], -0	+1/16 [2], -1/8 [3]
f: +1/16 [2], -0	Not Limited
α: +10°, -0°	+10°, -5°
r: +1/8 [3], -0	±1/16 [2]

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening (R), in [mm]	Root Face (f), in [mm]	Groove Angle			
SMAW	B-U9	U	—	0 to 1/8 [3]	1/8 [3]	α = 45°	All	—	Br, C, M, N
GMAW FCAW	B-U9-GF		—	0 to 1/8 [3]	1/8 [3]	α = 30°	All	Not Required	Br, C, M, N

(U)

Note Br: Cyclic load application limits these joints to the horizontal welding position.

Note C: Backgouge root to sound metal before welding second side.

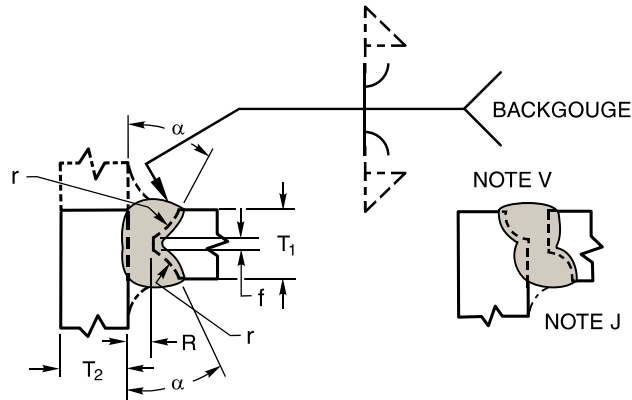
Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note N: The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

T- or Corner Joint (TC)
Unlimited (U)
Double J-Groove Weld (9)

Groove Radius (r) = 3/8 in [10 mm] for all



Tolerances, in [mm] for R, f, & r; ° for α	
As Detailed	As Fit-Up
R: +1/16 [2], -0	+1/16 [2], -1/8 [3]
f: +1/16 [2], -0	Not Limited
α : +10°, -0°	+10°, -5°
r: +1/8 [3], -0	±1/16 [2]

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions*	Gas Shielding for FCAW	Notes
				Root Opening (R), in [mm]	Root Face (f), in [mm]	Groove Angle			
		T ₁	T ₂						
SMAW	TC-U9a	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 45^\circ$	All	—	C, J, M, R, V
				0 to 1/8 [3]	1/8 [3]	$\alpha = 30^\circ$	F, OH	—	
GMAW FCAW	TC-U9a-GF	U	U	0 to 1/8 [3]	1/8 [3]	$\alpha = 30^\circ$	All	Not Required	C, J, M, R, V

(V)

Note C: Backgouge root to sound metal before welding second side.

Note J: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but need not exceed 3/8 in [10 mm]. Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to $1/4T_1$, but need not exceed 3/8 in [10 mm].

Note M: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

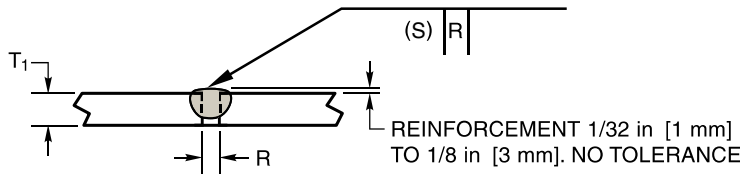
Note R: The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

* F = Flat, OH = Overhead, V = Vertical

Figure B.1 (Continued)—Typical Complete Joint Penetration Groove Welded Joints

Butt Joint (B)
Partial Joint Penetration (P)
Square-Groove Weld (1)



Welding Process	Joint Designation	Base Metal Thickness, in [mm]		Groove Preparation			Permitted Welding Positions	Weld Size (S), in [mm]	Notes
				Root Opening, in [mm]	Tolerances, in [mm]				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	B-P1a	1/8 [3]	—	R = 0 to 1/16 [2]	+1/16 [2], -0	±1/16 [2]	All	T ₁ - 1/32 [1]	B
	B-P1c	1/4 [6] max	—	R = T ₁ /2 minimum	+1/16 [2], -0	±1/16 [2]	All	T ₁ /2	B

(A)

Note B: Joint is welded from one side only.

Butt Joint (B)

Partial Joint Penetration (P)

Square-Groove Weld (1)

$S_1 + S_2$ MUST NOT EXCEED $3T_1/4$

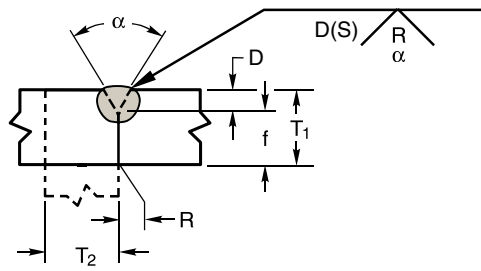
Welding Process	Joint Designation	Base Metal Thickness, in [mm]		Groove Preparation			Permitted Welding Positions	Total Weld Size (S ₁ + S ₂), in [mm]	Notes
		T ₁	T ₂	Root Opening, in [mm]	Tolerances, in [mm]				
					As Detailed	As Fit-Up			
SMAW	B-P1b	1/4 [6] max	—	R = T ₁ /2 minimum	+1/16 [2], -0	±1/16 [2]	All	3T 1/4	C2

(B)

Note C2: Root need not be gouged before welding other side.

Figure B.2—Typical Partial Joint Penetration Groove Welded Joints

**Butt or Corner Joint (BC)
Partial Joint Penetration (P)
Single-V-Groove Weld (2)**



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S), in [mm]	Notes
				Root Opening, Root Face (f), in [mm] Groove Angle	Tolerances, in [mm] for R & f; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	BC-P2	1/4 [6] min	U	R = 0 f = 1/8 [3] min α = 60°	±0 ±1/16 [2] +10°, -0°	+1/16 [2], -0 ±1/16 [2] +10°, -5°	All	D	B, E, Q2
GMAW FCAW	BC-P2-GF	1/4 [6] min	U	R = 0 f = 1/8 [3] min α = 60°	±0 ±1/16 [2] +10°, -0°	+1/16 [2], -0 ±1/16 [2] +10°, -5°	All	D	B, E, Q2
SAW	BC-P2-S	7/16 [11] min	U	R = 0 f = 1/4 [6] min α = 60°	±0 ±1/16 [2] +10°, -0°	+1/16 [2], -0 ±1/16 [2] +10°, -5°	Flat	D	B, E, Q2

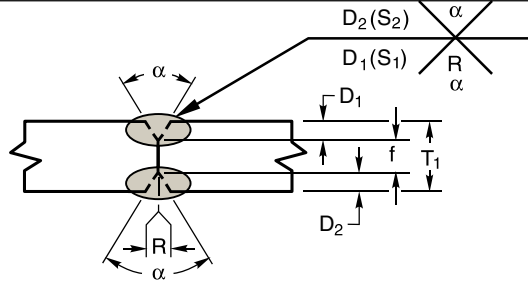
(C)

Note B: Joint is welded from one side only.

Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt Joint (B) Partial Joint Penetration (P) Double-V-Groove Weld (3) 									
Welding Process	Joint Designation	Base Metal Thickness, in [mm]		Groove Preparation			Permitted Welding Positions	Weld Size (S), in [mm]	Notes
				Root Opening, Root Face (f), in [mm]	Tolerances, in [mm] for R & f; ° for α				
		T ₁	T ₂		Groove Angle	As Detailed			
SMAW	B-P3	1/2 [13] min	—	R = 0 f = 1/8 [3] min α = 60°	+1/16 [2], -0 -0 +10°, -0°	±1/16 [2] ±1/16 [2] +10°, -5°	All	D ₁ + D ₂	E, Mp, Q2
GMAW FCAW	B-P3-GF	1/2 [13] min	—	R = 0 f = 1/8 [3] min α = 60°	+1/16 [2], -0 -0 +10°, -0°	±1/16 [2] ±1/16 [2] +10°, -5°	All	D ₁ + D ₂	E, Mp, Q2
SAW	B-P3-S	3/4 [20] min	—	R = 0 f = 1/4 [6] min α = 60°	±0 -0 +10°, -0°	+3/16 [5], -0 ±1/16 [2] +10°, -5°	Flat	D ₁ + D ₂	E, Mp, Q2

(D)

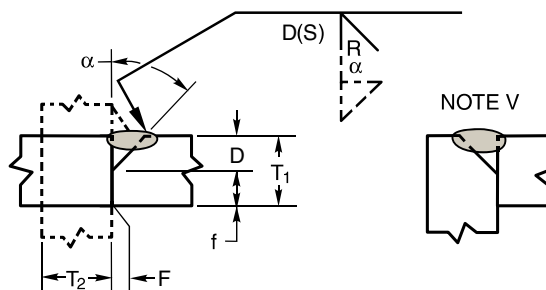
Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

Note Mp: Double-groove welds may have grooves of unequal depth, provided these conform to Note E. Also, the weld size (S), less any reduction, applies individually to each groove.

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt, T-, or Corner Joint (BTC)
Partial Joint Penetration (P)
Single-Bevel-Groove Weld (4)
U = Unlimited



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions*	Weld Size (S), in [mm]	Notes
				Root Opening, Root Face (f), in [mm] Groove Angle	Tolerances, in [mm] for R & f; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	BTC-P4	U	U	R = 0 f = 1/8 [3] min α = 45°	+1/16 [2], -0 -0" +10°, -0°	±1/16 [2] ±1/16 [2] +10°, -5°	All	D	B, E, J2, Q2, V,
GMAW FCAW	BTC-P4-GF	1/4 [6] min	U	R = 0 f = 1/8 [3] min α = 45°	+1/16 [2], -0 -0" +10°, -0°	±1/16 [2] ±1/16 [2] +10°, -5°	F, H	D	B, E, J2, Q2, V,
							V, OH	D – 1/8 [3]	
SAW	BTC-P4-S	7/16 [11] min	U	R = 0 f = 1/4 [6] min α = 60°	±0 +U, -0 +10°, -0°	+3/16 [5], -0 ±1/16 [2] +10°, -5°	Flat	D	B, E, J2, Q2, V,

(E)

Note B: Joint is welded from one side only.

Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

Note J2: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to 1/4T₁, but not exceed 3/8 in [10 mm].

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

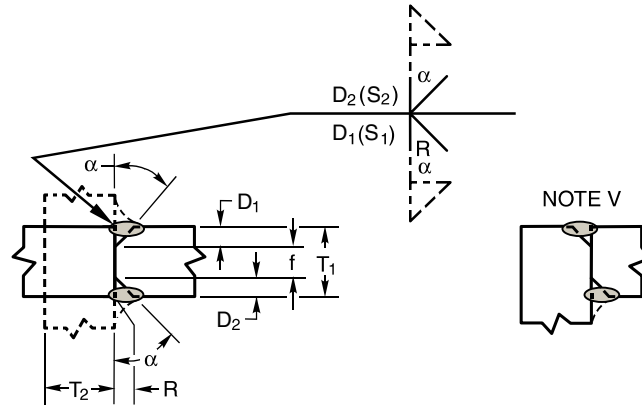
Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

* F = Flat, OH = Overhead, V = Vertical

** For flat and horizontal positions, f = +U, -0

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt, T-, or Corner Joint (BTC)
Partial Joint Penetration (P)
Double-Bevel-Groove Weld (5)
U = Unlimited



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation		Permitted Welding Positions*	Effective Throat (S), in [mm]	Notes
				Root Opening, Root Face (f), in [mm] Groove Angle	Tolerances, in [mm] for R & f; ° for α			
		T ₁	T ₂		As Detailed As Fit-Up			
SMAW	BTC-P5	5/16 [8] min	U	R = 0 f = 1/8 [3] min α = 45°	+1/16 [2], -0 U** +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] +10°, -5°	All	(D ₁ + D ₂) -1/4 [6] E, J2, L, Mp, Q2, V
GMAW FCAW	BTC-P5-GF	1/2 [13] min	U	R = 0 f = 1/8 [3] min α = 45°	+1/16 [2], -0 U** +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] +10°, -5°	F, H V, OH	(D ₁ + D ₂) -1/4 [6] E, J2, L, Mp, Q2, V
SAW	BTC-P5-S	3/4 [20] min	U	R = 0 f = 1/4 [6] min α = 60°	±0 +U, -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] +10°, -5°	Flat	D ₁ + D ₂ E, J2, L, Mp, Q2, V

(F)

Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

Note J2: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to 1/4T₁, but not exceed 3/8 in [10 mm].

Note L: Butt and T-joints are not prequalified for cyclically loaded structures.

Note Mp: Double-groove welds may have grooves of unequal depth, provided these conform to Note E. Also, the weld size (S), less any reduction, applies individually to each groove.

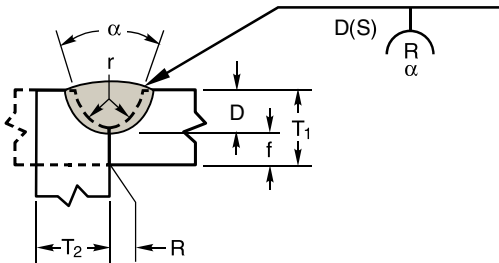
Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

* F = Flat, OH = Overhead, V = Vertical

** For flat and horizontal positions, f = +U, -0

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt or Corner Joint (BC) Partial Joint Penetration (P) Single-U-Groove Weld (6) U = Unlimited									
Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S), in [mm]	Notes
				Root Opening, Root Face (f), in [mm] Groove Angle	Tolerances, in [mm] for R, f & r; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	BC-P6	1/4 [6] min	U	R = 0 f = 1/32 [1] min r = 1/4 [6] α = 45°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D	B, E, Q2
GMAW FCAW	BC-P6-GF	1/4 [6] min	U	R = 0 f = 1/8 [3] min r = 1/4 [6] α = 20°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D	B, E, Q2
SAW	BC-P6-S	7/16 [11] min	U	R = 0 f = 1/4 [6] min r = 1/4 [6] α = 20°	±0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] ±1/16 [2] +10°, -5°	Flat	D	B, E, Q2

(G)

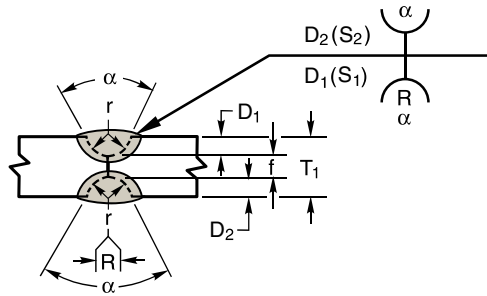
Note B: Joint is welded from one side only.

Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt Joint (B)
Partial Joint Penetration (P)
Double-U-Groove Weld (7)
U = Unlimited



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S) in (mm)	Notes
				Root Opening Root Face (f), in (mm) Groove Angle	Tolerances In (mm) for R, f, & r; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	B-P7	1/2 [13] min (5/8 [16] min for cyclically loaded applications)	—	R = 0 f = 1/8 [3] min r = 1/4 [6] α = 45°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D ₁ + D ₂	E, Mp, Q2
GMAW FCAW	B-P7-GF	1/2 [13] min (5/8 [16] min for cyclically loaded applications)	—	R = 0 f = 1/8 [3] min r = 1/4 [6] α = 20°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D ₁ + D ₂	E, Mp, Q2
SAW	B-P7-S	3/4 [20] min (7/8 [22] min for cyclically loaded applications)	—	R = 0 f = 1/4 [6] min r = 1/4 [6] α = 20°	±0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] ±1/16 [2] +10°, -5°	Flat	D ₁ + D ₂	E, Mp, Q2

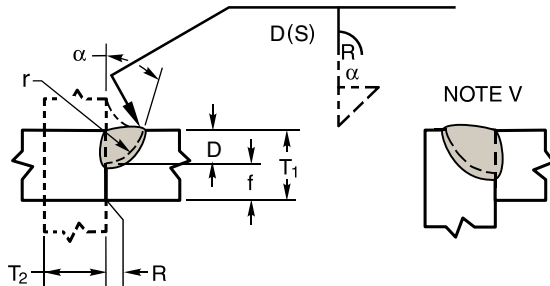
(H)

Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

Note Mp: Double-groove welds may have grooves of unequal depth, provided these conform to Note E. Also, the weld size (S), less any reduction, applies individually to each groove.

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt or Corner Joint (BC) T- or Corner Joint (TC) Corner Joint (C) Partial Joint Penetration (P) Single-J-Groove Weld (8) U = Unlimited 									
Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S) in (mm)	Notes
				Root Opening Root Face (f), in (mm) Groove Angle	Tolerances In (mm) for R, f, & r; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	TC-P8 (T and Inside Corner Joints)	1/4 [6] min	U	R = 0 f = 1/8 [3] min r = 3/8 [10] α = 45°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D	E, J2, Q2, V
	BC-P8 (Butt and Outside Corner Joints)	1/4 [6] min	U	R = 0 f = 1/8 [3] min r = 3/8 [10] α = 30°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D	
GMAW FCAW	TC-P8-GF(T and Inside Corner Joints)	1/4 [6] min	U	R = 0 f = 1/8 [3] min r = 3/8 [10] α = 45°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D	E, J2, Q2, V
	BC-P8-GF (Butt and Outside Corner Joints)	1/4 [6] min	U	R = 0 f = 1/8 [3] min r = 3/8 [10] α = 30°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D	
SAW	TC-P8-S (T- and inside corner)	7/16 [11] min	U	R = 0 f = 1/4 [6] min r = 1/2 [13] α = 45°	±0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] ±1/16 [2] +10°, -5°	Flat	D	E, J2, Q2, V
	C-P8-S (Outside corner)	7/16 [11] min	U	R = 0 f = 1/4 [6] min r = 1/2 [13] α = 20°	±0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] ±1/16 [2] +10°, -5°	Flat	D	

(I)

Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

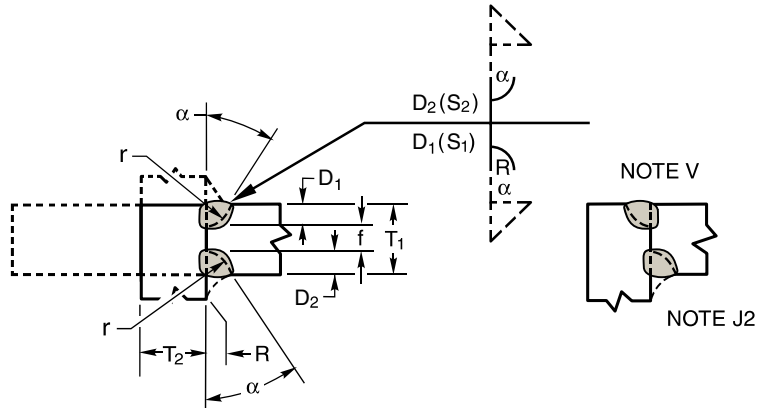
Note J2: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but not exceed $3/8$ in [10 mm].

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt, T-, or Corner Joint (BTC)
Corner Joint (C)
T-Joint (T)
Partial Joint Penetration (P)
Double-J-Groove Weld (9)
U = Unlimited



Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S) in (mm)	Notes
				Root Opening Root Face (f), in (mm) Groove Angle	Tolerances In (mm) for R, f, & r; ° for α				
		T ₁	T ₂		As Detailed	As Fit-Up			
SMAW	BTC-P9 (butt, T-, & inside corner joints)	1/2 [13] min	U	R = 0 f = 1/8 [3] min r = 3/8 [10] α = 45°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D ₁ + D ₂	E, J2, Mp, Q2, V
GMAW FCAW	BTC-P9-GF (butt, T-, & outside corner joints)	1/2 [13] min	U	R = 0 f = 1/8 [3] min r = 3/8 [10] α = 30°	+1/16 [2], -0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/8 [3], -1/16 [2] ±1/16 [2] ±1/16 [2] +10°, -5°	All	D ₁ + D ₂	E, J2, Mp, Q2, V
SAW	C-P9-S (inside corner joints)	3/4 [20] min	U	R = 0 f = 1/4 [6] min r = 1/2 [13] α = 45°	±0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] ±1/16 [2] +10°, -5°	Flat	D ₁ + D ₂	E, J2, Mp, Q2, V
	C-P9-S (outside corner joints)	3/4 [20] min	U	R = 0 f = 1/4 [6] min r = 1/2 [13] α = 20°	±0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] ±1/16 [2] +10°, -5°	Flat	D ₁ + D ₂	
		T-P9-S	3/4 [20] min	U	R = 0 f = 1/4 [6] min r = 1/2 [13] α = 45°	±0 +U, -0 +1/4 [6], -0 +10°, -0°	+1/16 [2], -0 ±1/16 [2] ±1/16 [2] +10°, -5°	Flat	D ₁ + D ₂

(J)

Note E: Minimum weld size (S) as shown in Table 10; D as specified on drawings.

Note J2: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but not exceed $3/8$ in [10 mm].

Note Mp: Double-groove welds may have grooves of unequal depth, provided these conform to Note E. Also, the weld size (S), less any reduction, applies individually to each groove.

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Note V: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

Butt, T-, or Corner Joint (BTC)
T-Joint (T)
Partial Joint Penetration (P)
Flare-Bevel-Groove Weld (10)
U = Unlimited

The diagram illustrates a T-joint weld configuration. The main view shows a vertical plate of thickness T_3 and a horizontal plate of thickness T_1 and width T_2 intersecting. The weld is a partial joint penetration (P) type. Key dimensions include the root opening R , the root face f , and the fillet weld size C . A detail view (S) shows the fillet weld profile with a radius R and a depth f .

Welding Process	Joint Designation	Base Metal Thickness, in [mm] (U = Unlimited)			Groove Preparation			Permitted Welding Positions	Weld Size (S) in (mm)	Notes
					Root Opening Root Face (f), in (mm) Bend Radius(***)	Tolerances In (mm) for R, f, & r; ° for α				
		T ₁	T ₂	T ₃		As Detailed	As Fit-Up			
SMAW	BTC-P10	3/16 [5] min	U	T ₁ min	R = 0 f = 3/16 [5] min C = 3T ₁ /2 min	+1/16 [2], -0 +U, -0 +U, -0	+1/8 [3], -1/16 [2] +U, -1/16 [2] +U, -0	All	5T ₁ /8	J2, Q2, Z
GMAW FCAW	BTC-P10-GF	3/16 [5] min	U	T ₁ min	R = 0 f = 3/16 [5] min C = 3T ₁ /2 min	+1/16 [2], -0 +U, -0 +U, -0	+1/8 [3], -1/16 [2] +U, -1/16 [2] +U, -0	All	5T ₁ /8	J2, Q2, Z
SAW	T-P10-S	1/2 [13] min	1/2 [13] min	NA	R = 0 f = 1/2 [13] min C = 3T ₁ /2 min	±0 +U, -0 +U, -0	+1/8 [3], -1/16 [2] +U, -1/16 [2] +U, -0	Flat	5T ₁ /8	J2, Q2, Z

(K)

Note J2: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4T_1$, but not exceed $3/8$ in [10 mm].

Note Q2: The member orientation may be changed provided that the groove dimensions are maintained as specified.

Note Z: Weld size (S) is based on joints welded flush.

*** For cold formed (A500) rectangular tubes, C dimension is not limited.

Figure B.2 (Continued)—Typical Partial Joint Penetration Groove Welded Joints

This page is intentionally blank.

Annex C (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D14.4/D14.4M:2012, *Specification for the Design of Welded Joints in Machinery and Equipment*, but is included for informational purposes only.

C1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

C2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
8669 Doral Blvd.
Doral, FL 33166

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

C2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

C2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

C2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

C2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

C3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

C4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

C5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

C6. AWS Technical Committees

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

Annex D (Informative)

Bibliography

This annex is not part of AWS D14.4/D14.4M:2012, *Specification for the Design of Welded Joints in Machinery and Equipment*, but is included for informational purposes only.

American Welding Society (AWS) References

AWS A1.1, Metric Practice Guide for the Welding Industry

AWS A5.01, Filler Metal Procurement Guidelines

AWS B2.1-x-xxx, Standard Welding Procedure Specifications

AWS F4.1, Recommended Safe Practices for the Preparation for Welding and Cutting of Containers and Piping That Have Held Hazardous Substances.

American Association of State Highway & Transportation Officials (AASHTO)

Standard Specifications for Highway Bridges

American Institute of Steel Construction, Inc. (AISC)

AISC 360-05, Specification for Structural Steel Buildings

American National Standards Institute (ANSI)

ANSI Z87.1, Practice for Occupational and Educational Eye and Face Protection.

ANSI Z49.1, Safety in Welding and Cutting and Allied Processes (Published by AWS).

American Society of Mechanical Engineers (ASME)

ASME B46.1, Surface Texture (Surface Roughness, Waviness, and Lay)

ASME Section IX, ASME Boiler and Pressure Vessel Code – Section IX: Welding and Brazing Qualifications

American Society of Testing and Materials (ASTM)

ASTM E 390, Reference Radiographs for Steel Fusion Welds

Canadian Standards Association (CSA)

W178.2, Certification of Welding Inspectors

Compressed Gas Association (CGA)

Publication P-1, Safe Handling of Compressed Gases in Containers

This page is intentionally blank.

List of AWS Documents on Machinery and Equipment

Designation	Title
D14.1	<i>Specification for Welding Industrial and Mill Crane and Other Material Handling Equipment</i>
D14.3	<i>Specification for Welding Earthmoving, Construction, and Agricultural Equipment</i>
D14.4	<i>Specification for the Design of Welded Joints in Machinery and Equipment</i>
D14.5	<i>Specification for Welding of Presses and Press Components</i>
D14.6	<i>Specification for Welding of Rotating Elements of Equipment</i>
D14.7	<i>Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls</i>
D14.8	<i>Standard Methods for the Avoidance of Cold Cracks</i>

This page is intentionally blank.

