TERMINOLOGY

Excessive melt-through. A hole through the weld metal, usually occurring in the first pass.

Inadequate Joint penetration. Joint penetration that is less than that specified.

Incomplete fusion. A weld discontinuity in which fusion did not occur between weld metal and joint fusion faces or between adjoining weld beads.

Incomplete joint penetration. Joint penetration that is unintentionally less than the thickness of the weld joint.

Joint misalignment. In plate, offset or mismatch in a direction perpendicular to the plate surface and weld axis. In pipe, offset or mismatch in the radial direction at a butt joint or a T-joint.

Warpage. Buckling of sheet or plates parallel or transverse to the weld axis.

Lamination. A type of discontinuity with separation or weakness generally aligned parallel to the worked surface of a metal. It may be the result of piping blisters, seams, inclusions, or segregations that became elongated and made directional by working.

Lap. A surface imperfection, caused by folding over hot metal, fins, or sharp corners and then rolling or forging them into the surface.

Seam. An un-welded fold or lap that appears as a crack on the surface of a metal product, usually resulting from a discontinuity formed during casting or rolling.

Surface irregularities. Any number of surface conditions that result in notches or abrupt changes in thickness. Some are excessive reinforcement, convexity, concavity, undercut, and overlap.

Tungsten Inclusion. Droplets from the tungsten electrode entrapped in weld metal or along the weld interfaces.

Location and occurrence of discontinuities

Discontinues in weldments may be found in the weld metal, the weld heat-affected zone, and the base metal. The common weld discontinuities, general locations, and specific occurrences are presented in Table 11.3. The discontinuities listed in Table 11.3 are depicted in butt, lap, corner, and T-joints in Figures 11.1 through 11.6. Where the list indicates that a discontinuity is generally located in the weld, it may be expected to appear in almost any type of weld. However, there are exceptions. For example, tungsten inclusions are only found in welds made by the gas tungsten arc welding process, and micro-fissures normally occur only in electro-slag and electro-gas welds.

Type of Discontinuities		Discontinuities identification	Location	Remarks
Porosity			W	Weld only, as discussed herein
	Uniformly scattered	1a		
	Cluster	1b		
	Linear	1c		
	Piping	1d		
Inclusion				
	Slag	2a	W	
Incomplete fusion		3	W	At joint boundaries or between the passes
Inadequate joint preparation		4	W	Root of weld preparation
Under cut		5	HAZ	Junction of weld and base metal at surface
Under fill		6	W	Outer surface at joint preparation
Over lap		7	W / HAZ	Junction of weld and base metal at surface
Lamination		8	BM	Base metal, generally mid thickness of section
Delamination		9	BM	Base metal, generally mid thickness of section
Seams and lap		10	BM	Base metal surface, almost always longitudinal
Lamellar tears		11	BM	Base metal, near weld HAZ
Cracks (including hot cracks and cold cracks)				
	Longitudinal	12a	W, HAZ	Weld or base metal adjacent to weld fusion boundary
	Transverse	12b	W, HAZ, BM	Weld may propagate into HAZ and base metal
	Crater	12c	W	Weld, at point where arc is terminated
	Throat	12d	W	Weld axis
	Toe	12e	HAZ	Junction between face of weld and base metal
	Root	12f	W	Weld metal, at root
	Under bead and heat affected zone	12g	HAZ	Base metal, in HAZ
	Fissures		W	Weld metal

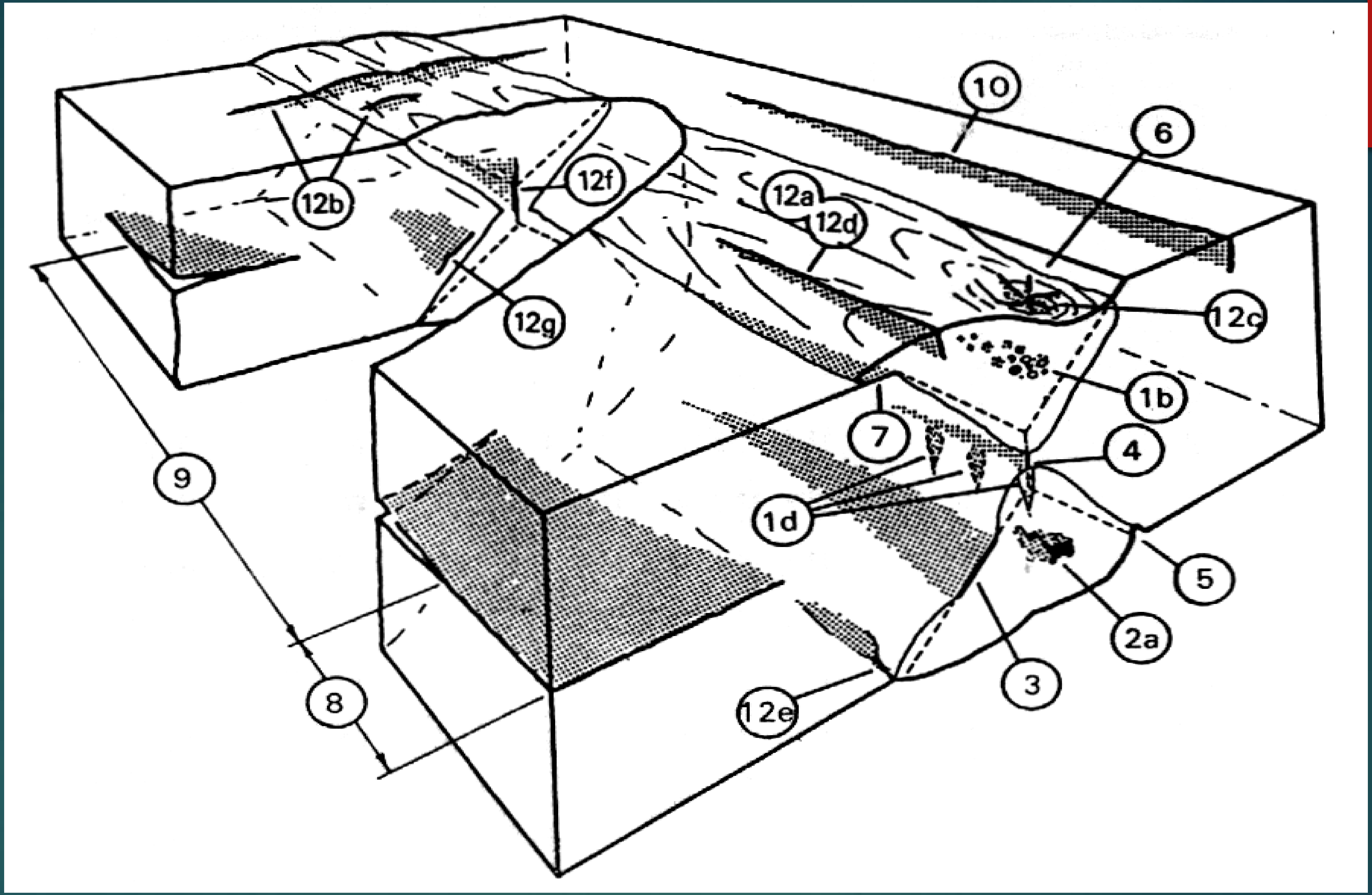


Figure 1—Double-V-Groove Weld in Butt Joint

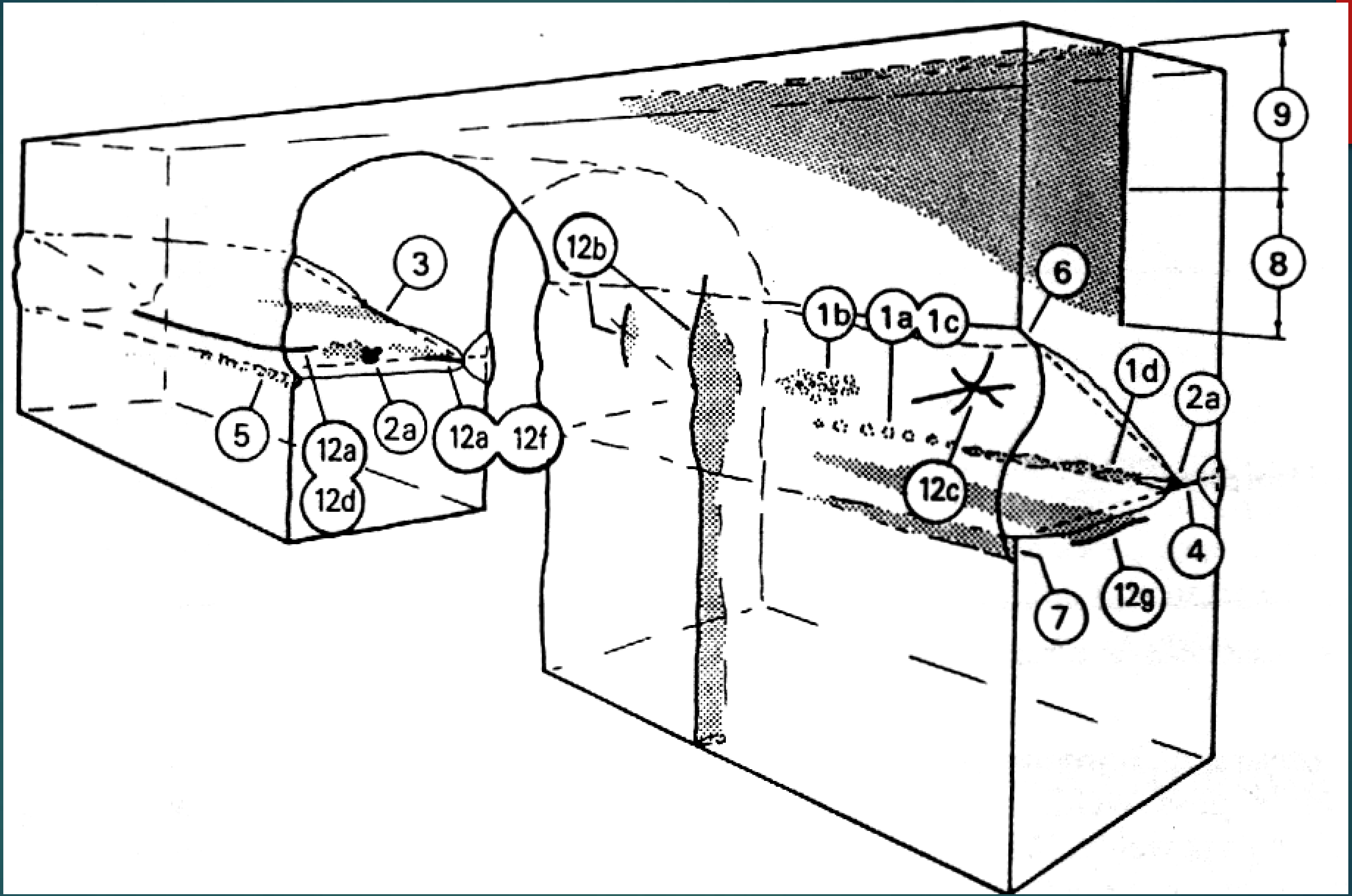


Figure 2—Single-Bevel-Groove Weld in Butt Joint

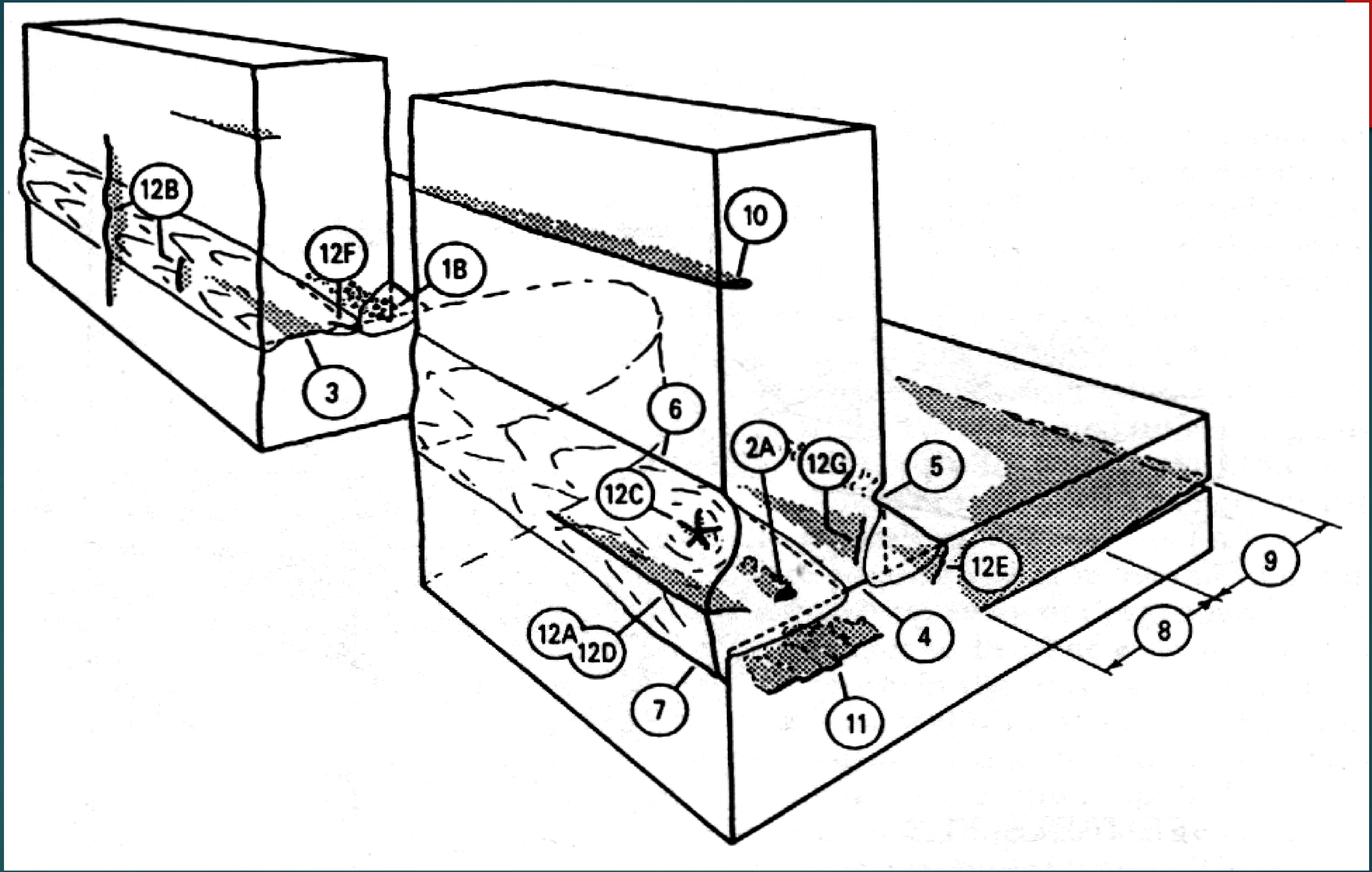


Figure 3—Welds in Corner Joint

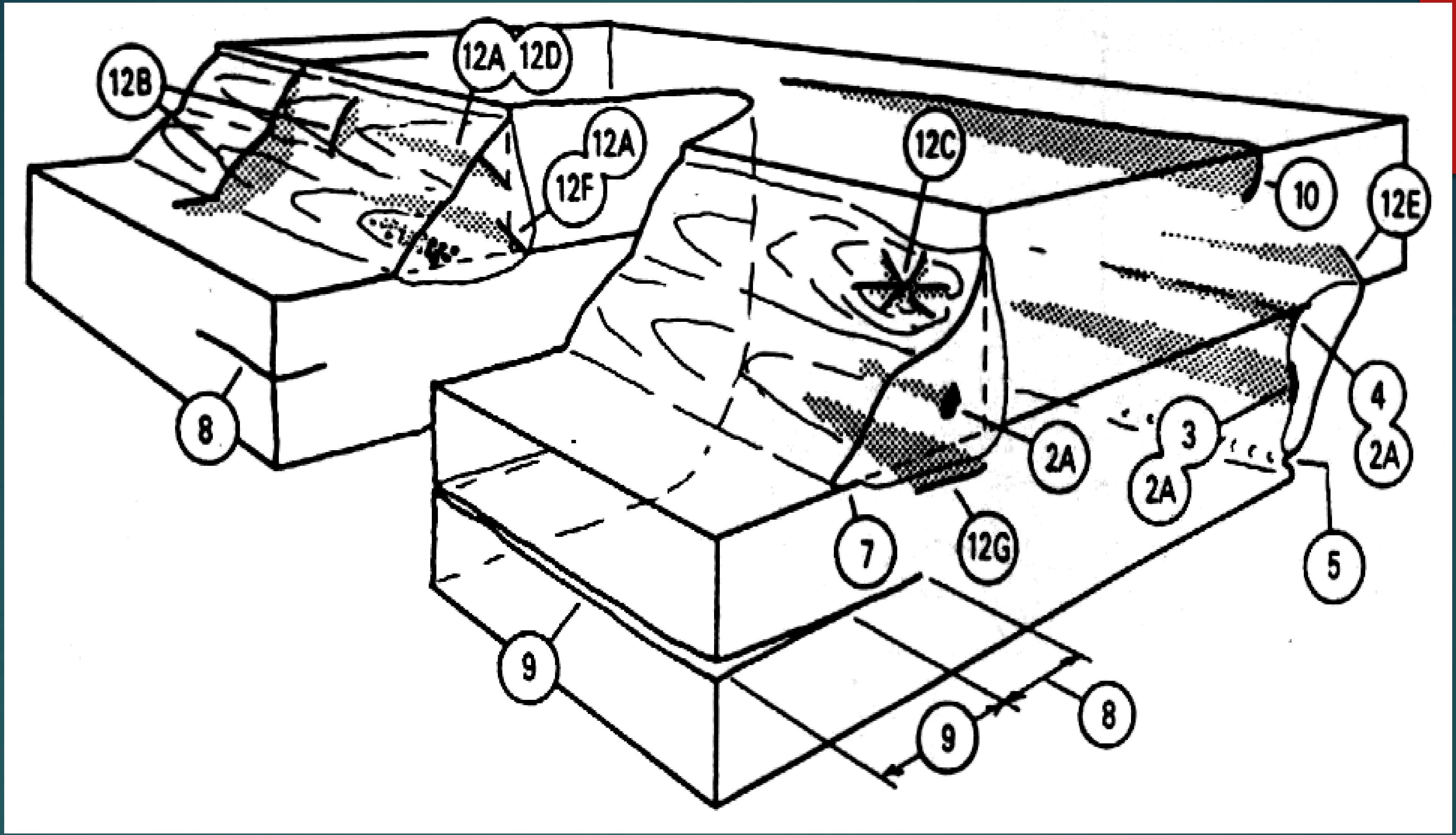


Figure 4 — Double Fillet Weld In Lap Joint

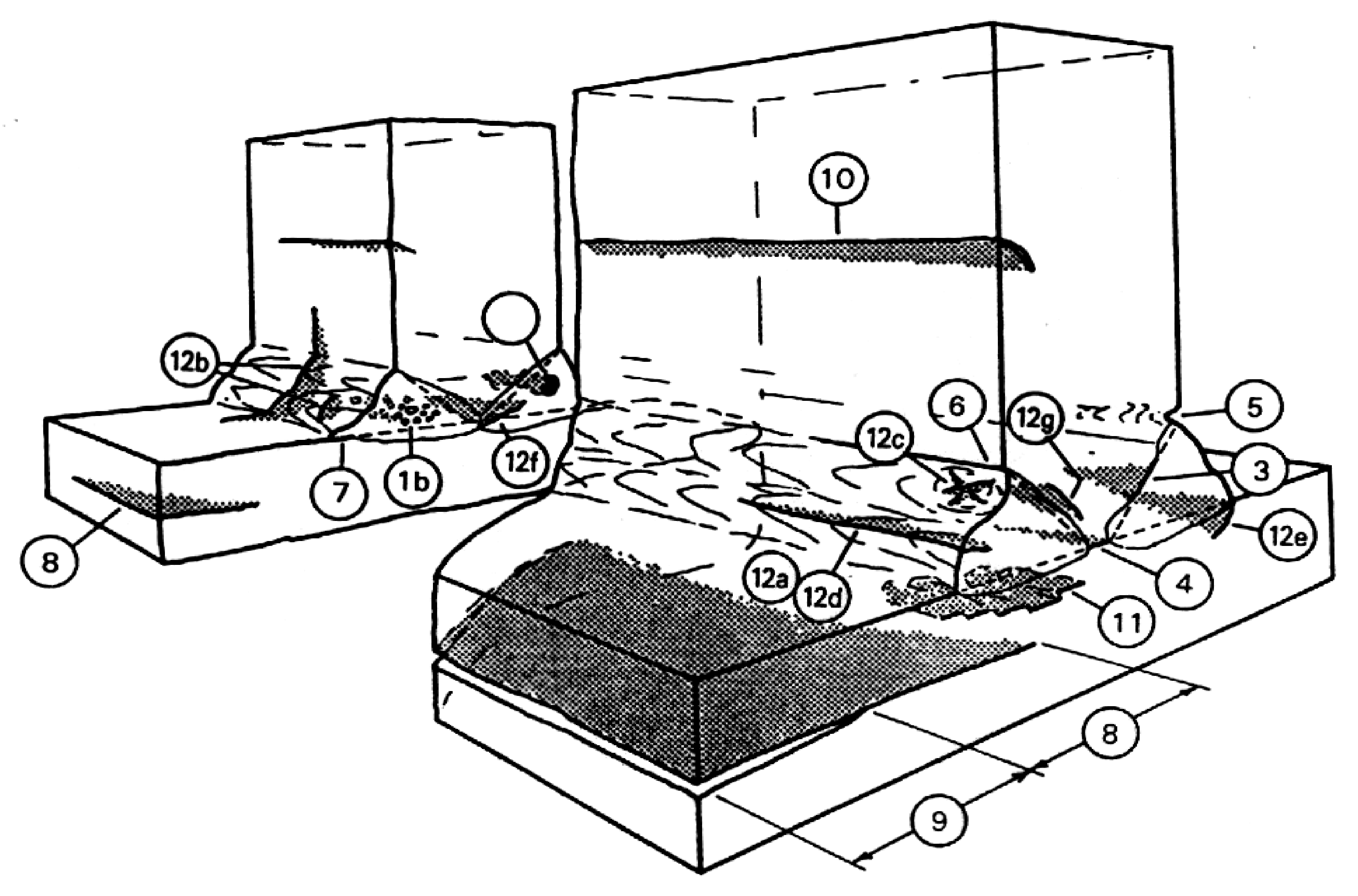


Figure 5—Combined Groove and Fillet Welds in T-Joint

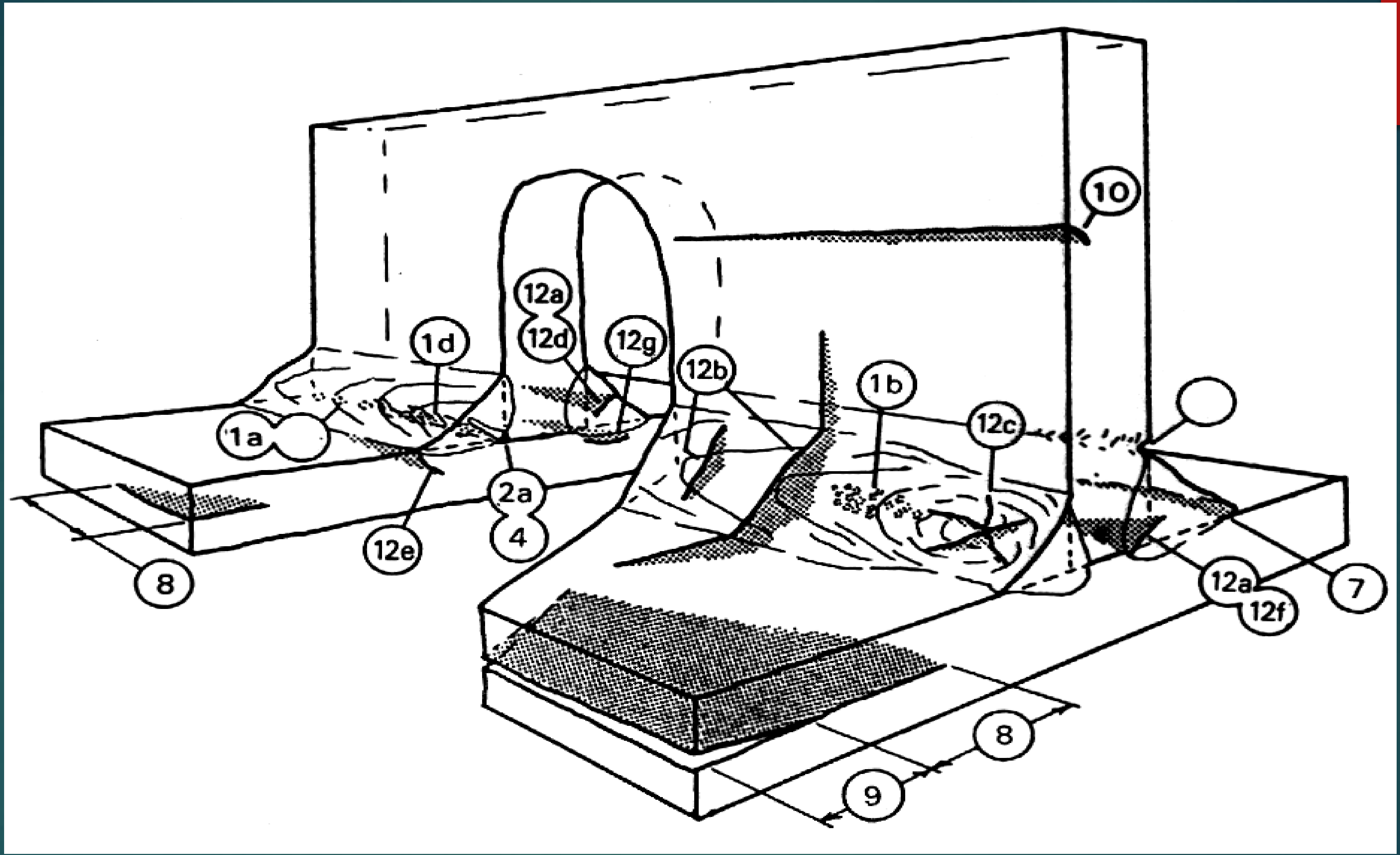


Figure 11.6—Single Pass Fillet Welds ins T-Joint

FUSION WELD DISCONTINUITIES

POROSITY

Porosity is the result of gas being entrapped in solidifying weld metal. The discontinuity is generally spherical, but it may be elongated. Uniformly scattered porosity may be distributed throughout single pass welds or throughout several passes of multiple pass welds. When ever uniformly scattered porosity is encountered, the cause is generally faulty welding technique or defective materials, or both.

Cluster porosity is a localized grouping of pores that may result from improper initiation or termination of the welding arc.

Linear porosity may be aligned along (1) a weld interface, (2) the root of a weld or (3) a boundary between weld beads. Linear porosity is caused by gas evolution from contaminants along a particular boundary.

Piping porosity is a term for elongated gas pores. Piping porosity in fillet welds normally extends from the root of the weld toward the face. When one or two pores are seen in the surface of the weld, it is likely that many subsurface piping pores are interspersed among the exposed pores. Much of the piping porosity found in welds does not extend to the surface. Piping porosity in electro-slag welds may be relatively long.

INCLUSIONS

Slag Inclusions are nonmetallic solid materials trapped in the weld metal or at the weld metal interfaces. They may be present in welds made by most arc welding processes. In general, slag inclusions result from faulty welding techniques, improper access to the joint for welding, or both. With proper welding techniques, molten slag will float to the surface of the molten weld metal. Sharp notches in joint boundaries or between weld passes promote slag entrapment in the weld metal.

TUNGSTEN INCLUSIONS are particles trapped in weld metal deposited with the gas tungsten arc welding process. These inclusions may be trapped in a weld if the tungsten electrode is dipped into the molten weld metal, or if the welding current is too high and causes melting and transfer of tungsten droplets into the molten weld metal. Tungsten inclusions appear as light areas on radiographs because tungsten is more dense than the surrounding metal and absorbs larger amounts of x-rays or gamma radiation. Almost all other weld discontinuities are indicated by dark areas on radiographs.

INCOMPLETE FUSION

Incorrect welding techniques, improper preparation of the materials for welding or wrong joint designs promote incomplete fusion in welds.

The welding condition that principally contribute to incomplete fusion are insufficient welding current and lack of access to all faces of the weld joint that should be fused during welding. Insufficient pre-weld cleaning may contribute to incomplete fusion, even if the welding conditions and technique are adequate. Pre-weld cleaning is more critical in certain metals.

INADEQUATE JOINT PENETRATION

When the actual root penetration of a weld is less than specified in the design, the discontinuity at the root is called inadequate penetration. This condition may result from insufficient welding heat, improper joint design (too much metal for the welding arc to penetrate), Incorrect bevel angle or poor control of the welding arc. Some welding processes have great penetrating ability, and that characteristic is often used to advantage. However, the process must be matched to the joint preparation or incomplete fusion will result.

Many welding procedures for double groove welds require back gouging of the root of the first weld to expose sound metal prior to depositing the first pass on the second side. This procedure is used to ensure that there are no areas of inadequate joint penetration.

UNDERCUT

Visible undercut is generally associated with either improper welding techniques or excessive welding currents or both. It is generally located parallel to the junction of weld metal and base metal at the toe or root of the weld. Undercut discontinuities create a mechanical notch at the weld interface. If examined carefully, many welds have some undercut. Often, the undercut may only be seen in metallographic tests where etched weld cross sections are examined under magnification. When undercut is controlled within the limits of the specifications and does not constitute a sharp or deep notch, it is usually not deleterious.

The term undercut is sometimes used in the shop to describe melting away of the groove face of a joint at the edge of a layer or bead of weld metal. This “undercut” forms a recess in the joint face where the next layer or bead of weld metal must fuse to the base metal. If the depth of fusion at this location is too shallow when the next layer of weld metal is applied, voids may be left in the fusion zone. These voids would more correctly be identified as incomplete fusion. This undercut is usually associated with incorrect manipulation of the welding electrode while depositing a weld bead or layer next to the joint face.

UNDERFILL: Underfill results simply from the failure of the welder or welding operator to fill the joint with weld metal as called out in the welding procedure specification or on the design drawing. Normally, the condition is corrected by adding one or more additional layers of weld metal in the joint prior to subsequent processing.

OVERLAP: Overlap is usually caused by incorrect welding procedures, wrong selection of welding materials or improper preparation of the base metal prior to welding. If tightly adhering oxides on the base metal interfere with fusion, overlap will result along the toe, face or root of the weld. Overlap is a surface discontinuity that forms a severe mechanical notch parallel to the weld axis.

CRACKS

Cracks will occur in weld metal and base metal when localized stresses exceed the ultimate strength of the metal. Cracking is often associated with stress amplification near discontinuities in welds and base metal or near mechanical notches associated with the weldment design. Hydrogen embrittlement often contributes to crack formation in steel. Plastic deformation at the crack edges is very limited.

Cracks can be classified as either hot or cold types. Hot cracks develop at elevated temperatures. They commonly form during solidification of the weld metal. Cold cracks develop after solidification of a fusion weld as result of stresses.

Cold cracks in steel are sometimes called delayed cracks and are often associated with hydrogen embrittlement. Hot cracks propagate between the grains while cold cracks propagate both between grains and through grains.

Cracks may be longitudinal or transverse with respect to the weld axis. Longitudinal weld metal cracks and the heat-affected zone cracks are parallel to the axis of the weld; transverse cracks are perpendicular to the weld axis.

Throat cracks

Throat cracks run longitudinally in the face of the weld and extend toward the root of the weld. They are generally, but not always hot cracks.

Root cracks

Root cracks run longitudinally and originate in the root of the weld. Both hot cracks and cold cracks can form in the root of the weld.

Longitudinal cracks

Longitudinal cracks in automatic submerged arc welds are commonly associated with high welding speeds, and are sometimes related to internal porosity. Longitudinal cracks in small welds between heavy sections are often the result of high cooling rates and high restraint.

Transverse cracks. Transverse cracks are nearly perpendicular to the axis of the weld. They may be limited in size and completely within the weld metal, or they may propagate from the weld metal into the adjacent heat-affected zone, and the base metal. Transverse cracks are generally the result of longitudinal shrinkage strains acting on weld metal of low ductility. Transverse cracks in steel weld metals are almost always related to hydrogen embrittlement.

Crater cracks. Crater cracks are formed by improper termination of a welding arc. They are usually shallow hot cracks and sometimes are referred to as star cracks when they form a star-like cluster.

Toe cracks. Toe cracks are generally cold cracks that initiate approximately normal to the base material surface and then propagate from the toe of the weld where residual stresses are higher. These cracks are generally the result of thermal shrinkage strains acting on a weld heat-affected zone that has been embrittled. Toe cracks sometimes occur when the base metal cannot accommodate the shrinkage strains that are imposed by welding.

Under bead cracks

Under bead cracks are generally cold cracks that form in the heat-affected zone. They may be short and discontinuous, but may also extend to form a continuous crack. Underbead cracking can occur in steels when three elements are present:

(1) Hydrogen in solid solution

(2) A crack-susceptible microstructure

(3) High residual stresses

When present, these cracks are usually found at regular intervals under the weld metal, and do not normally extend to the surface. They cannot be detected by visual inspection, and may be difficult to detect by ultrasonic and radiographic examinations.

Fissures are crack - like separations of small or moderate size along internal grain boundaries. They can occur in fusion welds made by most welding processes, but they are more frequent in electro - slag welds because of the larger grain sizes in the weld. The separations can be either hot or cold cracks. Their effects on the performance of welded joints are the same as cracks of similar sizes in the same location and orientations.

BASE METAL DISCONTINUITIES

Not all discontinuities are a result of improper welding procedures. Many difficulties with weld quality may be traced to the base metal. Base metal requirements are usually defined by an ASTM specification. Departure from these requirements should be considered cause for rejection. Base metal properties that should meet specification requirements include chemical composition, cleanliness, laminations, stringers, surface conditions (scale, paint, oil), mechanical properties, and dimensions. The inspector should keep such factors in mind when evaluating the sources of indications in welded joints that have no apparent cause. Several flaws that may be found in base metal are also shown in Figures 11.1 through 11.6.

Laminations

Laminations in plate and other mill shapes are flat, generally elongated discontinuities found in the central zone of wrought products. Laminations may be completely internal and only detectable by ultrasonic tests, or they may extend to an edge or end where they may be visible at the surface. They may also be exposed when the base metal is cut.

Laminations are flattened discontinuities that run generally parallel to the surfaces of rolled products, and are most commonly found in mill shapes and plates. Some laminations are partially welded together during hot rolling operations. Other laminations may be so tight that they may not be detected by ultrasonic tests. Structural wrought shapes containing laminations cannot be relied upon to carry tensile stress in the through-thickness direction.

Delamination in the base metal may occur when the laminations are subject to transverse stresses. The stresses may be residual from welding or they may result from external loading. Delamination may be detected visually at the edges of pieces or by ultrasonic testing with longitudinal waves through the thickness. Delaminated metal should not be used to transmit tensile loads.

Lamellar Tears

Some rolled structural shapes and plates are susceptible to a cracking defect known as lamellar tearing. Lamellar tearing, a form of fracture resulting from high stress in the through-thickness direction, may extend over long distances. Lamellar tears are generally terrace-like separations in base metal typically caused by thermally-induced shrinkage stresses resulting from welding. The tears take place roughly parallel to the surface of rolled products. They generally initiate either in regions having a high incidence of coplanar, stringer-like, nonmetallic inclusions or in areas subject to high residual (restraint) stresses, or both. The fracture usually propagates from one lamellar plane to another by shear along planes that are nearly normal to the rolled surface.

LAPS AND SEAMS

Laps and Seams are longitudinal flaws at the surface of the base metal that may be found in hot-rolled mill products. When the flaw is parallel to the principal stress, it is not generally a critical defect; if the lap or seam is perpendicular to the applied or residual stresses, or both, it will often propagate as a crack. Seams and laps are surface discontinuities. However, their presence may be masked by manufacturing processes that have subsequently modified the surface of a mill product. Welding over seams and laps can cause porosity, incomplete fusion, and cracking. Seams and laps may be harmful in applications involving welding, heat treating or upsetting and also in certain components that will be subjected to cyclic loading. Mill products can be produced with special procedures to control the presence of laps and seams. Open laps and seams can be detected by magnetic particle, penetrant and ultrasonic inspection methods, but those tightly closed may be missed during inspection.

ARE STRIKES

Striking an arc on base metal that will not be fused into the weld metal should be avoided. A small volume of base metal may be momentarily melted when the arc is initiated. The molten metal may crack from quenching, or a small surface pore may form in the solidified metal. These discontinuities may lead to extensive cracking in service. Any cracks or blemishes caused by arc strikes should be ground to a smooth contour and re-inspected for soundness.

DIMENSIONAL DISCREPANCIES

The production of satisfactory weldments depends upon, among other things, the maintenance of specified dimensions. These may be the size and shape of welds or the finished dimensions of an assembly. Requirements of this nature will be found in the drawings and specifications. Departures from the requirements in any respect should be regarded as dimensional discrepancies that, unless a waiver is obtained, must be corrected before acceptance of the weldments. Dimensional discrepancies can be largely avoided if proper controls are exercised when the base metals are cut to size.

WARPAGE

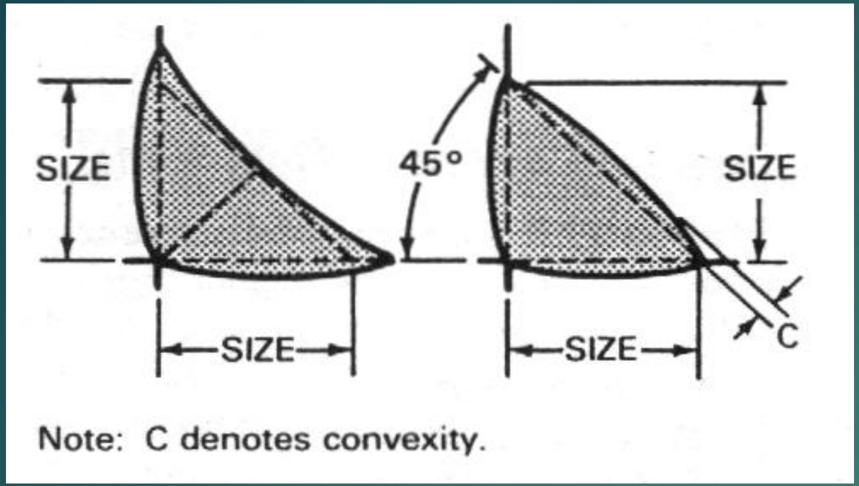
Warpage or distortion is generally controllable by using suitable jigs or welding sequences, or by presetting of joints prior to welding. The exact method employed should be dictated by the size and shape of the parts as well as by the thickness of the metal.

INCORRECT JOINT PREPARATION

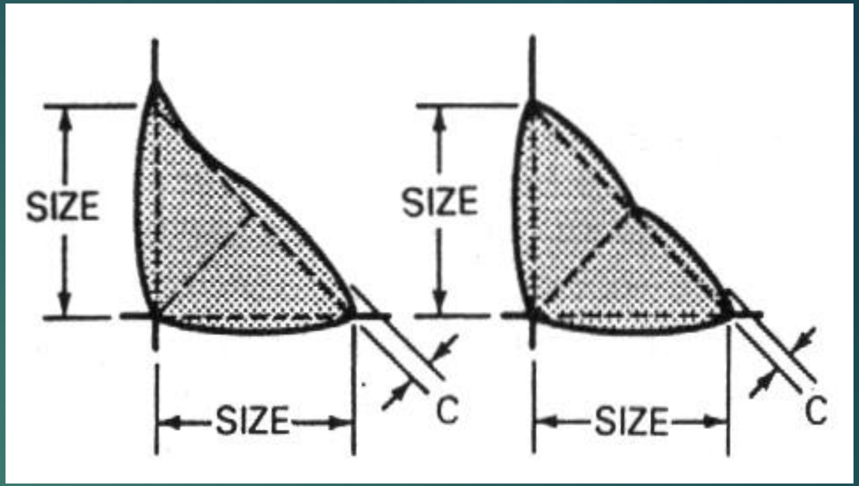
Established welding practices require proper dimensions for each type of joint geometry consistent with the base metal composition and thickness and the welding process. Departure from the required joint geometry may increase the tendency to produce weld discontinuities. Therefore, joint preparation should meet the requirements of the shop drawings, and be within the specified limits.

WELD PROFILES

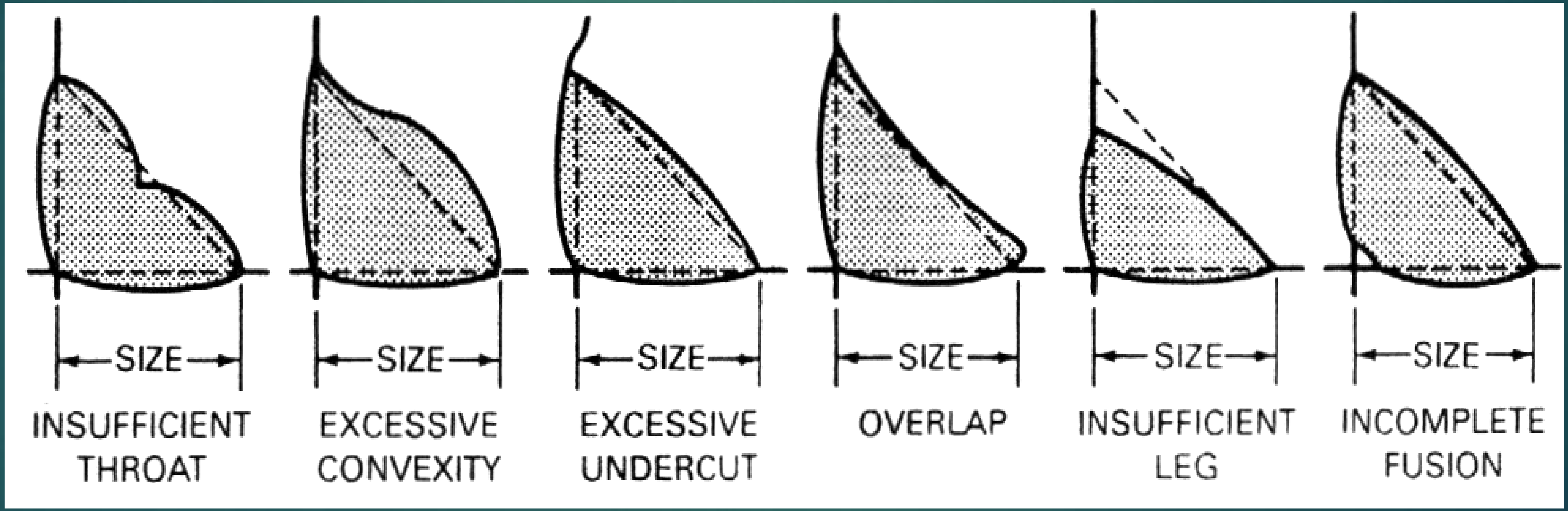
The profile of a finished weld may affect the service performance of the joint. The surface profile of an internal pass or layer of a multiple pass weld may contribute to the formation of incomplete fusion or slag inclusion. when the next layer is deposited. Requirements concerning discontinuities of this nature in finished weld usually included in the specifications. Figure 11.9 illustrates various types of acceptable and unacceptable w’ profiles in fillet and groove welds.



Desirable Fillet Weld Profiles



Acceptable Fillet Weld Profiles



Unacceptable Fillet Weld Profiles

Common Causes and Remedies of Porosity	
Cause	**Remedies**
Excessive hydrogen, nitrogen, or oxygen in welding atmosphere	Use low-hydrogen welding process; filler metals high in deoxidizers increase shielding gas flow
High solidification rate	Use preheat or increase heat input
Dirty base metal	Clean joint faces and adjacent surfaces
Dirty filler wire	Use specially cleaned and packaged filler wire, and store it in clean area
Improper arc lengtlt welding current, or electrode manipulation	Change welding conditions and techniques
Volatization of zinc horn brass	Use copper-silicon filler metal reduce heat input
Galvanized steel	Use E6013 electrodes and manipulate the arc heat to volatilize the zinc ahead of the molten weld pool
Excessive moisture in electrode covering or on joint surfaces	Use recommended procedures for baking and storing electrodes Preheat the base metal
High sulfur base metal	Use electrodes with basic slagging reactions

Common Causes and Remedies of Slag Inclusions	
Cause	Remedies
Failure to remove slag	Clean surface and previous weld bead
Entrapment of refractory oxides	Power wire brush the previous weld bead
Tungsten in the weld metal	Avoid contact between the electrode and the work use larger electrode
Improper joint design	Increase groove angle of joint
Oxide inclusions	Provide proper gas shielding
Slag flooding ahead of the welding arc	Reposition work to prevent loss of slag control
Poor electrode manipulative technique	Change electrode or flux to improve slag control
Entrapped pieces of electrode covering	Use undamaged electrodes

Common Causes and Remedies of Incomplete Fusion	
Cause	**Remedies**
Insufficient heat input, wrong type or size of electrode, improper joint design, or inadequate gas shielding	Follow correct welding procedure specification
Incorrect electrode position	Maintain proper electrode position
Weld metal running ahead of the arc	Reposition work, lower current, or increase weld travel speed
Trapped oxides or slag on weld groove or weld face	Clean weld surface prior to welding

Common Causes and Remedies of Inadequate Joint Penetration	
Cause	**Remedies**
Excessive thick root face or insufficient root opening	Use proper joint geometry
Insufficient heat input	Follow welding procedure
Slag flooding ahead of welding arc	Adjust electrode or work position
Electrode diameter too large	Use small electrodes in root or increase root opening
Misalignment of second side weld	Improve visibility or back gouge
Failure to back gouge when specified	Back gouge to sound metal if required in welding procedure specification
Bridging of root opening	Use wider root opening or smaller electrode in root pass

Common Causes and Remedies of Cracking	
Causes	**Remedies**
Weld Metal Cracking	
Highly rigid joint	Preheat
	Relieve residual stresses mechanically
	Minimize shrinkage stresses using backstep or block welding sequence
Excessive dilution	Change welding current and travel speed
	Weld with covered electrode negative; butter the joint faces prior to welding
Defective electrodes	Change to new electrode bake electrodes to remove moisture
Poor fit-up	Reduce root opening build up the edges with weld metal
Small weld bead	Increase electrode size; raise welding current reduce travel speed
High sulfur base metal	Use filler metal low in sulfur
Angular distortion	Change to balanced welding on both sides of joint
Crater cracking	Fill crater before extinguishing the arc use a welding current dy device when terminating the weld bead

Common Causes and Remedies of Cracking	
Causes	**Remedies**
Heat-Affected Zone	
Hydrogen in welding atmosphere	Use low-hydrogen welding process preheat and hold 2 hr after welding or post-weld heat treat immediately
Hot cracking	Use low heat input deposit thin layers; change base metal
low ductility	Use preheat; anneal the base metal
High residual stresses	Redesign the weldment; change welding sequence; apply intermediate stress-relief heat treatment
High hardenability	Preheat; increase heat input; heat treat without cooling to room temperature
Brittle phases in the microstructure	Solution heat teat prior to welding