

UNSIGNED HARDCOPY
NOT CONTROLLED



Instruction
Hardware Engineering

LMS 7-1

SUBJECT: Arc Welding

APPROVED BY Manager, Hardware Engineering

STATUS Maintenance Revision

PURPOSE Establishes requirements for fusion welding of aluminum and steel. Refer to LMS 7-3 for Resistance Spot Welding (RSW) requirements. All arc welding performed for L-3 Communications Corporation, Link Simulation & Training Division (hereafter referred to as Link) shall conform to this instruction.

AFFECTED FUNCTIONS Hardware Engineering
Manufacturing

REFERENCES: LMS **1-6, "Workmanship for Electronic Assemblies"**
LMS **8-1, "Sheet Metal, Miscellaneous Metal and Nonmetals"**
LMS **"9-1, Painting"**
AWS A2.4, Standard Symbols for Welding, Brazing and Nondestructive Examination
ASTM E 1742, Inspection, Radiographic
AWS D1.1/D1.1M, Structural Welding Code- Steel
AWS D17.1, Specification for Fusion Welding for Aerospace Applications
ASTM E 1417, Standard Practice for Liquid Penetrant Testing

DEFINITIONS

Arc strike. A discontinuity consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any part of a weld or base metal resulting from an arc.

As-welded condition. The condition of welded metal, welded joint, and weldment(s) after welding, but prior to any subsequent thermal, mechanical, or chemical treatments.

Backstep sequence. A longitudinal sequence in which weld passes are made in the direction opposite to the progress of welding (Figure 8).

Burn through. A nonstandard term for excessive melt-through or a hole through a root bead.

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Cognizant inspector. The inspector or a designee normally assigned to the welding shop.

Concavity. The maximum distance from the face of a concave fillet weld perpendicular to a line joining the weld toes (Figure 2).

Convexity. The maximum distance from the face of a convex fillet weld perpendicular to a line joining the weld toes (Figure 1).

Crack. A fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement (Figure 4).

Crater. A depression at the termination of a weld bead.

Full-fillet weld. A fillet weld equal in size to the thickness of the thinner member joined.

Inclusion. Entrapped subsurface foreign particle.

Incomplete fusion. The failure to fuse together adjacent layers of weld metal or adjacent weld metal and base metal.

Intermittent weld. A weld in which the continuity is broken by recurring unwelded spaces (Figure 9).

Joint penetration. The depth a weld extends from its face into a joint, exclusive of reinforcement. (Figures 3 and 5).

Melt-through. Visible root reinforcement produced in a joint welded from one side (Figure 6).

Mismatch. Misalignment of members of a groove joint (Figure 10).

Partial joint penetration. Joint penetration that is intentionally less than complete (Figure 5).

Overlap. The protrusion of weld metal beyond the weld toe or weld root (Figure 7).

Penetration. A noninstruction term for joint penetration and root penetration.

Porosity. Cavity-type discontinuities formed by gas entrapment during solidification.

Root penetration. The depth that a weld extends into the joint root (Figure 5).

Skip weld. A nonstandard term for intermittent weld.

Spatter. The metal particles expelled during fusion welding that do not form a part of the weld.

Undercut. A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal (Figure 7).

Underfill. A depression on the weld face or root surface extending below the adjacent surface of the base metal (Figure 7).

Welding procedure specification (WPS). A document providing, in detail, the required variables for a specific application to assure repeatability by properly trained welders and welding operators.

1. Requirements

- 1.1 Welding. Welding shall be performed in accordance with AWS D17.1 for aluminum and/or AWS D1.1/D1.1M for steel. Unless otherwise specified on the drawing, all aluminum welds shall be considered Class C in accordance with AWS D17.1. All steel welds shall be in accordance with AWS D1.1/D1.1M.
- 1.2 Joint designation. Weld symbols shall be interpreted in accordance with AWS A2.4.
- 1.3 Weld beads. Weld beads shall be terminated to avoid critical areas of the weld. Wherever practical, the weld bead should exceed the print length to allow for imperfections at the start and stop of the weld. With approval by Engineering, the pitch of intermittent welds may be adjusted to avoid interference with adjoining details and to insure that the ends or corners of a detail are secured. Weld beads should not terminate in inside corners or in other critical areas such as changes in welding direction or abrupt sudden changes in section thickness. On inside corners, the bead should be within one inch (2.54 cm) of the corner.

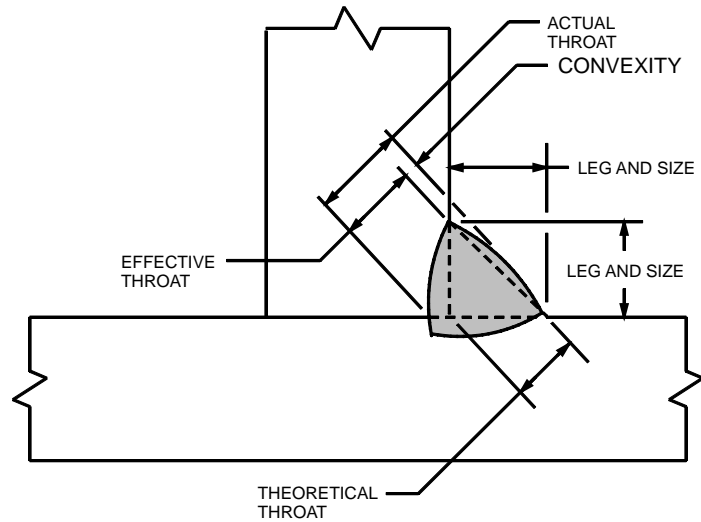
- a. Cracks, incomplete fusion, and overlap are not acceptable in any aluminum weldment. Two or more adjacent surface discontinuities shall be treated as one when the space between them is less than the dimension of the smallest discontinuity. The dimension of any discontinuity shall be defined by its largest dimension. Interconnecting discontinuities shall be considered as a single discontinuity. Limits of discontinuity when specified in terms of percentage of thickness “T”, shall be based on the thinner member of the joints. In the case of weldments with variations in cross section along the joint, “T” shall be considered to be the minimum thickness at the specific discontinuity location.
 - b. Arc strikes, arc burns from loose electrical connections, and gouge marks on the base metal of the finished weldment are acceptable.
 - c. Welds made from one side only in material under .125 inch thick may have the root surface faired in by using a cosmetic weld pass or by grinding that surface, provided that complete penetration was obtained in the original weld.
- 1.4 Postweld cleaning. The finish of areas adjacent to a weld bead shall be controlled by [LMS 9-1](#), as applicable.
- Weldments which will contain electrical components and/or printed circuit assemblies shall have all loose weld metal (i.e., spatter) removed from all internal surfaces prior to any subsequent finishing operation.
- 1.5 Soundness. Unless otherwise specified on the drawing, all welds shall comply with Tables I and V. Aluminum welds shall also be in accordance with Table II. Steel welds shall also be in accordance with Tables III and IV.
- 1.6 Weldment tolerances. Unless otherwise specified on the drawing, the following tolerances shall apply to the completed weldments:
- a. Perpendicularity (squareness): ± 0.062 inch (0.157 cm) up to and including 36 inches (91.44 cm) and ± 0.125 inch (0.318 cm) over 36 inches (91.44 cm).
 - b. Parallelism: ± 0.062 inch (0.157 cm) up to and including 36 inches (91.44 cm) and ± 0.125 inch (0.318 cm) over 36 inches (91.44 cm).

- c. Straightness, flatness, and contour: ± 0.062 inch (0.157 cm) per 12 inches (30.48 cm).
 - d. Intermittent weld tolerance shall be within ± 25 percent of the pitch dimension callout of the drawing and shall be applied nonaccumulatively over the length of each intermittent symbol requirement.
- 1.7 Liquid penetrant inspection. When liquid penetrant inspection is required, it shall be accomplished in accordance with ASTM E 1417.
- 1.8 Radiographic inspection. When radiographic inspection is required, it shall be accomplished in accordance with ASTM E 1742.
- 1.9 In-process corrective action. At the discretion of the cognizant inspector, welding defects listed below may be corrected in accordance with the following, provided the weldment has not left the welding shop inspection area, and subsequent operations have not been performed.
- a. On aluminum weldments, each initial weld may be rewelded once, and if satisfactory assembly is not achieved, Link's Material Review Board action shall be required. On steel weldments, an unlimited number of rewelds of any weld is permissible with appropriate disposition and approval.
 - b. If the weld is otherwise acceptable, defects such as underfill, undercut, low weld bead, and crack free craters shall be corrected by laying an additional bead, joining the original weld and the base metal, and filling the depression. If visual inspection can verify full penetration, none of the original weld need be removed.
 - c. Defects such as cracks, porosity, inclusions, and surface imperfections must be removed from the original weld by machining, grinding, or chipping prior to rewelding. Areas with inadequate joint penetration may have weld deposit partially removed prior to rewelding. When 100 percent penetration can be obtained in thin section(s) (up to .10 inch [2.54 mm] thick), cracks may be rewelded without prior removal of the weld deposit.
 - d. When a bend relief is used on sheet metal (see LMS 8-1) and the joint to which it is associated is welded, the bend relief may be filled with weld material and ground to contour of the base metal configuration.

- 1.10 Weld repair. Except as noted in the above paragraph, repair of defective welds shall require a written repair procedure. The procedure requires Link's Material Review Board approval prior to implementation. The procedure shall contain, as a minimum, the following information:
- a. The method to be used for removal of the defect(s).
 - b. The method of inspection used to ensure removal of the defect(s).
 - c. The contour of the cavity prior to welding, such as minimum root dimensions and the included angle.
- 1.11 Correction of overlap. Unacceptable overlap shall be removed by dressing the weld deposit.
- 1.12 Marking. The documentation accompanying each welded assembly shall be marked with the date and the signature or individually assigned stamp or code of the welder who made the weld. Each weldment shall be permanently marked with the number assigned to the person (or persons) who made the weld. The marking used shall not degrade the part and may be steel impression stamping, electric etch, or any other suitable, permanent method.
- 1.13 Marking repairs. The areas repaired shall be marked using the method specified in paragraph 1.12. If the original welder makes the repair welds, the marking may be made beside (or near) the original marking. When the repairs are made by another welder, each weld bead being repaired shall be marked by the repair welder. Shop reworks (in-process corrections) shall be identified in the same manner.

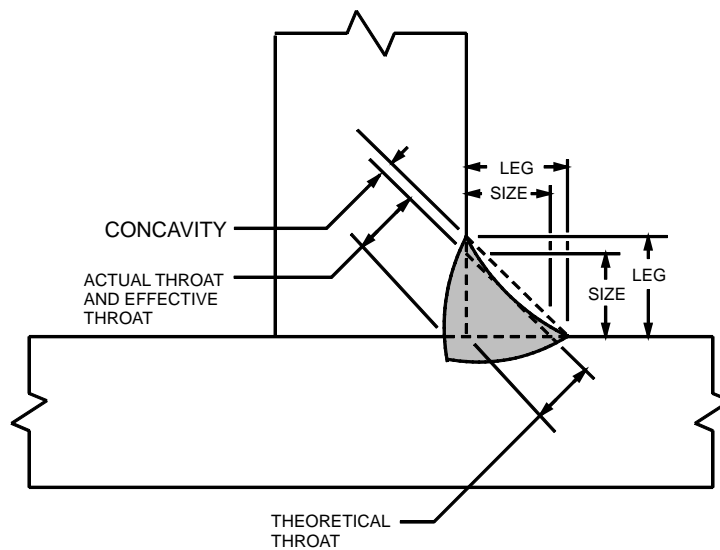
2. Quality Assurance Provisions
 - 2.1 Visual. All welds shall be subject to visual inspections to assure compliance with the drawing and this instruction.
 - 2.2 Nondestructive test (NDT). Liquid penetrant and/or radiography shall be performed only as specified on the Engineering Drawing in accordance with ASTM E 1742 and ASTM E 1417.
 - 2.3 Other. In addition to the above, all inspections and/or tests specified on the drawing shall be conducted.
 - 2.4 In the event that there may be doubt as to the adequacy of weldments which have been subjected to postwelding treatments, such as mechanical straightening, NDT methods may be opted for verification of the integrity of the weld(s). Such NDT inspections may be by one of the following methods:
 - a. Magnetic particle*
 - b. Radiographic
 - c. Liquid penetrant
 - d. Ultrasonic*

* Requires outside vendor participation in order to utilize these methods of NDT.
3. Preparation For Delivery (Not Applicable)
4. Notes
 - 4.1 Refer to the paragraph on cleaning in [LMS 1-6](#) for additional cleaning requirements.



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Figure 1 Convex Fillet Weld



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Figure 2 Concave Fillet Weld

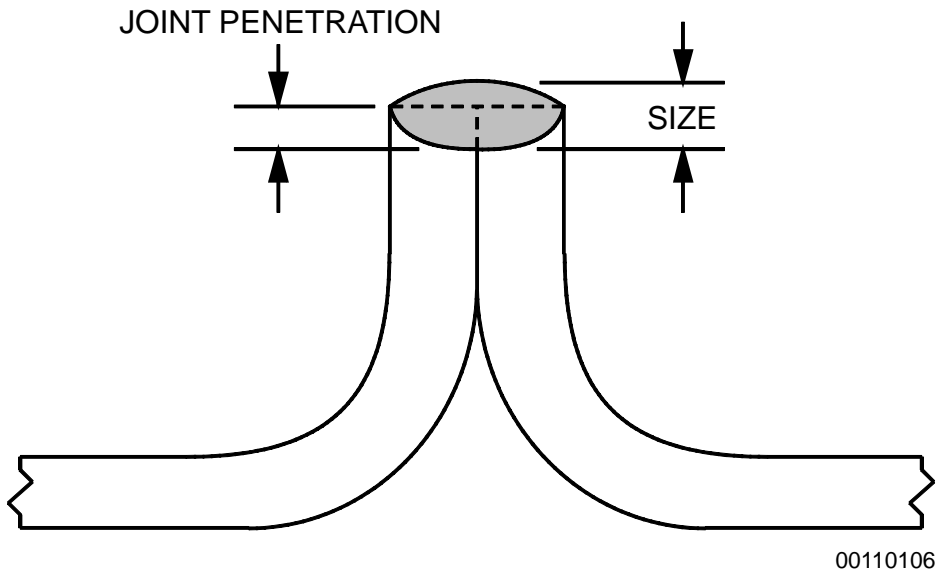
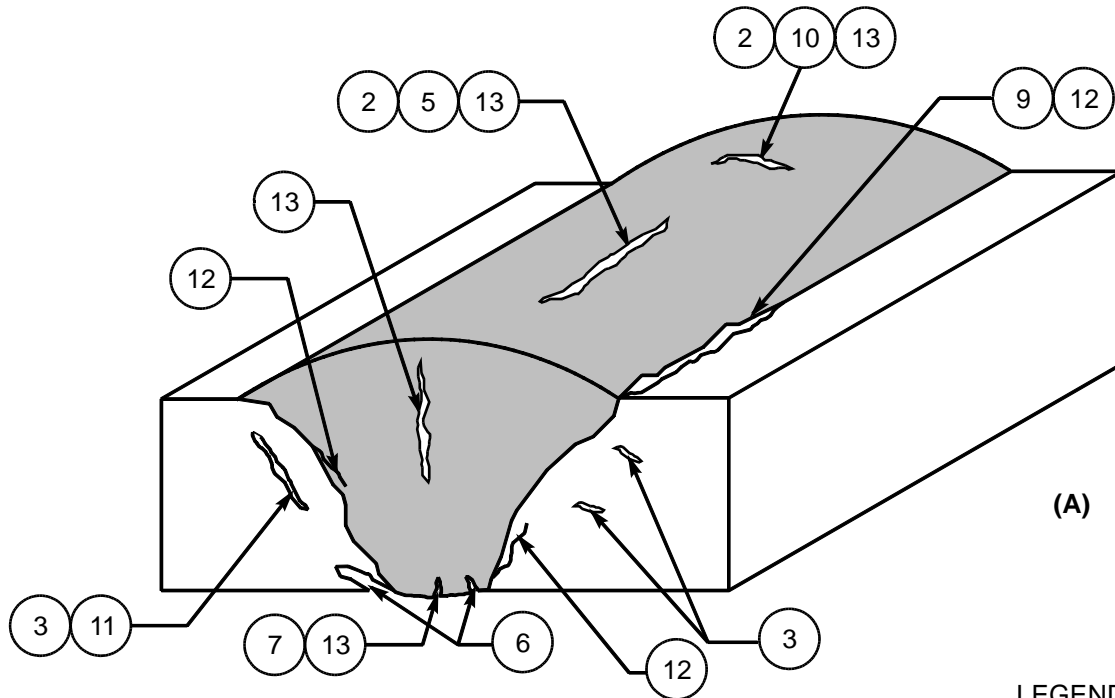


Figure 3 Edge or Flange Weld Size



LEGEND

1. Crater crack
2. Face crack
3. Heat-affected zone crack
4. Lamellar tear
5. Longitudinal crack
6. Root crack
7. Root surface crack
8. Throat crack
9. Toe crack
10. Transverse crack
11. Underbead crack
12. Weld interface crack
13. Weld metal crack

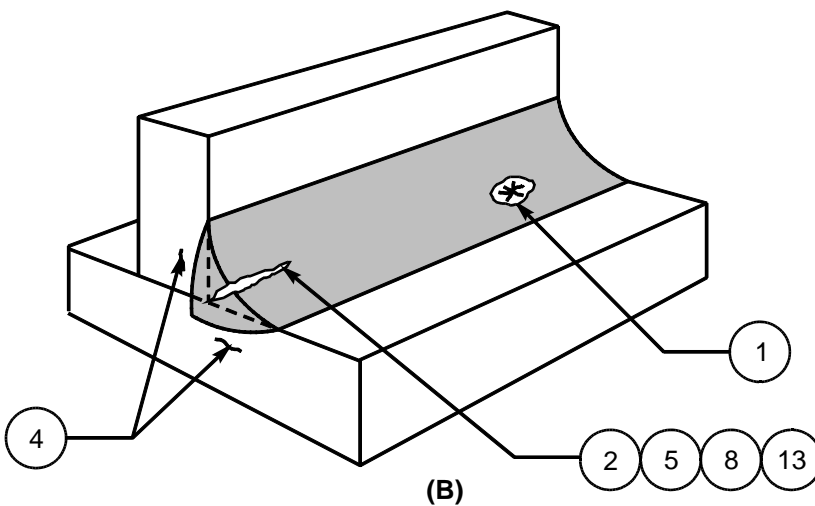


Figure 4 Crack Types

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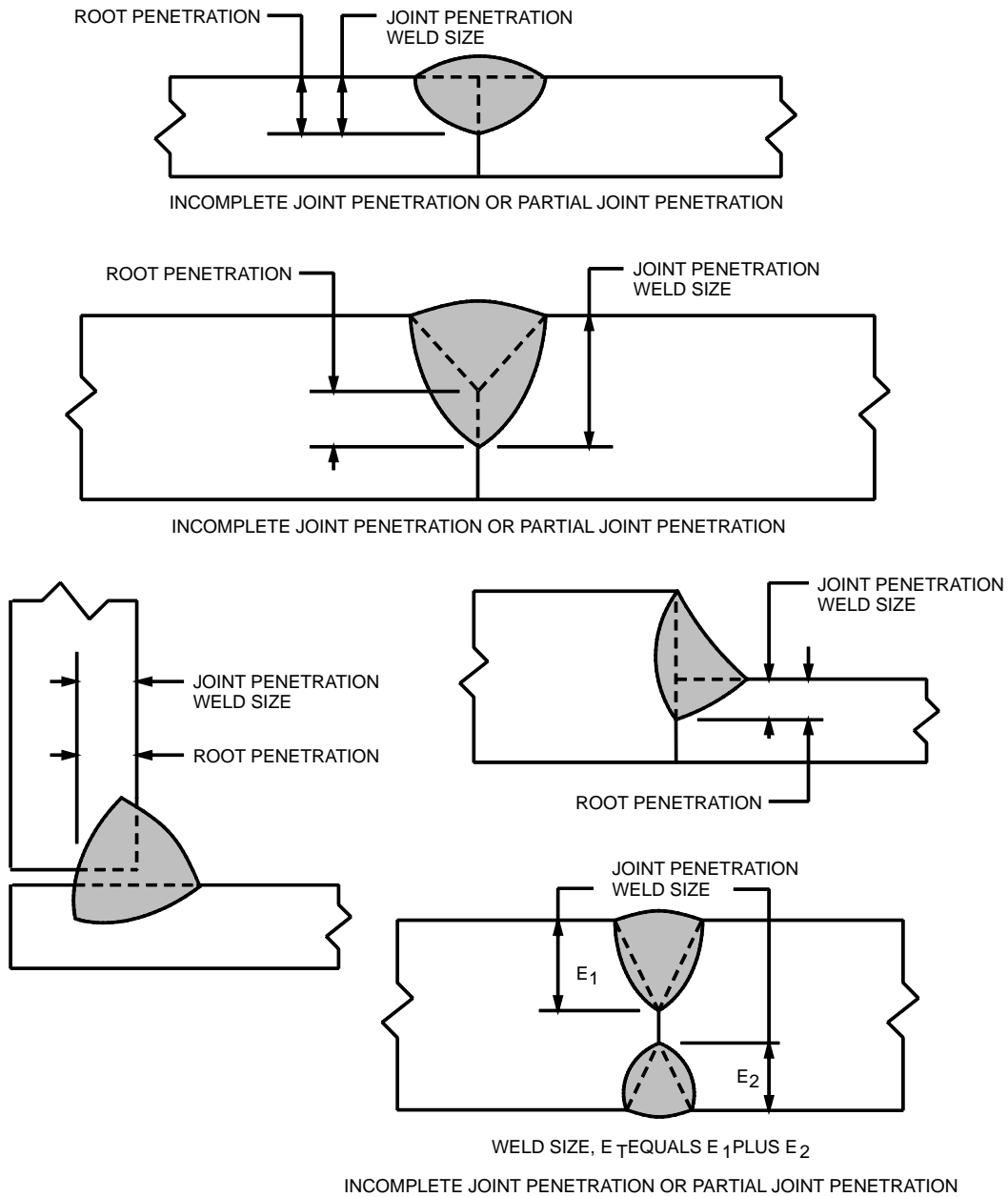
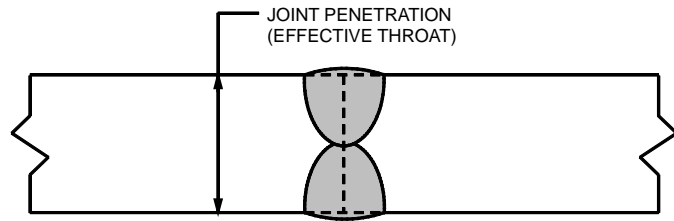
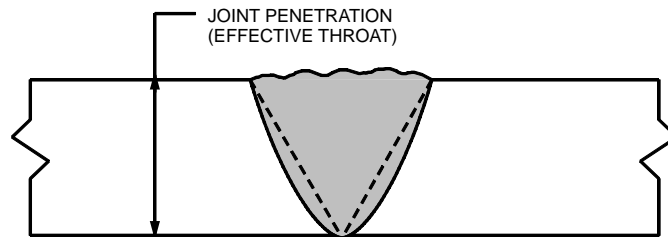


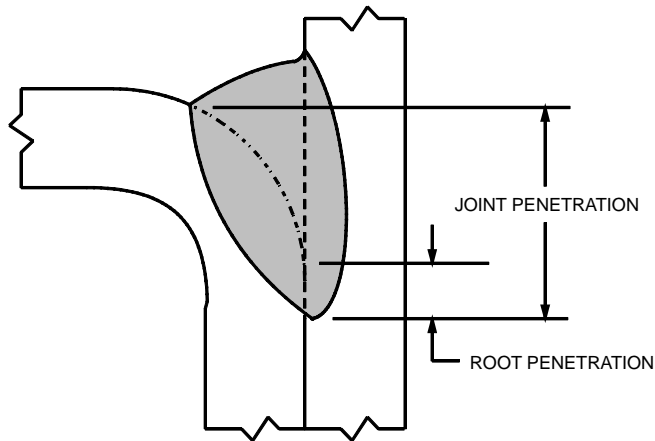
Figure 5 Joint and Root Penetration



A.



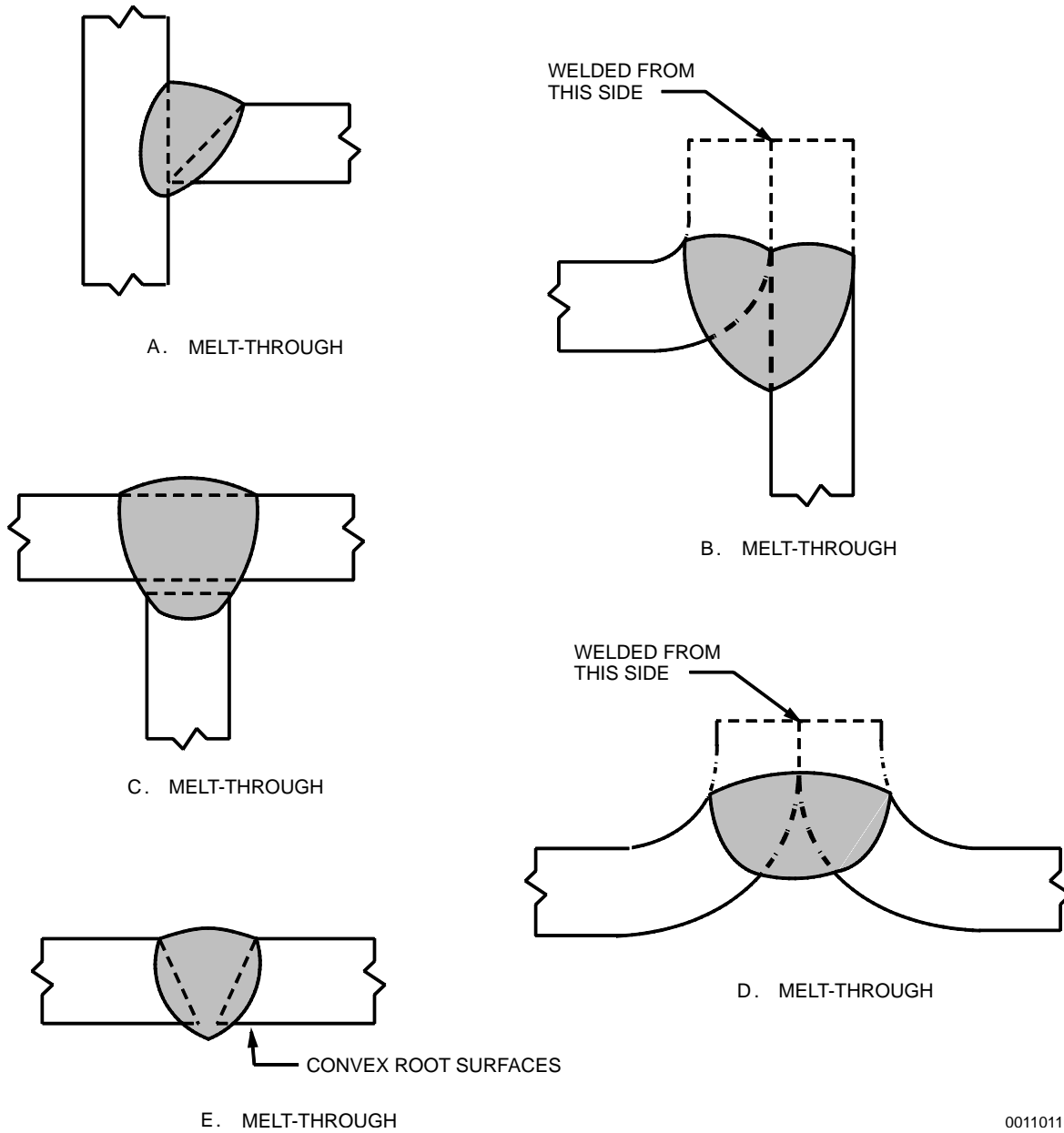
B.



C.

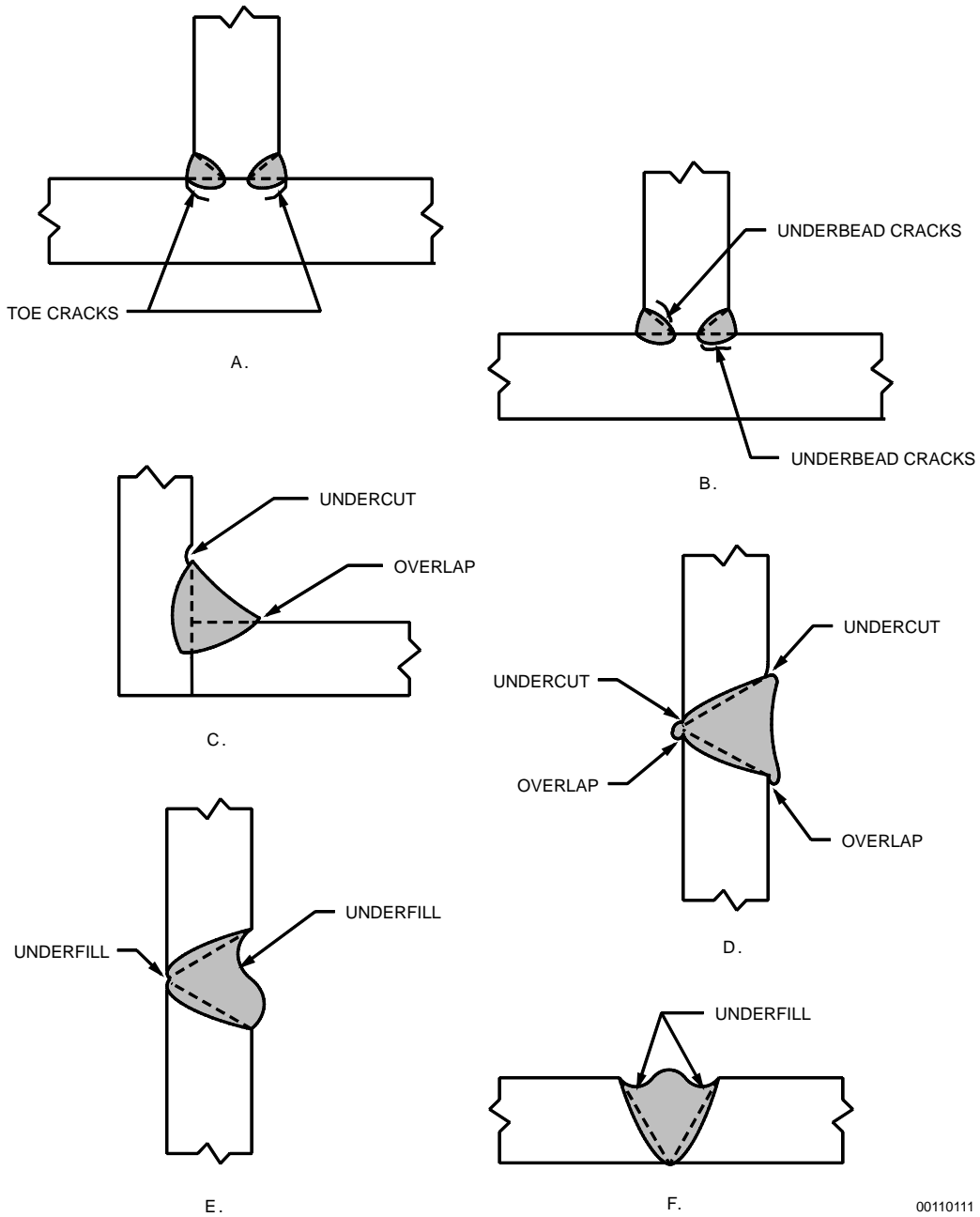
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Figure 5 Joint and Root Preparation (Cont.)



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Figure 6 Melt-Through



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Figure 7 Weld Flaws

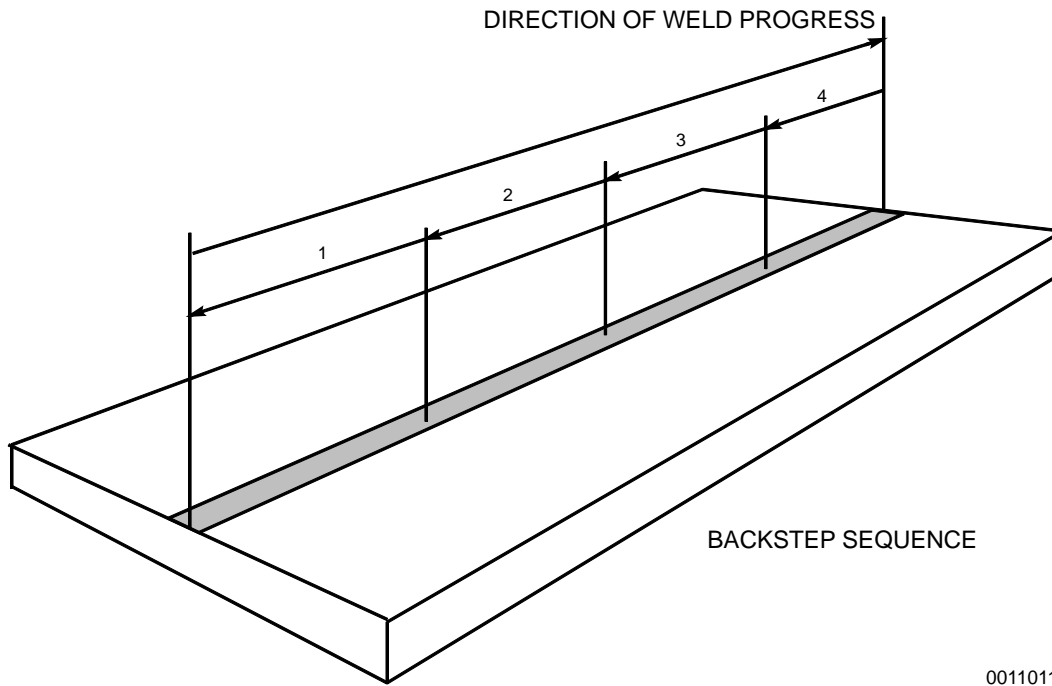
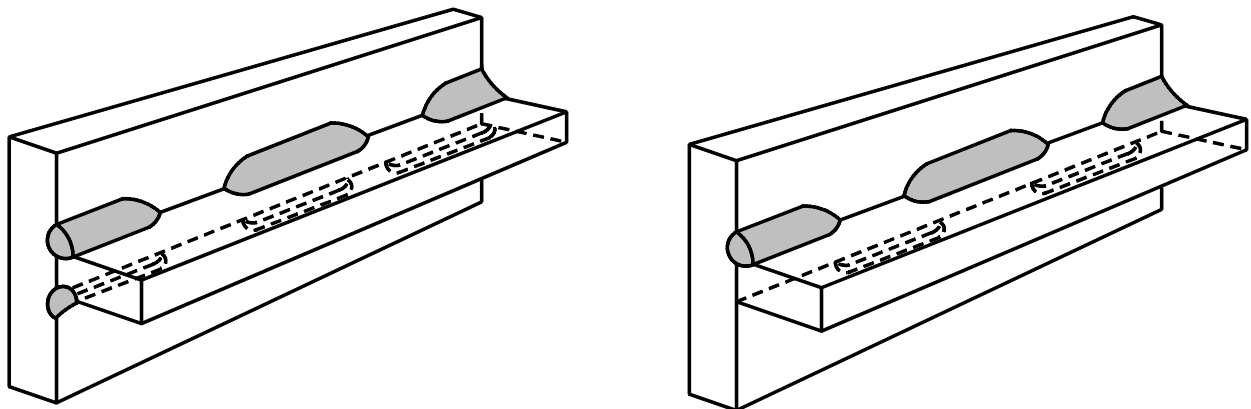


Figure 8 Welding Sequence

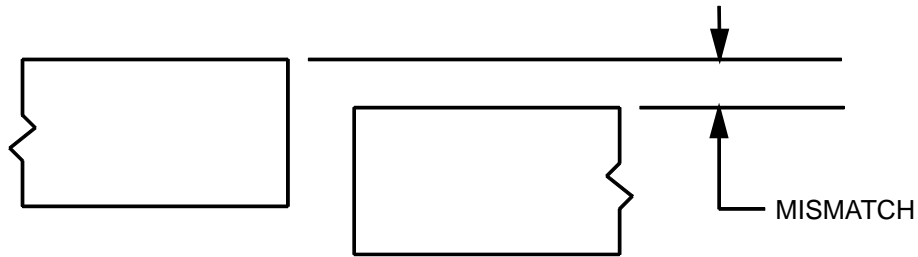


A. Chain Intermittent Fillet Weld

B. Staggered Intermittent Fillet Weld

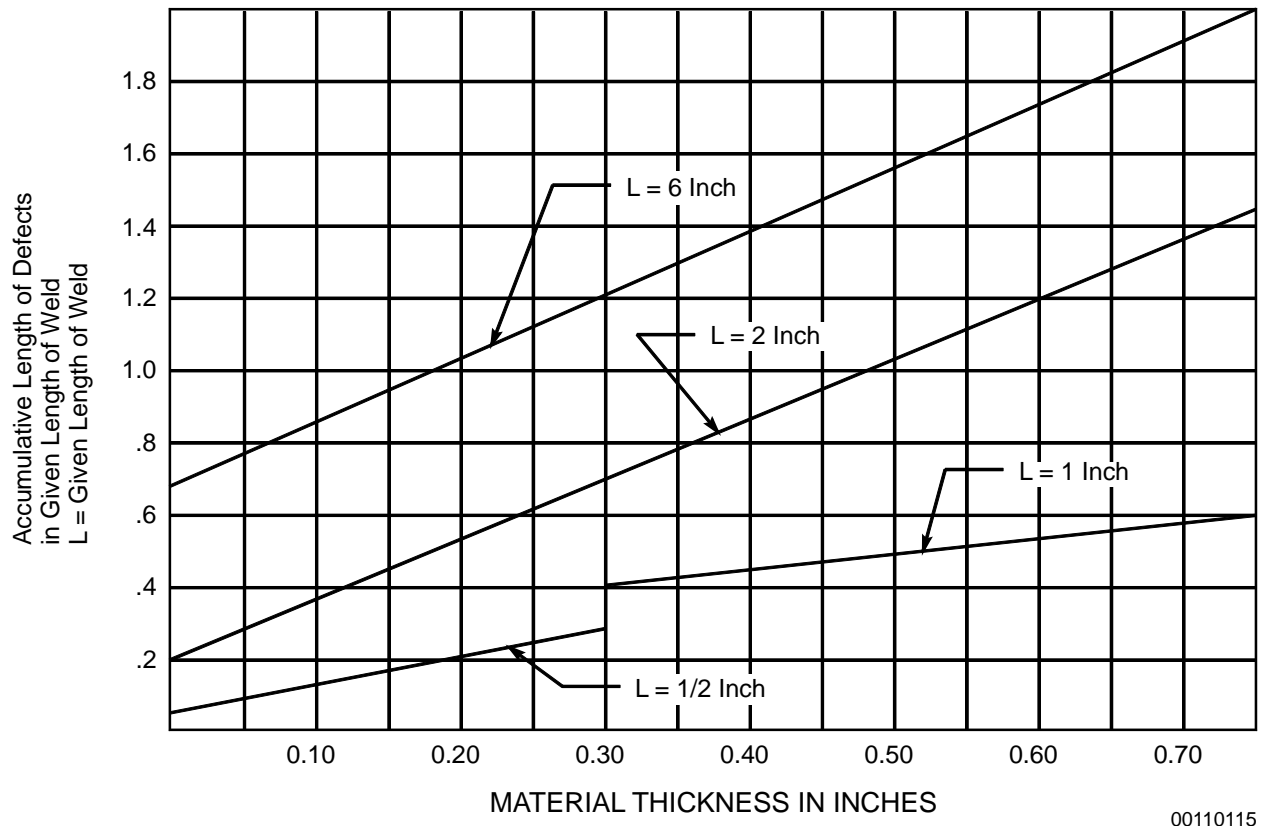
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Figure 9 Intermittent Weld



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Figure 10 Weld Mismatch



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Figure 11 Allowable Accumulation of Subsurface Defects for Class A and B Welds

Table I Acceptance Criteria - General Requirements for All Welds

DEFECT	ALLOWABLE LIMITS
Spatter	See paragraph 1.4.
Underfill	None (root underfill applies only to full penetration welds).
Weld Size	Weld size specified on drawing shall be considered minimum. For drawings that do not specify weld size, Table V for aluminum and Table IV for steel shall govern.
Convexity	Acceptable up to, but not including, an overlap condition.
Arc strike	None.
Unconsumed filler metal	None.

Table II Discontinuity Limits (Aluminum)

IMPERFECTION		CLASS OF WELDS		
		A	B	C
<u>Surface Porosity:</u>	Individual size maximum	0.25 T or 0.030 inch (0.762 mm), whichever is less	0.33 T or 0.060 inch (1.524 mm), whichever is less	0.50 T or 0.090 inch (2.286 mm), whichever is less
	Spacing - minimum	8 times the size of the larger adjacent imperfection	4 times the size of the larger adjacent imperfection	2 times the size of the larger adjacent imperfection
	Accumulated length in any 3 inches (7.62 cm) of weld - maximum	1 T or 0.12 inch (3.048 mm), whichever is less	1.33 T or 0.24 inch (6.096 mm), whichever is less	2 T or 0.36 inch (9.144 mm), whichever is less
<u>Undercut:</u>	For full length of weld - maximum depth	0.002 inch (0.051 mm)	0.015 T or 0.002 inch (0.051 mm), whichever is greater	0.025 T or 0.002 inch (0.051 mm), whichever is greater
	Individual defect maximum depth	0.07 T or 0.030 inch (0.762 mm), whichever is less	0.10 T or 0.050 inch (1.27 mm), whichever is less	0.20 T or 0.070 inch (1.778 mm), whichever is less
	Accumulated length in any 3 inches (7.62 cm) of weld - maximum	0.20 inch (5.08 mm)	0.60 inch (1.524 mm)	1.00 inch (2.54 cm)
<u>Underfill and/or Concavity:</u>	For full length of weld - maximum depth	0.005 inch (0.127 mm)	0.015 T or 0.005 inch (0.127 mm), whichever is greater	0.025 T or 0.005 inch (0.127 mm), whichever is greater
	Individual defect maximum depth	0.07 T or 0.030 inch (0.762 mm), whichever is less	0.10 T or 0.050 inch (1.27 mm), whichever is less	0.20 T or 0.070 inch (1.778 mm), whichever is less
	Accumulated length in any 3 inches (7.62 cm) of weld - maximum	0.20 inch (5.08 mm)	0.60 inch (1.524 mm)	1.00 inch (2.54 cm)
<u>Sub-Surface Porosity and Inclusions:</u>	Individual size maximum	0.33 T or 0.060 inch (1.524 mm), whichever is less	0.50 T or 0.090 inch (2.286 mm), whichever is less	Not applicable
	Spacing - minimum	4 times the size of the larger adjacent imperfection	2 times the size of the larger adjacent imperfection	Not applicable
	Accumulated length in any 3 inches (7.62 cm) of weld - maximum	1.33 T or 0.24 inch (6.036 mm), whichever is less	2 T or 0.36 inch (9.144 mm), whichever is less	Not applicable
<u>Incomplete Penetration:</u>	Maximum depth	0.20 T or 0.03 inch (0.762 mm), whichever is less	0.20 T or 0.05 inch (1.27 mm), whichever is less	0.20 T or 0.05 inch (1.27 mm), whichever is less
<u>Craters:</u>	Maximum depth	0.20 T or 0.03 inch (0.762 mm), whichever is less	0.20 T or 0.05 inch (1.27 mm), whichever is less	0.20 T or 0.05 inch (1.27 mm), whichever is less
	Maximum length	1 T	1 T	2 T
	Cracks:	None	None	None
	Cold Shut: 1./	1 T or 0.1 inch (2.54 mm), 2./, whichever is less.	1 T maximum length	2 T maximum length

- 1./ If the defects exhibit sharp radii, sharp termination, or are crack-like, they shall be removed by grinding. If the depression is not larger than permitted, it need not be rewelded.
- 2./ Where possible to determine, by metal removal, the depth of cold shut shall not cause joint thickness to be less than the thinner material being welded.

Table III Visual Inspection - Steel

DISCONTINUITY	CONDITION	ACCEPTANCE CRITERIA
a. Weld cracks	-	None allowed
b. Slag inclusions	-	None allowed
c. Porosity	-	1. Maximum pore size shall be .062 inch (1.575 mm) in diameter 2. There shall be no more than 6 pores for any 12-inch (30.48-cm) length of weld. For small weldments with continuous welds less than 12 inches (30.48 cm) in length, there shall be proportionately fewer pores allowed (example: a maximum of 3 pores for 6 inches [15.24 cm] of weld).
d. Overlap	-	The overlap condition shall not exceed 10% of the total weld length.
e. Undercut	1. Base materials .25 inch and less in thickness	a. The maximum depth of undercut shall be no greater than 10% of the material thickness which has the undercut. The extent of the undercut shall not exceed 10% of weld length, provided the weld seam meets minimum size. b. Maximum width of an undercut shall not exceed twice the depth. c. Melting of base metal on edges of material is not considered to be undercut. It is acceptable provided: (1). Weld seam meets the minimum size. (2). Melting does not exceed 10% thickness for 10% of weld length. (3). Melting of corners is not considered to be undercut. Melting shall not exceed 25% of material thickness.
	2. Base materials greater than .25 inch in thickness	a. Maximum depth of undercut shall be .031 inch (0.787 mm). b. Undercut must have a width no less than twice the depth, i.e., the undercut condition shall not create a notch in the undercut member. c. The length of undercut shall not exceed 2 inches (5.08 cm) cumulative in any continuous 24-inch (60.96-cm) length of weld. For continuous welds less than 24 inches (60.96 cm) in length, the maximum cumulative length shall be in direct proportion to this limit, or 1 inch (2.54 cm), whichever is greater. (Example: for an 8-inch (20.32-cm) continuous length of weld, maximum cumulative allowable undercut length is 1 inch (2.54 cm). d. Melting of base metal on edges of material is not considered to be undercut. It is acceptable provided: (1). Weld seam meets the minimum size. (2). Melting does not exceed 10% thickness for 10% of weld length. (3). Melting of corners is not considered to be undercut. Melting shall not exceed 25% of material thickness.

Table IV Weld Dimensions - Steel

TYPE OF WELD	WELD DIMENSIONS	ACCEPTANCE CRITERIA
Fillet	Less than .25 inch (6.35 mm)	The weld dimension is the minimum as specified on the drawing symbol.
Fillet	.25 inch (6.35 mm) and greater	The weld may be undersize by .062 inch (1.575 mm) for a maximum length of 10% of the continuous weld length.
Groove	Any dimension	No underfill is allowed.

Table V Weld Sizes - All Welds

THICKNESS OF THINNEST MEMBER (inches)	MINIMUM FILLET WELD SIZE - INCHES (mm)
Under 3/16	Equal to thickness of thinnest member
3/16	.156 (3.962)
1/4	.188 (4.775)
5/16	.250 (6.350)
3/8	.312 (7.925)
7/16	.375 (9.525)
1/2	.438 (11.125)
5/8	.500 (12.700)
3/4	.625 (15.875)
1	.750 (19.050)