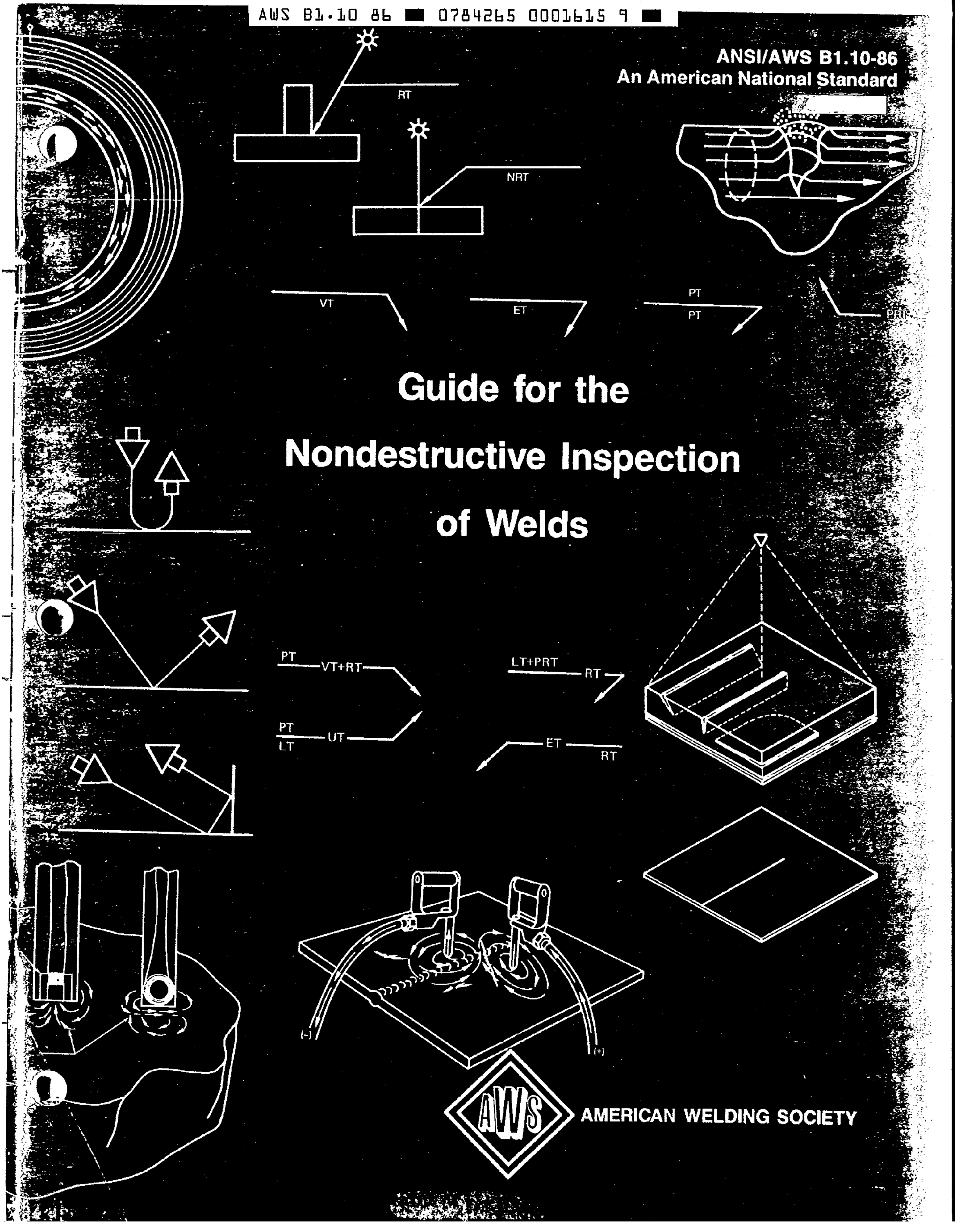
ANSI/AWS B1.10-86
An American National Standard

Guide for the Nondestructive Inspection of Welds



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Key Words—Guide, Eddy Current Inspection, Magnetic Particle Inspection, Nondestructive Inspection, Penetrant Inspection, Radiographic Inspection, Ultrasonic Inspection, Visual Inspection, Weld Discontinuities.

ANSI/AWS B1.10-86
An American National Standard

Approved by
American National Standards Institute
February 20, 1985

Guide for the Nondestructive Inspection of Welds

Second Edition

Superseding AWS B1.0-77

Prepared by
AWS Committee on Methods of Inspection

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors, October 22, 1984

Abstract

This Guide acquaints the reader with the common nondestructive inspection (NDT) methods available, and aids in selecting the method best suited for inspection of a given weld. The inspection methods included are Visual, Penetrant, Magnetic Particle, Radiography, Ultrasonic, and Eddy Current Inspection.

AMERICAN WELDING SOCIETY
550 N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135

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International Standard Book Number: 0-87171-259-8

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Printed in the United States of America
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Foreword

The Guide for the Nondestructive Inspection of Welds was first prepared by the AWS Committee on Methods of Inspection in 1977. This most recent edition updates a source of basic information on nondestructive inspection (NDT) methods. It acquaints the reader with common NDT methods available and aids in selecting the method best suited for inspection of a given weld, namely: visual, penetrants, magnetic particle, radiography, ultrasonic and eddy current.

The purpose of this guide is to give the reader an overview of the more common inspection methods available without unnecessary detail and to provide an aid in deciding which inspection method is generally best suited for the inspection of a given weld. The words evaluation, examination, inspection, and testing are considered synonymous when describing various nondestructive methods.

Included in this guide is a fundamental introduction to weld and weld related discontinuities; an introduction to the more commonly used NDI methods with discussions on their capabilities (including limitations); and a "wrap-up" on the "Interrelationships among Welding Processes, Discontinuities, and Inspection Methods." The guide also contains a useful appendix with brief summaries of typical considerations generally used in selecting an NDI method for Weld Inspection.

This guide has been prepared by the AWS Committee on Methods of Inspection to serve as a simple, but reliable, source of information. It is not intended that this document provide complete and comprehensive coverage of the subject. There are many reference manuals available. For more comprehensive coverage of welding inspector activities, this guide should be used in conjunction with the AWS book *Welding Inspection. Welding Inspection* provides a more thorough description of the duties and responsibilities of welding inspectors, the techniques and characteristics of the usual nondestructive inspection methods, and the major aspects of sampling and documentation required for an adequate quality control system. For more detailed information on the subject of inspection, also refer to the documents suggested in Section 5, Supplementary Reading Material.

Comments and suggestions regarding the Guide will be welcome. These comments should be sent to the Secretary, AWS Committee on Methods of Inspection, American Welding Society, 550 N.W. Lejeune Road, P.O. Box 351040, Miami, Florida 33135.

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Guide for the Nondestructive Inspection of Welds

1. Introduction

Nondestructive Inspection (NDT) is a general term used in this text to identify the major inspection methods that permit evaluation of welds and related materials without destroying their usefulness.

The terminology used in this guide has been established in AWS A3.0, *Standard Welding Terms and Definitions.* Accordingly, a discontinuity is defined as "an interruption of the typical structure of a weldment, such as a lack of homogeneity in the mechanical, metallurgical, or physical characteristics of the material or weldment." A discontinuity is established as a defect by a specification that states the sizes and types of discontinuities that are rejectable. For the purpose of this guide, reference will be made to detection of discontinuities without regard to the distinction between acceptance or rejection.

There are three principal parameters to be considered when choosing an inspection method (1) advantages and limitations of the inspection method, (2) acceptance standards, and (3) cost.

1.1 Limitations of the Inspection Method. The advantages and limitations of the inspection method can be used to determine which method(s) will provide the best results for a particular test. For example, radiography can detect cracks whose major planes are aligned parallel with the radiation beam; such cracks are usually normal to the plate surfaces. Radiography, however, usually cannot detect laminations in plate or cracks oriented parallel to the plate surface. On the other hand, ultrasonics can more readily detect cracks oriented in either direction provided the proper scanning technique is used.

1.2 Acceptance Standards. The statement "the weld shall be radiographically inspected" has no meaning unless acceptance standards are stated. Acceptance standards define different types of characteristics of discontinuities and whether particular types of discontinuities are permissible. If a particular type of discontinuity is permissible, then the acceptance standards must specify the maximum size at which that discontinuity is acceptable. Acceptance standards are an integral part of most codes and specifications listed in Section 5 and are commonly used as references in purchase specifications.

1.3 Cost. Different inspection methods have different costs in any particular stituation. Two basic cost factors which should be considered in the selection of a nondestructive inspection method are the initial equipment availability cost and the cost of performing the inspection. Visual inspection is almost always the least expensive, but it is also limited to the detection of surface discontinuities. In general, costs of radiographic, ultrasonic, and eddy current inspections are greater than those of visual, magnetic particle, and liquid penetrant inspections.

Selection of the proper inspection method can be quite complex. To meet the intended purpose and minimize cost, it is suggested that help be obtained from a qualified nondestructive testing engineer or technician.

2. Discontinuties

2.1 Discussion of Discontinuities. This guide is concerned only with discontinuities, which may be classed as defects (rejectable) depending upon particular specifications or codes. Discontinuities are rejectable only if they exceed specification requirements in terms of type, size, distribution, or location.

Discontinuities may be found in weld metal, heat-affected zones, and base metal of weldments made in the four basic weld joints considered in this guide— butt, T, corner, and lap joints. The following section presents a fairly comprehensive list of discontinuities which may be encountered in the fabrication of metals by welding. The list is limited to those discontinuities that are of general interest to owners, designers, and fabricators. When specific discontinuities are located in the weld metal, heat-affected zone, weld interface, or base metal, the abbreviations WM, HAZ, BM/WM, and BM, respectively, are used to indicate the location.

2.2 List of Discontinuities. The most common types of discontinuities in butt, T, corner, and lap joints are listed in Table 1 and depicted in Figs. 1 through 10. Where the list indicates that the discontinuity is generally located in the weld, it may be expected to appear in almost any type of weld. Tungsten inclusions are an exception. Tungsten inclusions are found only in welds made by the gas tungsten arc process.

Weld and base metal discontinuities of specific types are more common when certain welding processes and joint details are used, e.g. see Table 2. High restraint and limited access to portions of a weld joint may lead to a higher than normal incidence of weld and base metal discontinuities.

Each general type of discontinuity is discussed in detail in this section. AWS D1.1, *Structural Welding Code-Steel,* uses the term *fusion-type discontinuity* as all-encompassing to describe slag inclusions, incomplete fusion, incomplete joint penetration, and similar generally elongated discontinuities in fusion welds. Many codes and specifications consider fusion-type discontinuities less critical than cracks. However, some codes and specifications specifically prohibit not only cracks but also any incomplete fusion or incomplete joint penetration. Spherical discontinuities (almost always gas pores) can occur anywhere within the weld. Elongated discontinuities may be encountered in any orientation. Specific joint types, welding procedures, and restraint conditions have an effect on the type, location, and incidence of discontinuities. Examples of these factors as controlling conditions are described in the text in the following sections.

2.3 Porosity (1)*. The porosity discussed in this guide is the result of gas being entrapped in solidifying metal. The discontinuity formed is generally spherical but may be elongated. When there are gas pores in ingots that are reduced to wrought products, some of these gas pores may appear as laminations in the finished product.

Unless porosity is excessive[1], it is not as critical a discontinuity as sharp discontinuities that cause stress concentrations. Excessive porosity is a sign that the welding parameters, welding consumables, or joint fit-up are not being properly controlled for the welding process selected or that the base metal is contaminated or of a composition incompatible with the weld filler metal being used. Porosity is not caused exclusively by hydrogen, but the presence of porosity does indicate that there is a possibility of hydrogen in the weld and heat-affected zones that may lead to cracking in ferrous materials.

2.3.1 Uniformly Scattered Porosity (1a) is porosity uniformly distributed throughout the weld metal. When excessive[1] uniformly scattered porosity is encountered, the cause is generally faulty welding techniques or materials. The joint preparation technique or materials used may result in conditions that may cause porosity.

If a weld cools slowly enough to allow most of the gas to pass to the surface before weld solidification, there will be few pores in the weld.

2.3.2 Cluster Porosity (1b) is a localized grouping of pores. It often results from improper initiation or termination of the welding arc.

2.3.3 Linear Porosity (1c) is a series of pores which are aligned. It often occurs along a weld interface, the interface of weld beads, or near the weld root and is caused by contamination that leads to gas evolution at those locations.

2.3.4 Piping Porosity (1d) is an elongated gas pore. Piping porosity in fillet welds extends from the weld root toward the weld surface. When one or two pores are seen in the weld surface, careful excavation may also reveal subsurface porosity. Much of the piping porosity found in welds does not extend all the way to the surface. Piping porosity in electroslag welds can become very long; e.g., 20 in. (508.0 mm).

2.4 Inclusions (2)

2.4.1 Slag Inclusions (2a) are nonmetallic solid materials entrapped in weld metal or between weld metal and base metal. They can be found in welds made by many arc welding processes. In general, slag inclusions result from faulty welding techniques, the failure of designer to provide proper access for welding the joint, or improper cleaning of the weld between passes. Normally, molten slag will flow to the top of the weld. Sharp notches in the weld interface or between passes often cause slag to be entrapped under the molten weld metal.

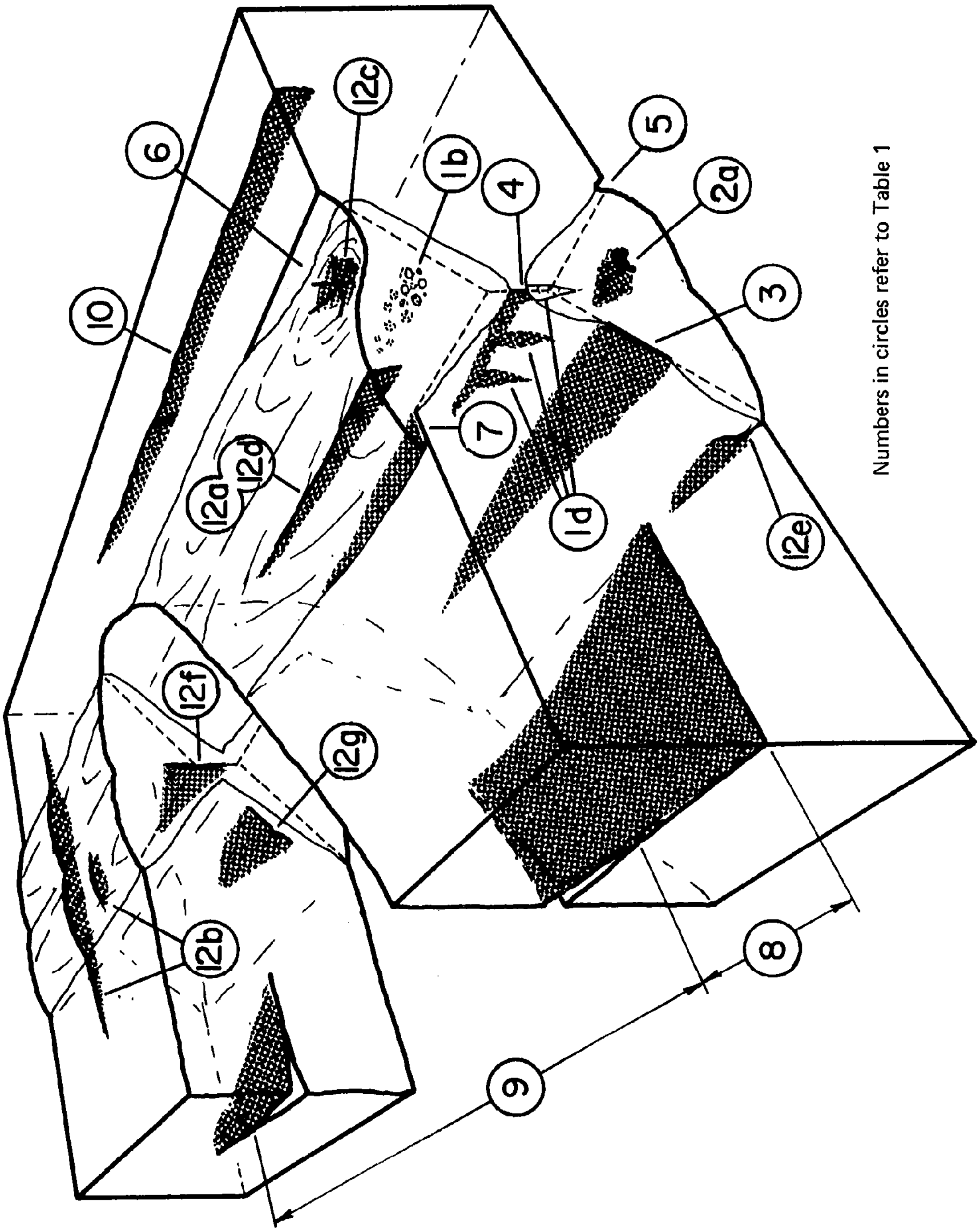
2.4.2 Tungsten Inclusions (2b) are tungsten particles trapped in weld metal and are peculiar to the gas tungsten arc welding process. In this process, a nonconsumable

*The numbers in parentheses in sections 2.3-2.17 refer to numbers in Table 1 and Figs. 1-7.
1. For the weld's intended use.

Table 1
Common types of discontinuities

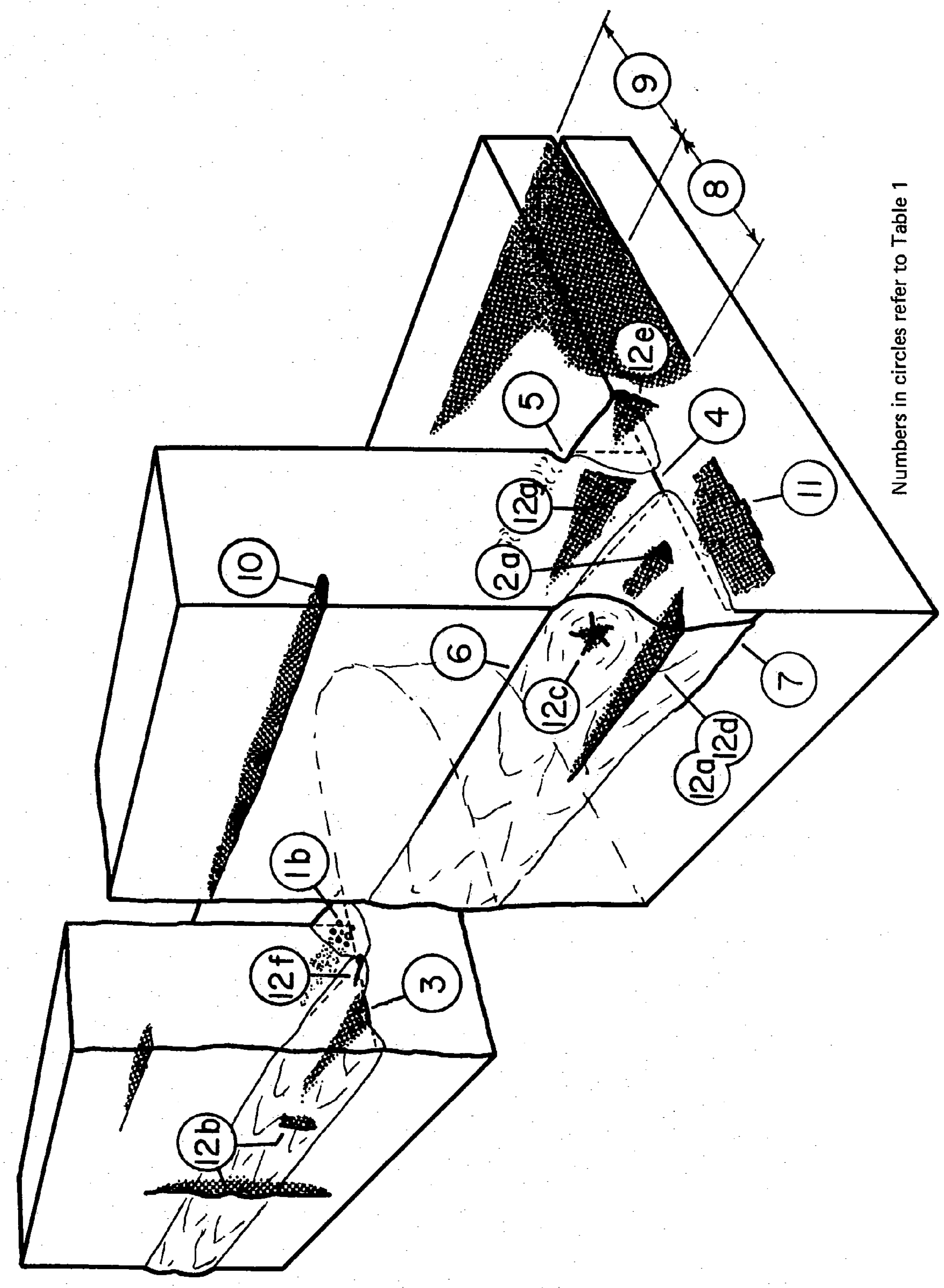
Type of Discontinuity	Section	Location*	Remarks
1 Porosity	2.3	WM	Porosity is also commonly found in the heat-affected zone if base metal is a casting.
(a) Uniformly scattered	2.3.1		
(b) Cluster	2.3.2		
(c) Linear	2.3.3		
(d) Piping	2.3.4		
2 Inclusions	2.4	WM	
(a) Slag	2.4.1		
(b) Tungsten	2.4.2		
3 Incomplete fusion	2.5	WM, BM/WM	Also between passes.
4 Incomplete joint penetration	2.6	BM	Weld root.
5 Undercut	2.7	BM/WM	Adjacent to weld toe or weld root in base metal.
6 Underfill	2.8	WM	Weld face or root surface.
7 Overlap	2.9	BM/WM	Weld toe or root surface.
8 Laminations	2.10	BM	Base metal, generally near midthickness of section.
9 Delamination	2.11	BM	Base metal, generally near midthickness of section.
10 Seam and laps	2.12		Base metal surface almost always aligned with rolling direction.
11 Lamellar tears	2.13	BM	Base metal, near HAZ.
12 Cracks (includes hot cracks and cold cracks described in text)	2.14 2.14.1		
(a) Longitudinal	2.14.2, 2.14.3	WM, HAZ	Weld metal or base metal adjacent to weld interface.
(b) Transverse	2.14.2, 2.14.4	WM, HAZ, BM	Weld metal (may propagate into HAZ and base metal).
(c) Crater	2.14.5	WM	Weld metal at point where arc is terminated.
(d) Throat	2.14.6	WM	Parallel to weld axis.
(e) Toe	2.14.7	BM/WM	
(f) Root	2.14.8	WM	Root surface.
(g) Underbead and heat-affected zone	2.14.9	BM/WM	
13 Insufficient throat	2.15	WM	Weld face.
14 Convexity or weld reinforcement	2.16	WM	Weld face.
15 Insufficient leg	2.17	WM	Fillet weld.

*WM—weld metal
BM—base metal
HAZ—heat affected zone
BM/WM—weld interface



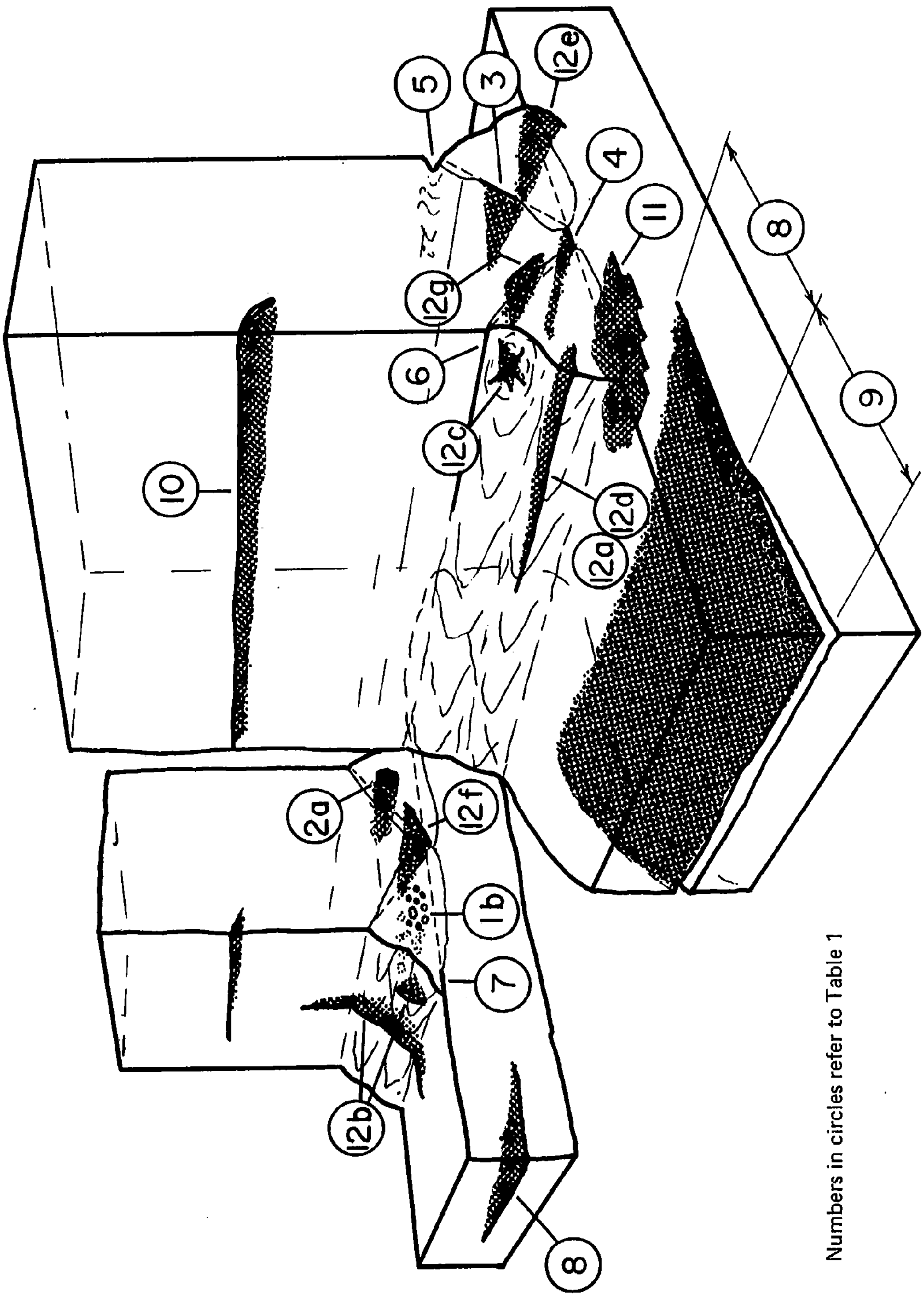
Numbers in circles refer to Table 1

Fig. 1—Double V-groove weld in butt joint



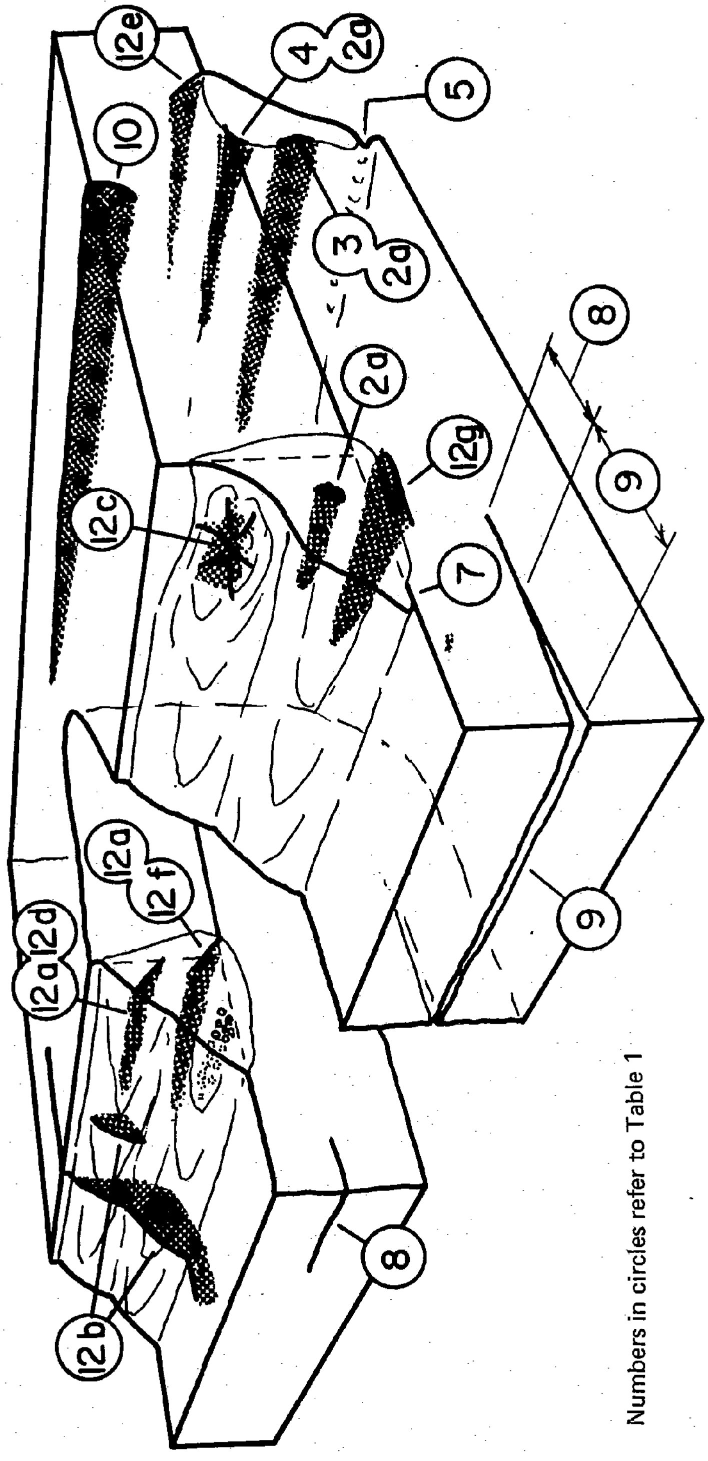
Numbers in circles refer to Table 1

Fig. 2—Single bevel groove and fillet welds in corner joint



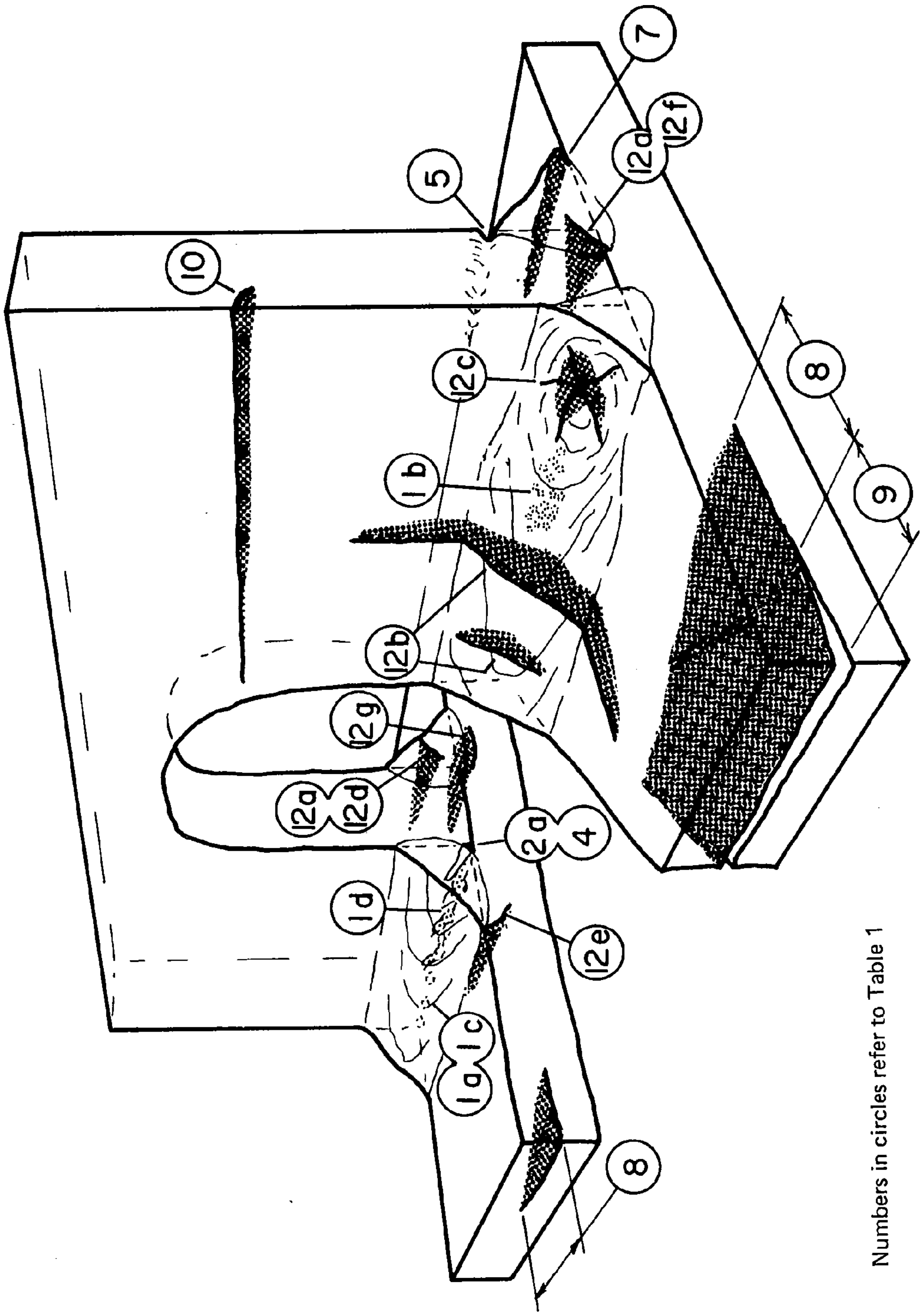
Numbers in circles refer to Table 1

Fig. 3—Double bevel groove weld in T-joint



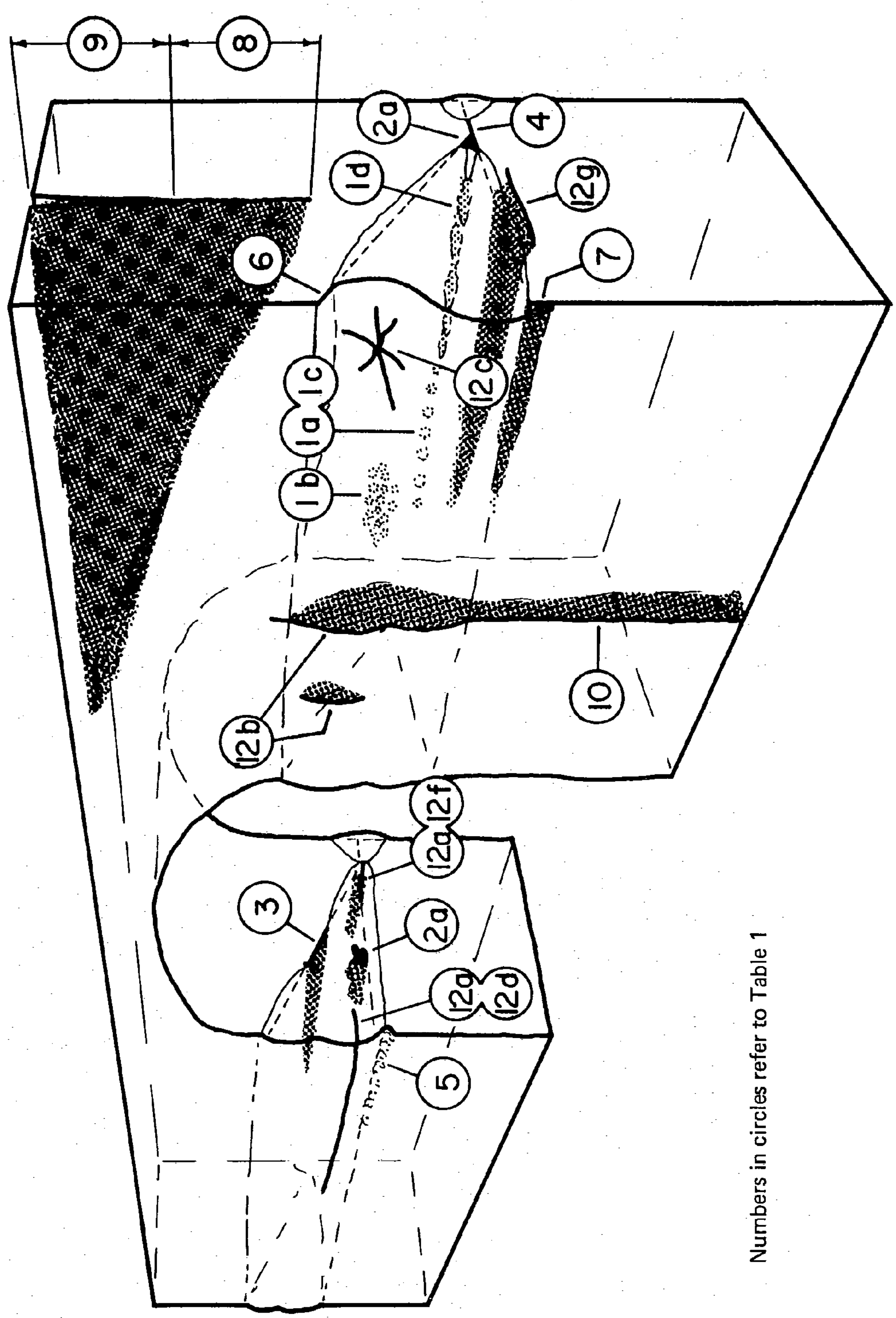
Numbers in circles refer to Table 1

Fig. 4—Double fillet weld in lap joint



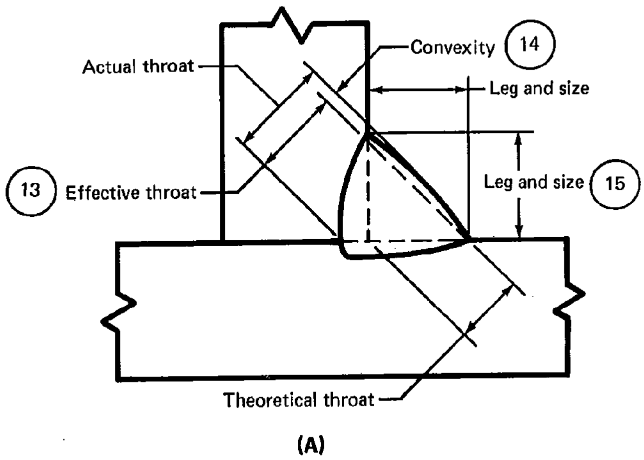
Numbers in circles refer to Table 1

Fig. 5—Single pass double fillet weld in a T-joint



Numbers in circles refer to Table 1

Fig. 6—Single bevel groove weld in butt joint



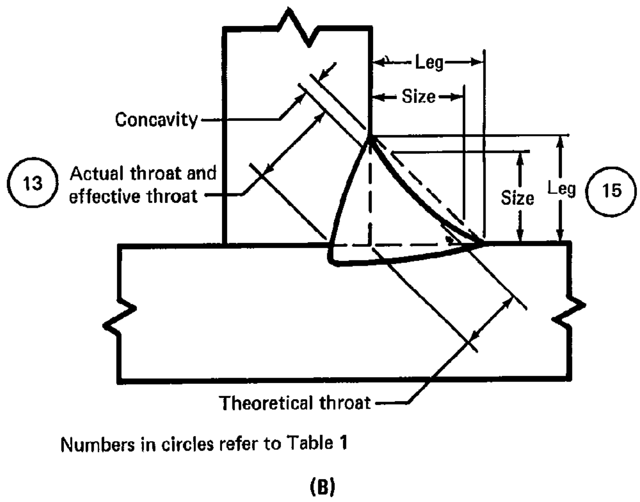


Fig. 7—Fillet weld terminology

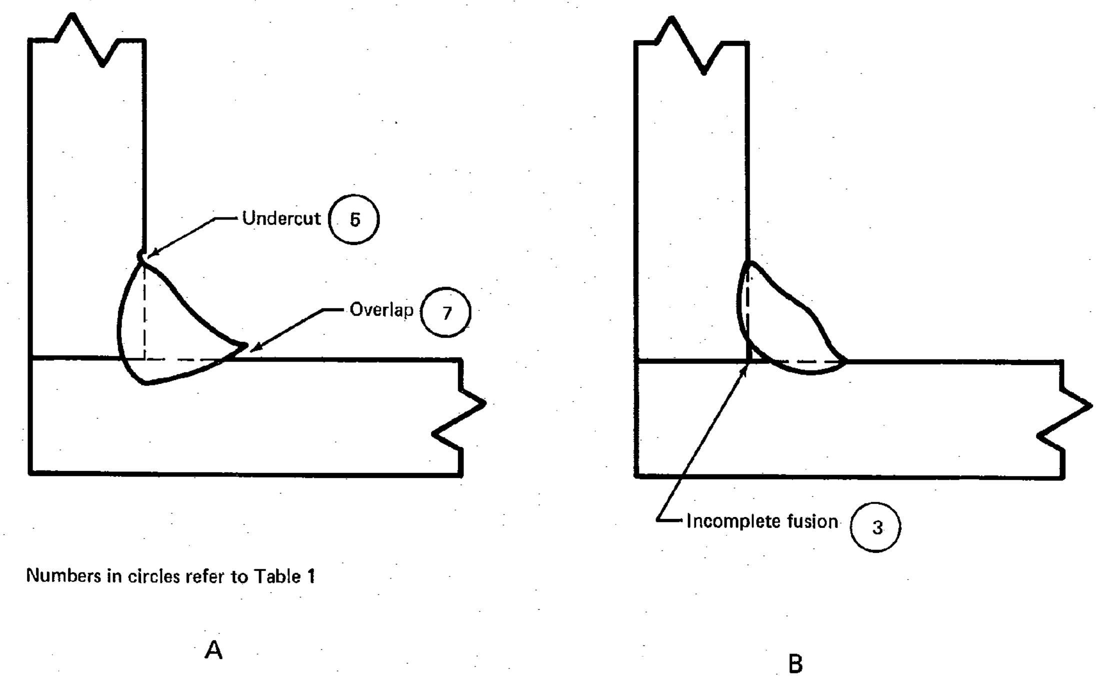


Fig. 8—Fillet weld discontinuities

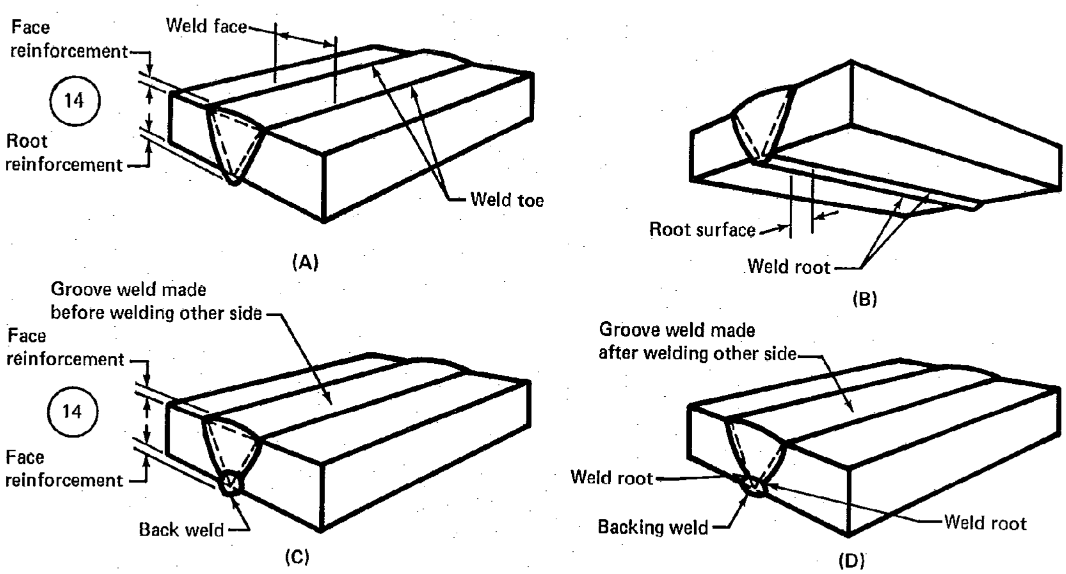


Fig. 9—Groove weld terminology

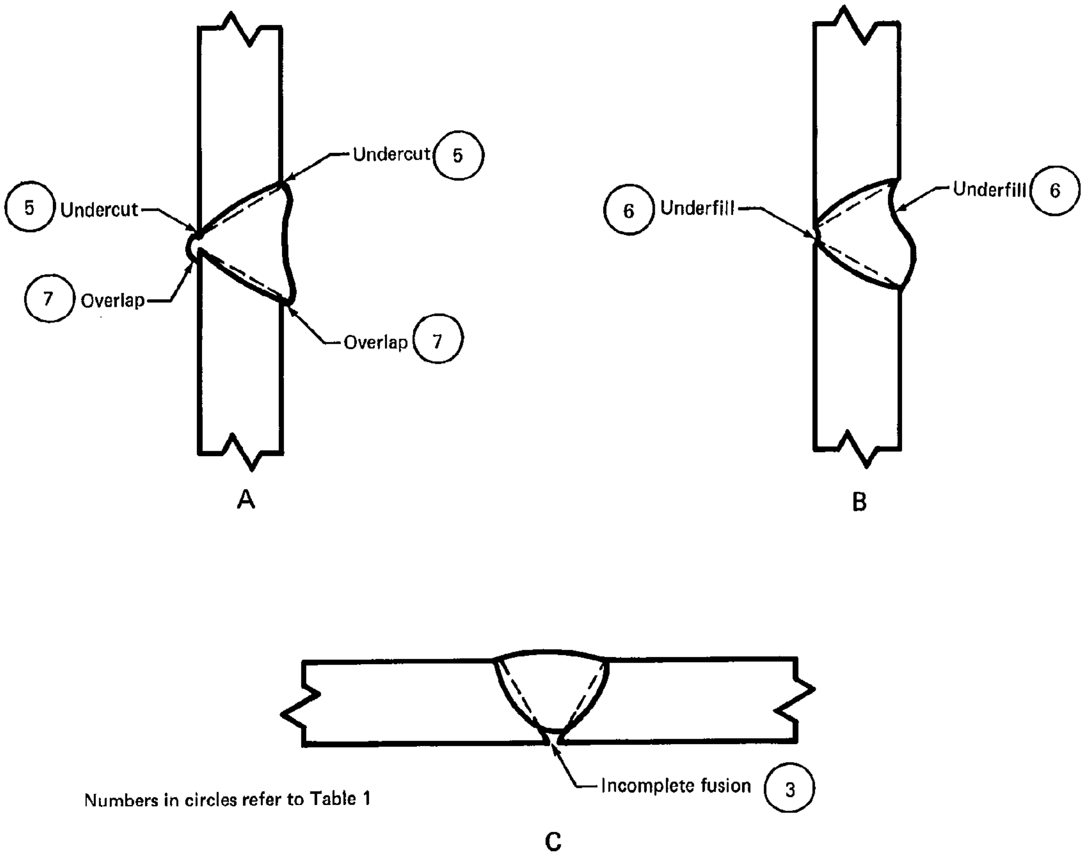


Fig. 10—Groove weld discontinuities

tungsten electrode is used to establish a welding arc between the electrode and the weld or base metal. If the tungsten electrode is dipped into the molten metal, or if the current is set too high so as to deposit tungsten droplets, tungsten inclusions will result. Tungsten inclusions appear as light marks or areas on radiographs because tungsten is more dense than steel or aluminum and absorbs more of the radiation. Almost all other weld discontinuities show as dark areas on radiographs.

2.5 Incomplete fusion (3) is the result of improper welding techniques, improper preparation of base metal, or improper joint design. Deficiencies causing incomplete fusion include insufficient welding heat or lack of access to all fusion faces, or both. Tightly adhering oxides will interfere with complete fusion, even when there is proper access for welding and proper welding heats are used.

2.6 Incomplete joint penetration (4) occurs when weld metal fails to penetrate the joint. The unpenetrated and unfused area is a discontinuity described as incomplete penetration. Incomplete penetration may result from insufficient welding heat, improper joint design (e.g., too much thickness for the welding arc to penetrate), or improper lateral control of the welding arc. Some welding processes have much greater penetrating ability than others. For joints welded from both sides, back gouging may be specified before welding the other side to ensure that there is no incomplete penetration. Pipe welds are especially vulnerable to this type of discontinuity, since the inside of the pipe is usually inaccessible. Designers often employ a backing bar or consumable inserts to aid welders in such cases. Welds which are required to have complete penetration are commonly inspected by some nondestructive method. This is especially true in bridges, pipe lines, pressure vessels, and nuclear applications.

Table 2
Discontinuities commonly encountered with welding processes

Welding Process	Type of Discontinuity						
Arc	**Porosity**	**Slag**	**Incomplete Fusion**	**Incomplete Penetration**	**Undercut**	**Overlap**	**Cracks**
SW—Stud welding			X		X		X
PAW—Plasma arc welding	X		X	X			X
SAW—Submerged arc welding	X	X	X	X	X	X	X
GTAW—Gas arc tungsten welding	X		X	X			X
GMAW—Gas metal arc welding	X	X	X	X	X	X	X
FCAW—Flux cored arc welding	X	X	X	X	X	X	X
SMAW—Shielded metal arc welding	X	X	X	X	X	X	X
CAW—Carbon arc welding	X	X	X	X	X	X	X
Resistance							
RSW—Resistance spot welding			X				X
RSEW—Resistance seam welding			X				X
PW—Projection welding			X				X
FW—Flash welding			X				X
UW—Upset welding			X				X
Oxyfuel Gas							
OAW—Oxyacetylene welding	X		X	X	X	X	X
OHW—Oxyhydrogen welding	X		X	X			X
PGW—Pressure gas welding	X		X				X
Solid state*							
CW—Cold welding			X				X
DFW—Diffusion welding			X				X
EXW—Explosion welding			X				
FOW—Forge welding			X				
FRW—Friction welding			X				
USW—Ultrasonic welding			X				
Other							
EBW—Electron beam welding	X		X	X			X
ESW—Electroslag welding	X	X	X	X	X	X	X
IW—Induction welding			X				X
LBW—Laser beam welding	X		X				X
PEW—Percussion welding			X				X
TW—Thermit welding	X	X	X				X

*Solid State is not a fusion process, so incomplete joining is incomplete welding rather than incomplete fusion.

2.7 Undercut (5) is generally associated with either improper welding techniques or excessive welding currents, or both. Undercut is a groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal. This groove creates a mechanical notch which is a stress concentrator. When undercut is controlled within the limits of specifications and does not constitute a sharp or deep notch, it is not considered a weld defect.

2.8 Underfill (6) is a depression on the weld face or root surface extending below the adjacent surface of the base metal. It results from the failure of the welder to completely fill the weld joint as called for in the welding procedure.

2.9 Overlap (7) is the protrusion of weld metal beyond the weld toe or weld root. It can occur as a result of lack of control of the welding process, improper selection of welding materials, or improper preparation of base metal. If there are tightly adhering oxides on the base metal that interfere with fusion, overlap will often result.

Overlap is a surface discontinuity that forms a mechanical notch, and is nearly always considered rejectable.

2.10 Laminations (8) are flat, generally elongated base metal discontinuities found in the central thickness area of wrought products. Laminations may be completely internal and only detected nondestructively by ultrasonic inspections. They may also extend to an edge or end, where they are visible at the surface and may be detected by liquid penetrant or magnetic particle examination. They may be found when cutting or machining exposes internal laminations. Laminations are formed when gas voids, shrinkage cavities, or nonmetallic inclusions in the original ingot are rolled flat. They generally run parallel to the surface of rolled products and are most commonly found in shapes and plates. Some laminations are eliminated by the high temperature and pressure of the rolling operation.

Metals containing laminations often cannot be relied upon to carry tensile stress in the through-thickness direction.

2.11 Delamination (9) is the separation of a lamination under stress. The stresses may be generated by welding or may be externally applied. The separation of existing lamellar discontinuities may be found visually at the edges of pieces, or ultrasonically by testing with a straight beam search unit. A delamination discontinuity, like laminations, cannot transmit tensile loads perpendicular to the plane of delamination.

2.12 Seams and laps (10) are longitudinal base metal discontinuities that may be found in wrought products. When the discontinuity is parallel to the principal stress, it is not generally a critical defect. When seams and laps are perpendicular to the applied or residual stresses, they will often propagate as cracks. Seams and laps are surface connected discontinuities. However, their presence may be masked by manufacturing processes that have subsequently modified the surface of the mill product. Welding over seams and laps can cause cracking.

2.13 Lamellar tears (11) are terrace-like fractures in the base metal with a basic orientation parallel to the wrought surface. They are caused by the high stress in the thickness direction that results from welding.

Lamellar tearing may extend over long distances and generally initiates in regions of the base metal having a high incidence of coplanar, stringer-like, nonmetallic inclusions or in areas of the base metal subject to high welding stresses, or a combination of the two. The fracture usually propagates from one lamellar plane to another by shear along lines that are near normal to the rolled surface.

2.14 Cracks (12) occur in weld and base metal when localized stresses exceed the ultimate strength of the material. Cracking is generally associated with stress amplification near discontinuities in welds and base metal, or near mechanical notches associated with the weldment design. High residual stresses are generally present and hydrogen embrittlement is often a contributor to crack formation. Welding related cracks are generally brittle in nature, exhibiting little plastic deformation at the crack boundaries.

2.14.1 Cracks can be classified as either hot cracks or cold cracks. Hot cracks develop during solidification. Cold cracks develop after solidification is complete. Cold cracks, sometimes called delayed cracking, are commonly associated with hydrogen embrittlement. Hot cracks propagate between the grains. Cold cracks propagate both between grains and through grains.

2.14.2 Crack orientation. Cracks may be termed longitudinal (12a) or transverse (12b), depending on their orientation. When a crack is parallel to the axis of the weld it is called a longitudinal crack regardless of whether it is a centerline crack in weld metal or a toe crack in the heat-affected zone of the base metal. Transverse cracks are perpendicular to the axis of the weld. These may be limited in size and contained completely within the weld metal or they may propagate from the weld metal into the adjacent heat-affected zone and into the base metal. In some weldments, transverse cracks will form in the heat-affected zone and not in the weld.

2.14.3 Longitudinal cracks (12a) in submerged arc welds are commonly associated with high welding speeds and sometimes related to porosity problems that do not show at the surface of the weld. Longitudinal cracks in small welds between heavy sections are often the result of high cooling rates and high restraint.

2.14.4 Transverse cracks (12b) are generally the result of longitudinal shrinkage stresses acting on weld metal of low ductility.

2.14.5 Crater cracks (12c) occur in the crater when the welding arc is improperly terminated. They are sometimes referred to as star cracks, though they may have other shapes. Crater cracks are shallow, hot cracks usually forming a pronged star-like network.

2.14.6 Throat cracks (12d) are longitudinal cracks in the weld face in the direction of the axis. They are generally, but not always, hot cracks.

2.14.7 Toe cracks (12e) are generally cold cracks. They initiate and propagate from the weld toe where shinkage stresses are concentrated. Toe cracks initiate approximately normal to the base metal surface. These cracks are generally the result of thermal shrinkage stresses acting on a weld heat-affected zone. Some toe cracks occur because the transverse tensile properties of the base metal cannot accommodate the shrinkage stresses that are imposed by welding.

2.14.8 Root cracks (12f) are longitudinal cracks at the weld root or in the root surface. They may be hot or cold forms of cracks.

2.14.9 Underbead and heat-affected zone cracks (12g) are generally cold cracks that form in the heat-affected zone of the base metal. They are generally short, but they may join to form a continuous crack. Underbead cracks can become a serious problem when three elements are present (1) hydrogen, (2) a microstructure of relatively low ductility, and (3) high residual stress. Underbead and heat-affected zone cracks can be both longitudinal and transverse. They are found at regular intervals under the weld and also outline boundaries in the heat-affected zone where residual stresses are highest.

2.15 Insufficient throat (13) is a depression on the fillet weld face causing the weld throat to be below specification for that size fillet. The welder failed to obtain fusion in the base metal, or to deposit sufficient filler metal in the throat area.

2.16 Convexity and weld reinforcement (14). Convexity is the configuration present in fillet welds described as the maximum distance from the face of a convex fillet weld perpendicular to a line joining the weld toes. In groove welds, weld reinforcement is described as that new metal in excess of the quantity required to fill a joint.

2.17 Insufficient leg (15) is an undersize fillet weld leg for the welds intended use.

3. Nondestructive Inspection Methods

Nondestructive inspection (NDT) is a general term used in this guide to identify all those inspection methods that permit evaluation of welds and adjacent areas without destroying their usefulness. Most readers already know that visual inspection certainly meets this criterion, but there are other nondestructive inspection methods. The purpose of this chapter is to acquaint the welding inspector with some of the more commonly used nondestructive inspection methods and the fundamental conditions for their use.

For the purpose of this guide the following basic NDT methods will be discussed:

(1) Visual
(2) Penetrant
(3) Magnetic Particle
(4) Radiographic
(5) Ultrasonic
(6) Eddy Current

The salient features of each method are summarized in tables in the Appendix. It should be noted that nondestructive inspection does not eliminate the need for destructive testing, but rather complements it. It is not uncommon for the acceptance-rejection criteria for nondestructive inspection to be developed by destructive testing investigations correlated with NDT results. The general knowledge presented in this guide should be of valuable assistance to the reader as it provides an overview of the inspection methods without unnecessary detail.

3.1 Visual Inspection. For many types of welds, integrity is verified principally by visual inspection (VT). Even for weldments with joints specified for inspection throughout by nondestructive inspection methods, visual inspection still constitutes an important part of practical quality control. Therefore, visual inspection is of the first order of importance. The most extensively used of any method of nondestructive inspection, visual inspection is easy to apply, quick, and often requires no special equipment other than good eyesight and some relatively simple and inexpensive equipment.

Despite the many advantages of visual inspection, a major disadvantage is the need for an inspector who has considerable experience and knowledge in many different areas which encompass visual welding inspection. The inspector must be familiar with drawings, codes, specifications, weld procedure and performance qualification requirements, workmanship standards, and all aspects of good shop practice. Some codes and specifications require that the welding inspector be qualified and, at times, be certified.

Certain tools are sometimes necessary for some aspects of visual weld inspection. Various measuring scales and fillet gages are used for checking the dimensions of the weld bead. There are many different types of fillet weld gages used throughout the world to determine the size of fillet welds. Some gages also verify root opening, weld reinforcement, and weld bevel angle. Measuring devices are used to check root openings, clearance dimensions of materials, backing materials, and alignment and fit-up of the work pieces. Temperature indicators verify correct preheat temperature as well as verification of interpass temperature. Boroscopes, flashlights, and mirrors are used in areas of limited accessibility. The development of flexible fiberoptic inspection systems enables the inspector to visually inspect areas previously inaccessible to other inspection devices.

3.1.1 Visual Inspection Prior to Welding. Material examination prior to fabrication can eliminate conditions that tend to cause weld defects. Scabs, seams, and scale may be detected at this time, and plate laminations may be observed on cut edges. Other areas requiring inspection prior to welding are

(1) Proper edge preparation, dimensions, and finish
(2) Clearance dimensions of backing strips, backing rings, and consumable inserts
(3) Alignment and fit-up of work pieces

(4) Verification of correct materials by check of records
(5) Verification of cleanliness requirements and condition of tack welds
(6) Verification of welding procedure and performance qualification

3.1.2 Visual Inspection During Welding. Visual inspection continues during the fabrication process. Various items that must be checked are the following:

(1) Welding process and conditions
(2) Welding variables
(3) Filler metal
(4) Flux and protective gases
(5) Preheat and interpass temperatures
(6) Distortion control
(7) Interpass chipping, grinding, or gouging
(8) Inspection intervals (either time or sequence)

3.1.3 Visual Inspection After Welding. Post welding visual inspection is a beneficial and proven practice which includes verification of such items as:

(1) Dimensional accuracy
(2) Completion of welding
(3) Size of legs and throat of fillet welds
(4) Contour, reinforcement, and surface finish of welds
(5) Degree of underfill, undercut, and overlap
(6) Weld spatter, crater cracks, impression marking, scratches, gouges, and arc strikes
(7) Handling damage
(8) Completion of post weld heat treatment
(9) Nondestructive inspections and results

Visual welding inspection, if used before, during, and after welding, has the proven ability to eliminate most discontinuities that would otherwise appear in further nondestructive inspection or failure in service.

3.2 Penetrant Inspection. Penetrant inspection (PT) is a sensitive method of detecting and locating discontinuities, provided the discontinuities are open to the surface. The method employs a penetrating liquid dye which is applied to the surface to be inspected and which enters the discontinuity. After a suitable dwell time, the excess penetrant is removed from the surface and the part is dried. A developer is then applied which acts as a blotter, drawing the penetrant out of the discontinuity. The penetrant, drawn from an opening on the surface, indicates the presence and location of a discontinuity.

There are two varieties of the penetrant method, both using a similar principle. One variety uses a visible dye and the other uses a fluorescent dye visible with ultraviolet light. Visible penetrant is usually red in color to provide a contrast against the white background from the developer. Normal white light is usually sufficient to view the discontinuities.

Fluorescent penetrants provide a greenish yellow indication against a dark background when viewed in a darkened area under a black (ultraviolet) light source. The fluorescent method is inherently more sensitive due to the fact that the human eye can more easily discern a fluorescent indication.

There are three different penetrants used with both the visible and fluorescent methods. These are solvent removable, water washable, and post emulsifiable.

Solvent removable penetrants are designed to be removed with a solvent cleaner, with a hand-wiping technique. The solvent removable penetrant is very portable and used often for "on location" inspections.

Water washable penetrants are designed to be removed with water. This method is restricted somewhat, since it requires facilities such as water, environmental control tank, and some means of drying the article. The water washable procedure is usually used at an "inspection station" and is very efficient for small objects.

Post emulsifiable penetrants are not water soluble. They are designed to be removed with a separate emulsifier. Post emulsifiable penetrants require the same facilities as water washable penetrants. Post emulsifiable penetrants are used when detection of very minute discontinuities is desired.

Penetrant inspection is applicable to magnetic and nonmagnetic materials and is particularly useful on nonmagnetic materials, since magnetic particle inspection cannot be used. The liquid penetrant method is used extensively for disclosing surface discontinuities in materials such as aluminum, magnesium, and austenitic steel welds. It is also useful for locating cracks or other discontinuities which may cause leaks in containers and pipes.

Penetrant inspection is relatively inexpensive and reasonably rapid. The process is simple and operators find little difficulty in learning to apply it properly. There are few, if any, false or nonrelevant indications on reasonably smooth surfaces, so interpretation is somewhat easier than with magnetic particle inspection where anomalies may more frequently give false indications. The success of penetrant inspection, like most other inspection methods, depends on the visual acuity of the inspector.

It should be pointed out that some substances in penetrants can have a deleterious effect on either welds or base metals on which they are used and can effect the service life of the weld or application of the product. Penetrants are difficult to remove completely from discontinuities, and if they are corrosive to the material, or otherwise not compatible with the product application, they should be avoided.

3.3 Magnetic Particle Inspection (MT) is used for locating surface or near surface discontinuities in ferromagnetic materials. Magnetic particle inspection is based on the principles that magnetic lines of force will be distorted by a change in material continuity; i.e., a discontinuity creating a magnetic field leakage (see Fig. 11).

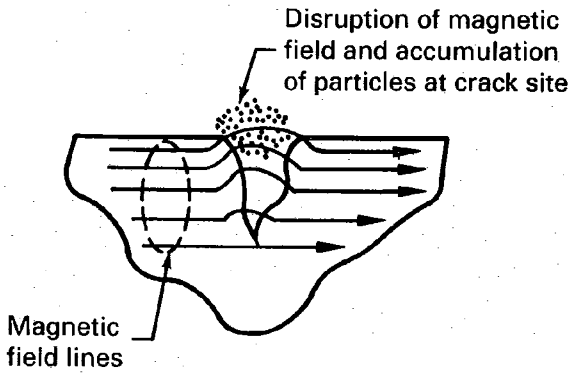


Fig. 11—Magnetic field leakage

A weld can be magnetized by passing an electric current through the weld (direct magnetization) or by placing it in a magnetic field (indirect magnetization).

The direct magnetization method (Fig. 12) is normally used with direct current (dc), half wave direct current (hwdc) or full wave direct current (fwdc). These types of currents have penetrating abilities that generally enable slightly subsurface discontinuities to be detected. Direct magnetization may also be used with alternating current (ac), which is limited to the detection of surface discontinuities only.

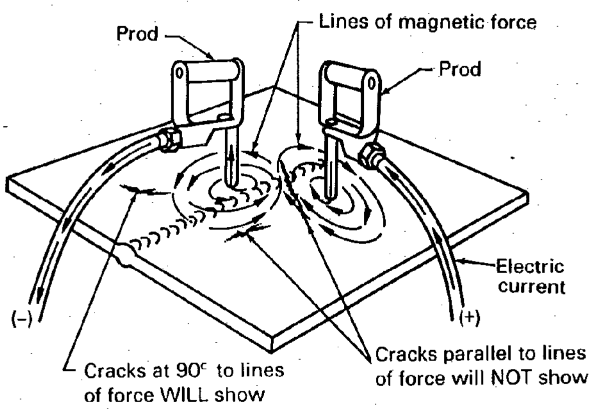


Fig. 12—Direct magnetization using dc prods

Detection of slightly subsurface discontinuities depends on several different variables—the magnetizing method, the type of current, the directions and density of the magnetic flux, and the material properties of the weld to be inspected. When evaluating surface discontinuities only, alternating current (ac) is preferred with the indirect magnetization method (Fig. 13). AC has a very low penetrating ability which allows the magnetic field to be concentrated at the surface of the weld. The alternating nature of the current provides continuous reversal of the magnetic field. This action provides greater particle mobility and, in turn, aids the detection of surface discontinuities.

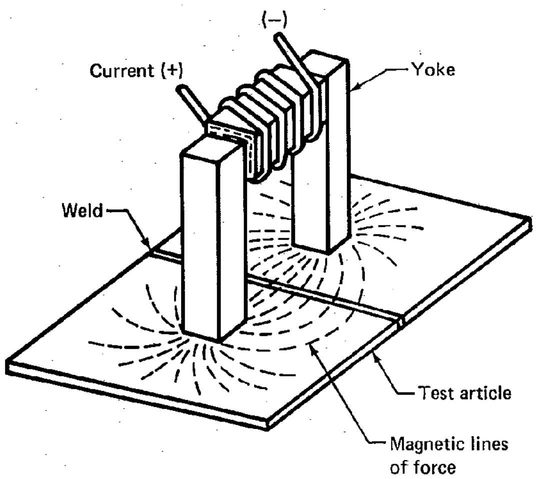


Fig. 13—Indirect magnetization using a yoke

When the magnetic field has been established within the weld, magnetic particles (medium) are applied to the inspection surface. After removal of excess particles, the residual particles trapped in the leakage field of a discontinuity reveal the location , shape and size of a detectable discontinuity. These indications usually are distinguishable by their appearance as sharp, well defined lines of medium against the background of the weld surface.

Magnetic particle inspection can be very beneficial as an in-process evaluation. Assurance of a sound weld before the weld is completed may prevent costly repairs of the final product. "In-Process" magnetic particle inspection has become more of a common practice due to the portability of modern lightweight equipment. This advantage aids in reducing production time.

The cost of magnetic particle inspection is considerably less expensive than radiography (RT) or ultrasonics (UT). Magnetic particle inspection equipment is relatively low in price compared to the equipment used with these other methods of nondestructive inspection. Less training time is generally required for personnel to become competent in performing magnetic particle inspection and evaluating discontinuities. Using the MT method, the inspector obtains an instant visible indication that can assist in removing a defect. Compared to penetrant inspection (PT), the MT method has the advantage of revealing discontinuities that are not open to the surface (i.e., cracks filled with carbon, slag or other contaminants) and therefore not detectable by penetrant inspection. Magnetic particle inspection is generally faster, requires less surface penetration and is therefore usually more economical than penetrant inspection.

The MT method is limited to ferromagnetic material. This method cannot be used to inspect nonferromagnetic materials such as aluminum, magnesium or austenitic steels. Difficulties may arise when inspecting welds where the magnetic characteristics of the weld metal differ appreciably from those of the base metal; i.e., austenitic steel surfacing weld on low carbon steel weld. Welded joints between metals of dissimilar magnetic characteristics may create magnetic particle indications even though the welds themselves are sound. Most weld surfaces are acceptable for magnetic particle inspection after the removal of slag, spatter, or other extraneous material which may mechanically hold the medium.

3.4 Radiographic Inspection. Radiography (RT) is a method of nondestructive inspection that utilizes radiation to penetrate a weld and reveal information about its internal conditions. When a weld is exposed to penetrating radiation, some radiation will be absorbed, some scattered, and some transmitted through the weld onto a recording device (see Fig. 14). Most conventional RT techniques used today involve exposures that record a permanent image on a photographic film, although other image recording methods are also used.

The basic process of radiographic inspection involves two general steps—the making of the radiograph and its interpretation.

The essential elements needed to carry out these two operations consist of:

(1) A source of radiation
(2) Weld to be radiographed
(3) An x-ray film enclosed in a lightproof film holder
(4) A skilled person capable of producing an exposed film
(5) A means of chemically processing the exposed film
(6) A skilled person capable of interpreting the radiographic images

Two types of radiation sources commonly used in weld inspection are x-ray machines and radioactive isotopes. X-radiation is produced by machines which range from portable, low energy units capable of radiographing relatively thin objects, to mammoth linear accelerators and betatrons capable of radiographing thick welds [for example — 20 in. (508.0 mm) of steel]. Gamma radiation is emitted by radioisotopes, the two most common being cobalt 60 and iridium 192. Cobalt 60 will effectively penetrate up to approximately 5 in. (127.0 mm) of steel; whereas, Iridium 192 is effectively limited to a steel thickness of about 3 in. (76.2 mm).

The weld test object is essential for obvious reasons; however, we should understand some basics about radiation interaction with the weld to fully appreciate the resultant film image. The radiographic process is dependent upon different amounts of radiation absorbed by different areas of the weld. Two key factors determine the rates of differential absorption — the amount of mass represented by the weld areas and the penetrating power (defined by the energy) of the radiation source. The amount of mass is related to the density or composition of the weld as well as the thickness. The penetrating power of the radiation source is dependent upon the instrument settings of the x-ray machine or the particular isotope selected for gamma radiography. The differences in absorption occur during the exposure process account for variations in dark and light regions on the radiograph.

Film, another obvious essential element to the radiographic process, is a thin transparent plastic base coated with fine crystals of silver bromide (emulsion). The emulsion is sensitive to radiation just as photographic film is to light. Developing (chemical processing) the film converts the image produced on the film emulsion by exposure to radiation into a visible, permanent image.

The interpretation of a radiograph involves evaluating images resulting from various light and dark regions on the film. The dark regions represent the more easily penetrated parts of the weld (for example—thin sections and most types of discontinuities) while the lighter regions represent the more difficult areas to penetrate (for example — thick sections). Interpretation is usually performed in a room of subdued background lighting by placing the radiograph in front of a relatively bright light source. The subdued background lighting reduces light reflections off the film surface which may obscure the interpreter's view of radiographic images. Figure 15 illustrates several types of weld discontinuities a film interpreter may encounter in his evaluation of weld radiographs.

A significant limitation of radiography is that discontinuities must be favorably aligned with the radiation beam to be reliably detected. This is usually not a problem for discontinuities such as porosity or slag since they are usually round in cross section and aligned with a beam from any direction. This is not the case with planet discontinuities such as cracks, incomplete fusion, and laminations. These discontinuities, or a substantial portion of

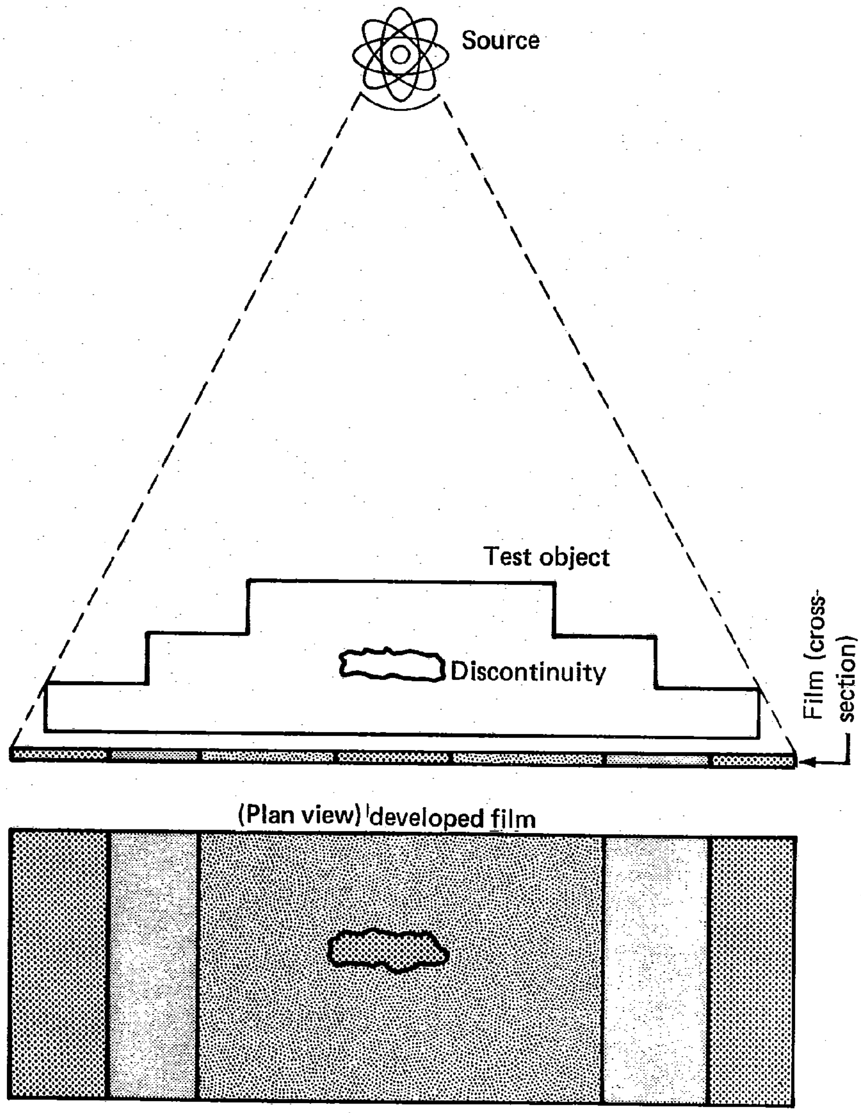


Fig. 14—Making a radiograph

them, must be favorably aligned with the radiation beam to be reliably detected by the interpreter. Figure 16 illustrates this limitation.

Radiography also has several other limitations:

(1) It presents a potential radiation hazard to personnel.

(2) The cost of radiographic equipment, facilities, safety programs, and related licensing is relatively high.

(3) there is usually a relatively long time between the exposure process and the availability of results.

(4) Accessibility to both sides of the weld is required to set-up apparatus.

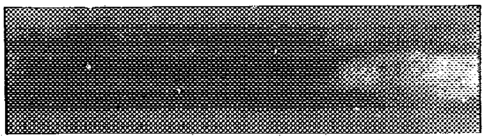
Compared to other nondestructive inspection methods, radiography has the following advantages:

(1) It is generally not restricted by the type of material or grain structure.

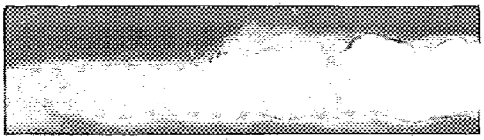
(2) It has surface and subsurface inspection capability.

(3) Radiographic images aid in characterizing (identifying type) discontinuities.

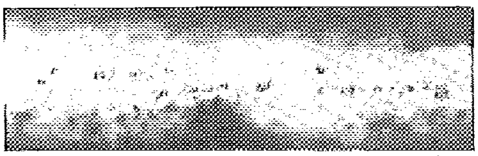
(4) It provides a permanent record for future review.



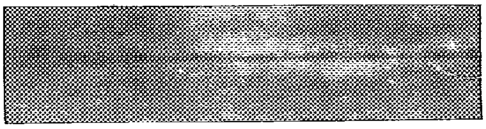
a. Slag Inclusions are usually indicated by elongated shadows of irregular shape, occurring singly, in a linear distribution, or scattered randomly.



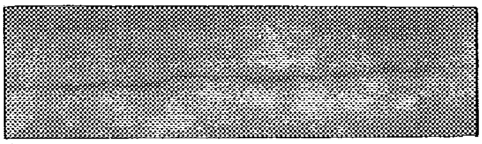
b. Undercutting appears as a dark linear shadow of wavy contour occurring adjacent to the weld toe. This discontinuity is usually detected visually, but its correct identification on the radiograph is needed to prevent misinterpretation as another type of internal discontinuity.



c. Porosity is shown as rounded shadows of varying size and density, occurring singly, in clusters, or randomly scattered.



d. Incomplete penetration is usually indicated as a straight, dark, continuous or intermittent line, near the center of the weld.



e. Cracks usually appear as fine, dark lines, which may be straight or wandering.

Fig. 15—Typical radiographs of weld discontinuities

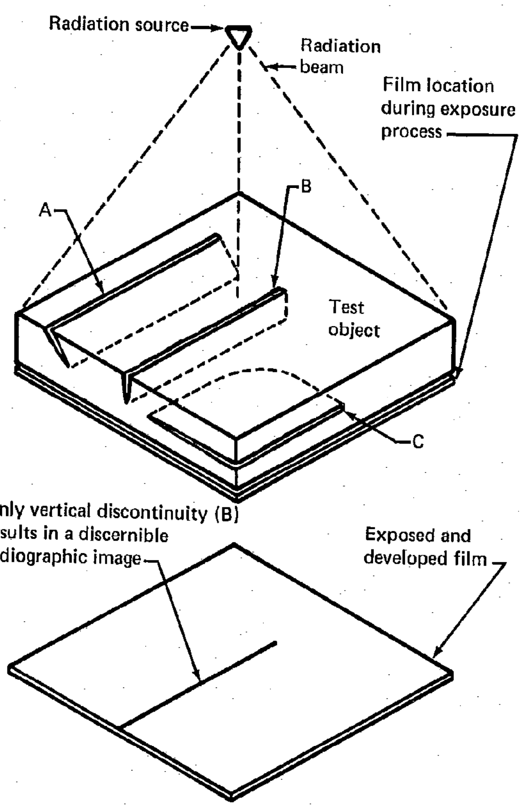


Fig. 16—Detection of planar defects at various orientations by radiography

The references of Section 5 provide additional information on industrial radiography.

3.5 Ultrasonic Inspection. Ultrasonic inspection (UT) is becoming one of the most widely used methods of nondestructive inspection. Its primary application is the detection and characterization of internal discontinuities. It is also used to detect surface discontinuities, to define bond characteristics, and to measure thickness. The pulse-echo method with A-scan data presentation is most commonly used for inspecting welds. This system utilizes a cathode ray tube (CRT) screen to display test information. The basic components of the pulse-echo method are shown in block diagram form in Fig. 17.

High-frequency sound waves are introduced into the material being inspected to detect surface and subsurface discontinuities. The sound waves travel through the material with some loss of energy (attenuation) and are reflected at interfaces. The reflected sound beam is detected and analyzed to define the presence and location of discontinuities.

In many respects, a beam of ultrasound is similar to a beam of light; both are waves and obey a general wave equation. Each travels at a characteristic velocity in a given homogeneous medium — a velocity that depends on the properties of the medium and the vibrational move of the wave. Like beams of light, ultrasonic beams are reflected from surfaces (Fig. 18); refracted when they cross a boundary between two substances that have different characteristic sound velocities (Fig. 19); and diffracted at edges or around obstacles (Fig. 20). Scattering by rough surfaces, particles, or coarse grains reduces the energy of an ultrasonic beam, similar to the manner in which scattering reduces the intensity of a light beam.

Ultrasonic inspection is usually performed with either longitudinal waves (straight beam) or shear waves (angle beam). The most commonly used frequencies are between 1 and 5 MHz, with sound beams at angles of 0°, 45°, 60°, and 70°.

In longitudinal beam testing (commonly used to inspect plate base material), sound in the form of ultrasonic vibrations is projected into the part perpendicular to the entry

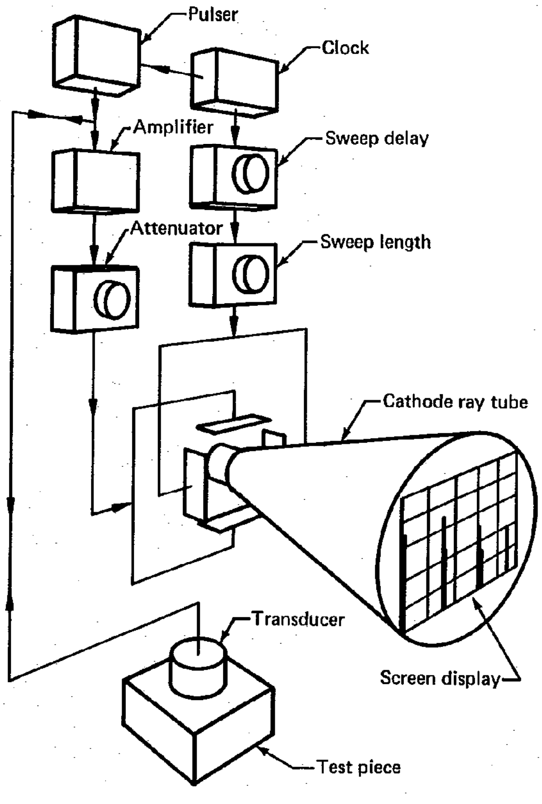
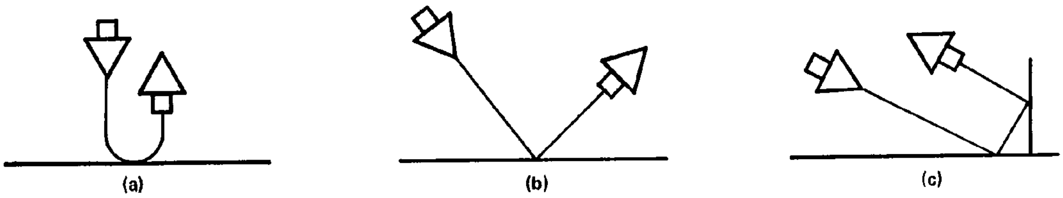


Fig. 17—Block diagram, pulse-echo flaw detector



(a) normal incidence (b) angle incidence (c) corner incidence

Fig. 18—Similarities between reflections of light and sound at boundaries

surface by a straight beam search unit (see Fig. 21). When the entry surface and the back surface are parallel, a back reflection will appear on the CRT. A discontinuity lying between the front and back surfaces will also be displayed on the CRT. By using the height of the reflection on the CRT, from a real or artificial discontinuity of a known size, a reference level can be established such that reflections from discontinuities of unknown sizes may be evaluated as to approximate size, length, and depth.

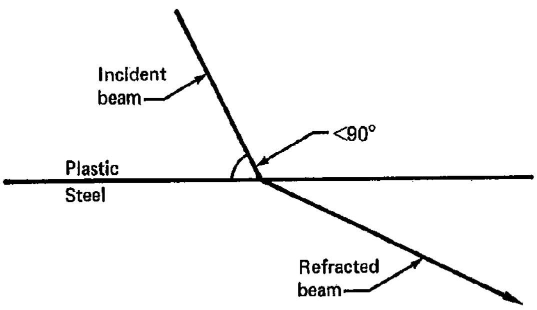


Fig. 19—Refraction

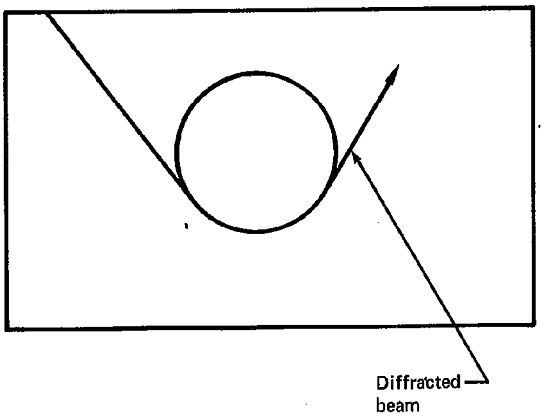


Fig. 20—Diffraction

Most weld inspection is performed using the angle beam technique (Fig. 22). Ideally, only discontinuities should appear on the CRT during angle beam inspection (Fig. 23). This is not the case, however, since the geometrical boundaries of the part being inspected often reflect sound back just as a discontinuity would. Therefore, care should be taken when ultrasonically inspecting joints with complex geometrics (such as welds with backing bars) to assure that ultrasonic indications are the result of the presence of discontinuities and not simply due to the configuration of the joint (Fig. 24). Figure 24 illustrates a true discontinuity (slag inclusion) masked by a false indication from the backing bar; however, this discontinuity can be evaluated by inspecting from the opposite side of the weld.

It is generally desirable that the sound beam intercept the plane of the discontinuity at or near 90 degrees so that a maximum reflected signal returns to the transducer. However, cracks that are not oriented perpendicular to the ultrasonic beam can be detected because their surfaces are not smooth and sound is reflected from the facets that are approximately perpendicular to the beam. The test surface used for scanning with the search unit is selected primarily on the basis of weld shape and structure, and often by the accessibility for testing. The scan pattern must be sufficient to pass the projected sound beam through the entire volume of weld and heat-affected zone to permit detection of possible discontinuities. This accounts for the wide variety of different angle search units available. In special cases, search units are made to particular nonstandard angles.

Since it is important to intercept the discontinuity at or near 90 degrees, it is common for more than one angle search unit to be used to inspect a particular weld. AWS D1.1 currently designates specific angles to be used for particular thicknesses and joint configurations.

The principal advantages of ultrasonic inspection, as compared to other methods of nondestructive inspection of metal parts are

(1) Superior penetrating power allows the detection of discontinuities deep in the part.

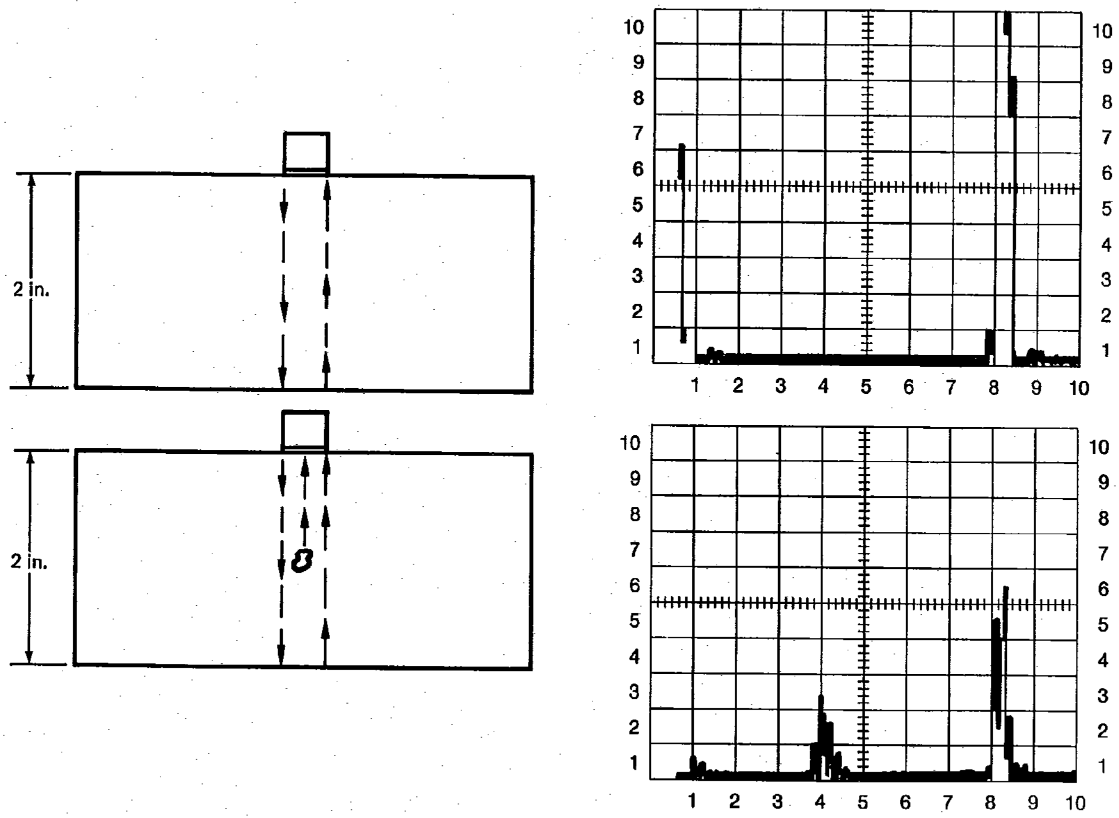


Fig. 21—Example of longitudinal testing

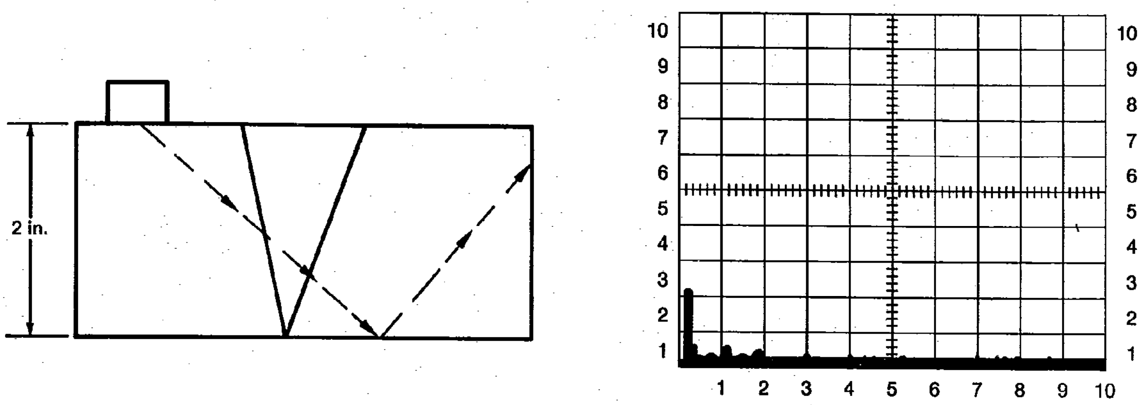


Fig. 22—No discontinuities

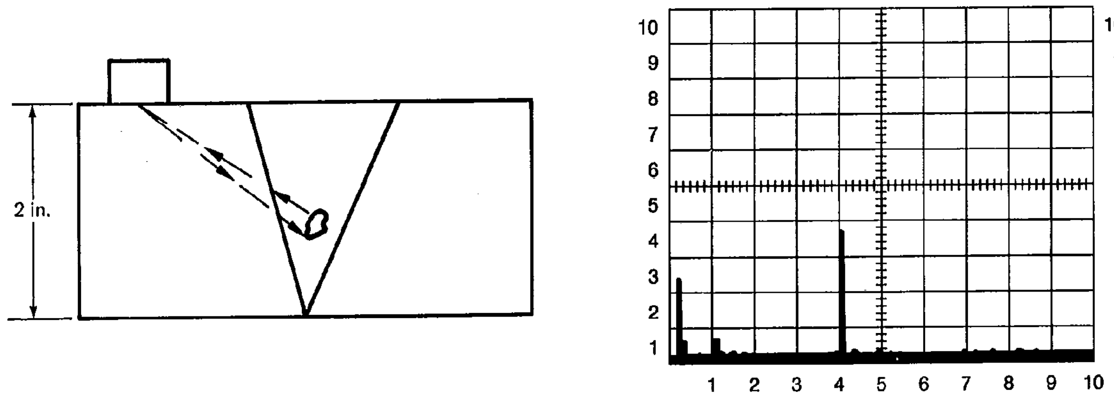


Fig. 23—Discontinuity

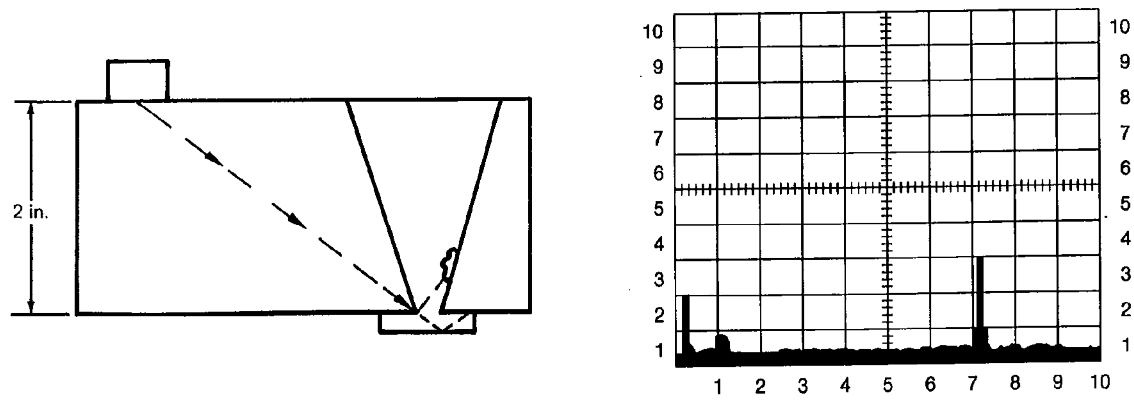


Fig. 24—Incomplete fusion of backing bar

(2) High sensitivity permits the detection of very small discontinuities.

(3) Greater accuracy in determining the position of internal discontinuities, estimating their size and characterizing their orientation, shape and nature.

(4) Only one surface need be accessible.

(5) Operation is electronic, which provides almost instantaneous indications of discontinuities. This makes the method suitable for immediate interpretation, automation, rapid scanning, production line monitoring and process control. With some systems, a permanent record of inspection results can be made for future reference.

(6) Scanning ability enables inspection of a volume of metal extending from front surface to back surface of a weld.

Some disadvantages of ultrasonic inspection include:

(1) Manual operation requires careful attention by experienced technicians.

(2) Extensive technical knowledge is required for the development of inspection procedures.

(3) Parts that are rough, irregular in shape, very small or thin, or inhomogeneous are difficult to inspect.

(4) Discontinuities that are present in a shallow layer immediately beneath the surface may not be detectable.

(5) Couplants are needed to provide effective transfer of ultrasonic-wave energy between search units and parts being inspected.

(6) Reference standards are needed for calibrating the equipment.

3.6 Eddy Current Inspection. Eddy current inspection (ET) can be defined as an electromagnetic nondestructive inspection method in which small electrical currents are induced in a material, and any changes in the flow of these currents due to inhomogeneities in the material are detected by a nearby coil for subsequent electronic processing and presentation. Its use for surface, and in some cases subsurface, inspection of welds for discontinuities (see Fig. 25) is only one of many applications. Eddy current techniques have also been successfully applied to measure conductivity, grain size, hardness, and thickness; identifying materials with different composition, microstructure, magnetic permeability, and heat treatment; and determining the thickness of coatings and plating on various materials.

In eddy current inspections, an alternating current is passed through a coil place in the proximity of the weld. The changing current in the coil creates an alternating magnetic field in the material. The varying magnetic field in the weld, in turn, creates electrical currents, or "eddy" currents, in the material. These eddy currents, which vary with the magnetic field, create their own magnetic field which interacts with the initial field. The test coil, or in some cases a separate "pickup" coil, is electronically monitored to detect any changes in this field interaction. Discontinuities in the weld will alter the magnitude and direction of the eddy currents and thus be detected through the test signal. The signal is then displayed on an analog meter, digital meter, cathode ray tube (CRT), X-Y plotter, or strip chart recorder depending on the particular equipment and application.

The most common eddy current coils used for weld inspection are shown in Figs. 26 and 27. Figure 26 shows an encircling coil which is used primarily on welded pipe with a longitudinal butt joint. Since the eddy currents flow in a circumferential direction, longitudinal discontinuities would produce the most significant change in eddy current flow. Hence, this technique would be most sensitive to longitudinally oriented discontinuities. The pipe is usually passed through the coil on rollers, which makes the technique suitable for automation. Figure 27 shows several types of surface probes commonly used. These probes can be used on welds in any position and are usually hand manipulated.

Their size, windings, and core (if any) vary with the type of material, orientation of discontinuities of interest, and size of the smallest discontinuity of interest.

Several advantages of using eddy current inspection on welds include:

(1) The equipment used with surface probes is generally lightweight and portable (see Fig. 25).

(2) Some weld surface conditions, such as excessive roughness and minor undercut, may result in nonrelevant indications. Welds with such conditions can usually be inspected by eddy current techniques without the need to verify the indication's relevance by further processing (i.e., grinding to remove the surface irregularity and retesting).

(3) Since intimate contact between the weld metal and probe is not required, painted or coated welds can be inspected. This can result in significant savings in the

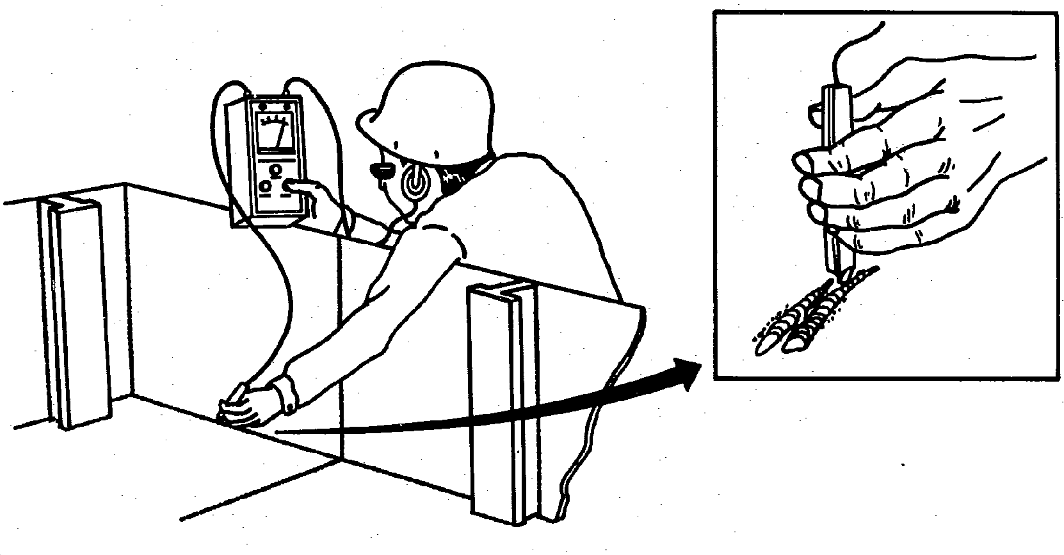


Fig. 25—Eddy current weld inspection

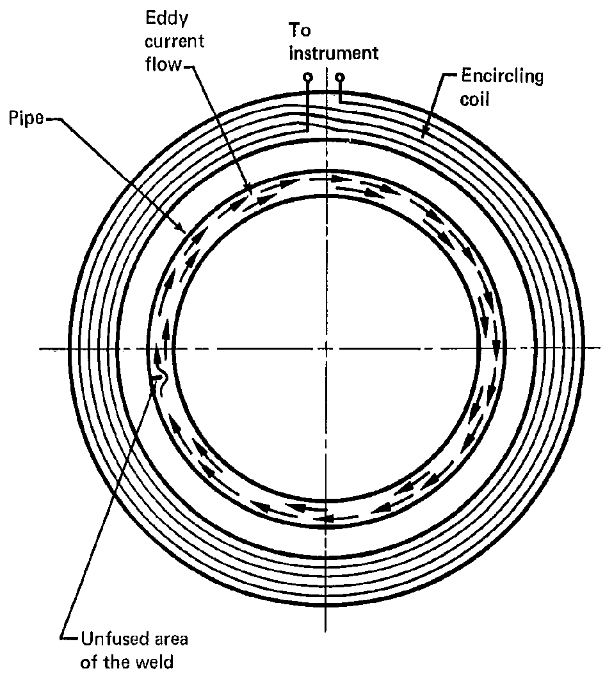


Fig. 26—Encircling coil for the eddy current inspection of welded pipe

areas of in-service inspections and periodic preventive maintenance inspections.

(4) In some instances, such as the inspection of welded pipe, the inspections can be partially or completely automated for a high speed, relatively inexpensive inspection.

There are three general limitations in using eddy current inspection on welds:

(1) The test article (i.e., weld) must be an electrical conductor. (This document addresses only conductive materials.)

(2) The depth of inspection is generally limited to 1/4 in. (6.4 mm) for nonferromagnetic materials and 0.010 in. (.25 mm) for ferromagnetic materials. The penetration in ferromagnetic materials may be significantly increased by using special techniques such as magnetic saturation of the area being inspected.

(3) Since many variables can affect an eddy current signal (i.e., permeability, conductivity, probe position and weld contour), care must be taken to suppress or separate variables of no concern from those of interest. In many cases, this is not readily accomplished.

4. Interrelationships Among Welding Processes, Discontinuities, and Inspection Methods

This section includes several tables indicating particular relationships existing between welding processes, discontinuities, and inspection methods. This information is provided as a reference only and should not be considered applicable for every specific inspection situation.

Many factors which are beyond the scope of this guide affect these relationships. For example, Table 2 lists the discontinuities for each welding process that may occur under varying conditions and with many combinations of filler and base metals. When specific welding variables are controlled, depending on the type of filler and base metals, some of the discontinuities would not be expected to form.

Table 3 relates inspection methods to the various types of discontinuities. Other factors also must be considered before the inspection method may be reliably chosen for consistent results. For example, the shape of the weld, the compatibility of the material with the inspection method, and the welding process all affect the choice of an inspection method.

Table 4 relates joint types to applicable nondestructive inspection methods. Again, further information is necessary before a preferred method can be chosen. Material type and shape, welding process, criticality level of the weldment, and unacceptable discontinuity types must be considered in selecting the most suitable method of inspection.

One should not attempt to draw conclusions by comparing one table to another. Each table stands by itself and is only provided as a general guide. If information beyond that presented by this document is needed, the supplementary reading material given in section 5 should be reviewed, or a competent nondestructive inspection consultant should be contacted.

Further information on the applicability of several of the nondestructive inspection methods may be found in the Appendix.

5. Supplementary Reading Material

(1) Betz, C. E., *Principles of Penetrants,* Chicago, IL: Magnaflux Corp. — *Principles of Magnetic Particle Testing,* Chicago, IL: Magnaflux Corp.

(2) Krautkramer, J., and H. Krautkramer, *Ultrasonic Testing of Materials,* New York, NY: Springer-Verlag, Inc.

(3) Libby, H. L., *Introduction to Electromagnetic Nondestructive Test Methods,* New York, NY: Wiley-Interscience.

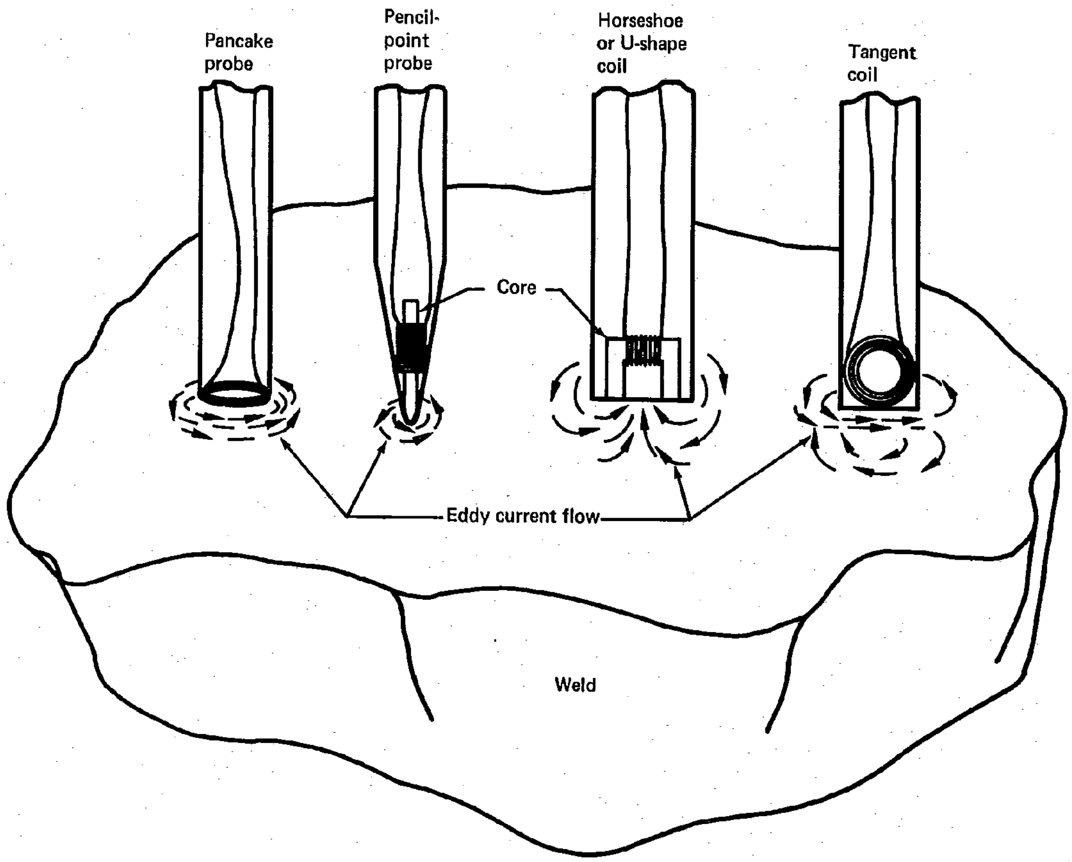


Fig. 27—Typical eddy current surface coils for the inspection of welds

(4) McGonnagle, W. J., *Nondestructive Testing*, New York, NY: McGraw-Hill Book Company, Inc.

(5) McMaster, Robert C. Ed., *Nondestructive Testing Handbook*, 2nd Ed., Columbus, OH: The American Society for Nondestructive Testing.

(6) *Nondestructive Inspection and Quality Control*, 8th Ed., ASM Metals Handbook, Vol. 11, Metals Park, OH: American Society for Metals.

(7) *Nondestructive Testing Training Handbook Series*, San Diego, CA: General Dynamics/Convair Division. [Programmed instruction (self study) and classroom training (reference texts) available for liquid penetrant, magnetic particle, ultrasonic, eddy current, and radiographic testing methods.]

(8) *Radiography in Modern Industry*, 4th Ed., Rochester, NY: Eastman Kodak Co.

(9) Richardson, H. D., *Industrial Radiography Manual*, Washington, D.C.: Government 1968. Reprinted 1979 by The American Society for Nondestructive Testing.

(10) *Standard Terminology and Definitions for Weld Conditions and Defects*, NAVSHIPS 250-634-7.

(11) *Symbols for Welding and Nondestructive Testing*, ANSI/AWS A2.4-79, Miami, FL: American Welding Society.

(12) *Welding Handbook*, 7th Ed., Vol. 1, Miami, FL: American Welding Society.

(13) *Welding Inspection*, 2nd Ed., Miami, FL: American Welding Society.

(14) *Welding Terms and Definitions*, ANSI/AWS A3.0-85, Miami, FL: American Welding Society.

Table 3
Applicable inspection methods vs. discontinuities

Discontinuities	Applicable inspection methods					
	RT	UT	PT	MT	VT	ET
Porosity	A	O	A[a]	O[b]	A[a]	O
Slag inclusions	A	A	U	O[b]	U	O
Incomplete fusion	O	A	U	O[b]	U	O
Incomplete penetration	A	A	U	O	U	O
Undercut	A	O	O	O	A	O
Overlap	U	O	A	A	O	O
Cracks	O	A	A[a]	A[b]	A[a]	A
Laminations	U	A	A[a,c]	A[b,c]	A[a,c]	U

Notes:
a. Surface
b. Surface and slightly subsurface
c. Weld preparation or edge of base metal

Legends:
RT—Radiographic testing
UT—Ultrasonic testing
PT—Penetrant testing, including both DPT (dye penetrant testing) and FPT (fluorescent penetrant testing)
MT—Magnetic particle testing
VT—Visual testing
ET—Eddy current testing

A—Applicable Method
O—Marginal applicability depending on other factors such as material thickness, discontinuity size, orientation and location

Table 4
Applicable inspection methods—four weld joint types

Joints	Inspection methods					
	RT	UT	PT	MT	VT	ET
Butt	A	A	A	A	A	A
Corner	O	A	A	A	A	O
T	O	A	A	A	A	O
Lap	O	O	A	A	A	O

Legends:
RT—Radiographic testing
UT—Ultrasonic testing
PT—Penetrant testing, including both DPT (dye penetrant testing) and FPT (fluorescent penetrant testing)
MT—Magnetic particle testing
VT—Visual testing
ET—Eddy Current testing

A—Applicable Method
O—Marginal applicability depending on other factors such as material thickness, discontinuity size, orientation and location

Appendix A

NDI Selection Guide

Equipment Needs	Applications	Advantages	Limitations
Visual			
Magnifiers, color enhancement, projectors, other measurement equipment, i.e., rulers, micrometers, optical comparators, light source.	Welds which have discontinuities on the surface.	Economical, expedient, requires relatively little training and relatively little equipment for many applications.	Limited to external or surface conditions only. Limited to the visual acuity of the observer or inspector.
Liquid Penetrant			
Fluorescent or dye penetrant, developers, cleaners (solvents, emulsifiers, etc.). Suitable cleaning gear. Ultraviolet light source if fluorescent dye is used.	Weld discontinuities open to surface, i.e., cracks, porosity.	Portable, relatively inexpensive equipment. Expedient inspection results. Results are easily interpreted. Requires no electrical energy except for light sources.	Surface films such as coatings, scale, smeared metal mask or hide rejectable defects. Seepage from weld porosity at the surface can also mask indications. Parts must be cleaned before and after inspection.
Magnetic Particle			
Prods, yokes, coils suitable for inducing magnetism into the weld. Power source (electrical). Magnetic powders. — some applications require special facilities and ultraviolet lights.	Most weld discontinuities open to the surface — some large voids slightly subsurface. Most suitable for cracks.	Relatively economical and expedient. Inspection equipment is considered portable. Unlike dye penetrants, magnetic particle can detect some discontinuities slightly below the surface.	Applicable only to ferromagnetic materials. Parts must be cleaned before and after inspection. Thick coatings may mask rejectable discontinuities. Some applications require parts to be demagnetized after inspection. Magnetic particle inspection requires use of electrical energy for most applications.
Radiography (Gamma)			
Gamma ray sources, gamma ray camera projectors, film holders, film, lead screens, film processing equipment, film viewers, exposure facilities, radiation monitoring equipment.	Welds which have voluminous discontinuities such as porosity, incomplete joint penetration, corrosion, etc. Lamellar type discontinuities such as cracks and incomplete fusion can be detected with a lesser degree of reliability. May also be used in certain applications to evaluate dimensional requirements such as fit-up, root conditions, and wall thickness.	Generally not restricted by type of material or grain structure. Surface and subsurface inspection capability. Radiographic images aid in characterizing discontinuities. Provides a permanent record for future review.	Planar discontinuities must be favorably aligned with radiation beam to be reliably detected. Radiation poses a potential hazard to personnel. Cost of radiographic equipment, facilities, safety programs, and related licensing is relatively high. A relatively long time between exposure process and availability of results. Accessibility to both sides of the weld required.
Radiography (X-Rays)			
X-ray sources (machines), electrical power source, same general equipment as used with gamma sources (above).	Same application as above.	Adjustable energy levels. Generally produces higher quality radiographs than gamma sources. Also, same advantages as above.	High initial cost of X-ray equipment. Not generally considered portable. Also, same limitations as above.
Ultrasonic			
Pulse-echo instrument capable of exciting a piezoelectric material and generating ultrasonic energy within a weld, and a suitable cathode ray tube scope capable of displaying the magnitudes of received sound energy. Calibration standards, liquid couplant.	Most weld discontinuities including cracks, slag, and incomplete fusion. Can also be used to verify weld thickness.	Most sensitive to planar type discontinuities. Test results known immediately. Portable. Most ultrasonic flaw detectors do not require an electrical power outlet. High penetration capability.	Surface condition must be suitable for coupling of transducer. Couplant (liquid) required. Small, thin welds may be difficult to inspect. Reference standards are required. Requires a relatively skilled operator or inspector.
Eddy Current			
An instrument capable of inducing electromagnetic fields within a weld and sensing the resulting electrical currents (eddy) so induced with a suitable probe or detector. Calibration standards.	Weld discontinuties open to the surface, (i.e. cracks, porosity, incomplete fusion) as well as some subsurface discontinuities. Alloy content, heat treatment variations.	Equipment used with surface probes is generally lightweight and portable. Painted or coated welds can be inspected. Can be partially or completely automated for a high speed, relatively inexpensive test.	Relatively shallow depth of inspection. Many material and test variables can affect the test signal.

Appendix B
NDI Symbols and Abbreviations

B1. Basic Symbols

B1.1 Basic Testing Symbols. Basic nondestructive testing (NDT) symbols should be as follows:

Type of Test	Symbols
Acoustic emission	AET
Eddy current	ET
Leak	LT
Magnetic particle	MT
Neutron radiographic	NRT
Penetrant	PT
Proof	PRT
Radiographic	RT
Ultrasonic	UT
Visual	VT

B1.2 Elements of the Testing Symbol. The testing symbol consists of the following elements:

- Reference line
  - — Arrow
  - — Basic testing symbol
  - — Test-all-around symbol
  - — (N) Number of tests
  - — Test in field
- Tail

  Specification or other reference

B1.3 Standard Location of Elements. The elements of a testing symbol should have standard locations with respect to each other as shown in Fig. B1.

B2. General Provisions

B2.1 Location Significance of Arrow. The arrow should connect the reference line to the part to be tested. The side of the part to which the arrow points should be considered the arrow side of the part. The side opposite the arrow side of the part should be considered the other side.

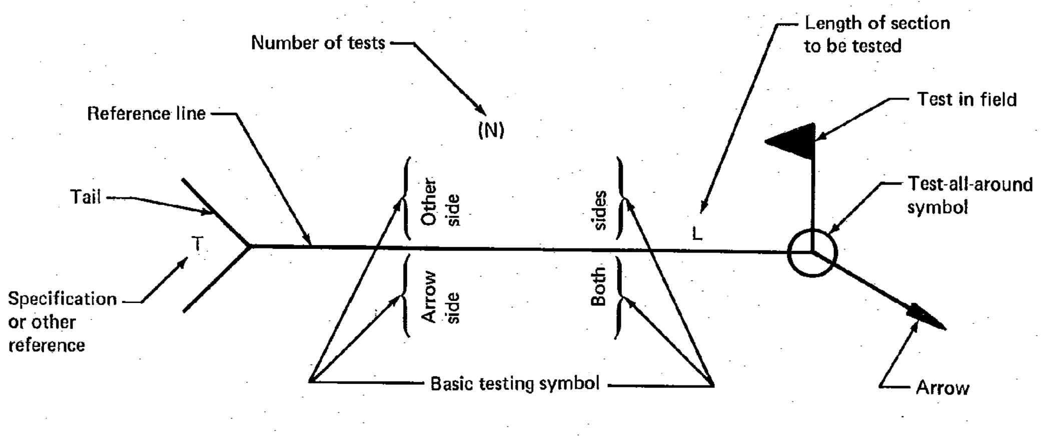
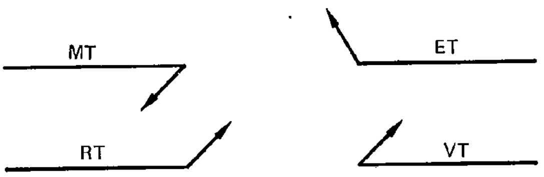


Fig. B1—Standard location of elements

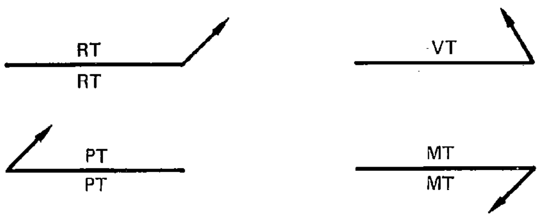
B2.2 Location of Testing Symbol

B2.2.1 Arrow Side Location. Tests to be made on the arrow side of the part should be indicated by a test symbol placed below the reference line.

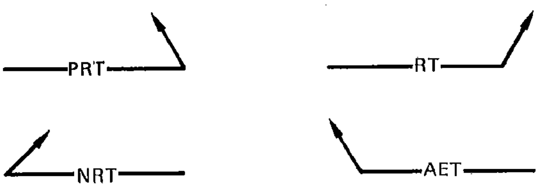
B2.2.2 Other Side Location. Tests to be made on the other side of the part should be indicated by a test symbol placed above the reference line away from the reader.



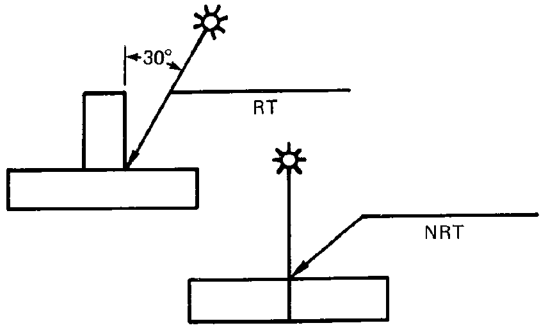
B2.2.3 Symbols on Both Sides. Tests to be made on both sides of the part should be indicated by test symbols placed above and below the reference line.



B2.2.4 Centered Symbols. When nondestructive testing symbols have no arrow or other side significance, the testing symbols should be centered on the reference line.

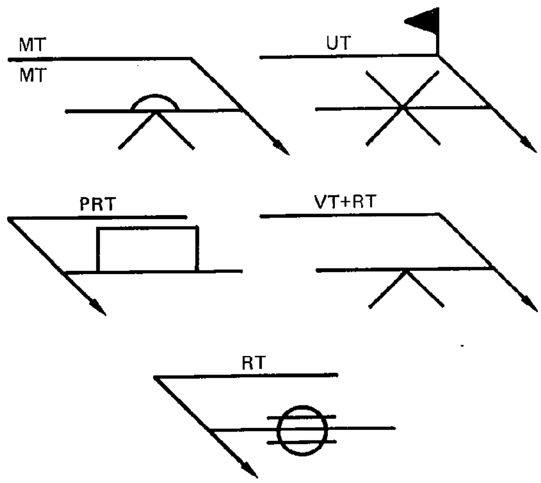


B2.3 Direction of Radiation. When specified, the direction of radiation may be shown in conjunction with the radiographic and neutron radiographic testing symbols. The direction of radiation may be indicated by a symbol located on the drawing at the desired angle.

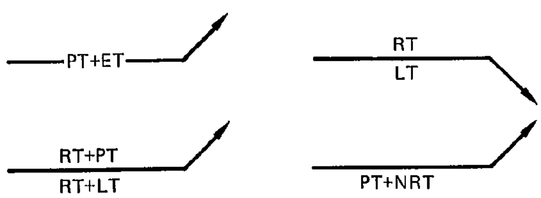


B2.4 Combination of Nondestructive Testing Symbols and Welding Symbols

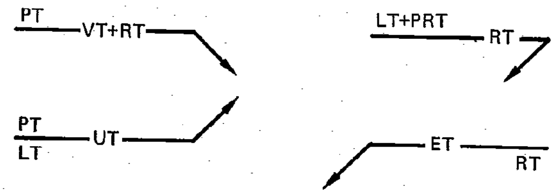
B2.4.1 Welding and NDT Symbols. Nondestructive testing symbols and welding symbols may be combined.



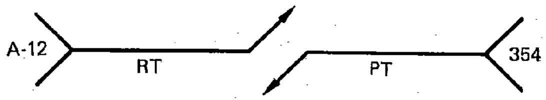
B2.4.2 Symbols Alone. Nondestructive testing symbols may be combined.



B2.4.3 Arrow Side Significance. In cases where a nondestructive testing symbol having no arrow or other side significance is combined with a symbol having such significance, the testing symbols may be combined.



B2.5 Use of References. Specifications or other references need not be used on testing symbols when the examination procedure is prescribed elsewhere. When a specification or other reference is used with a testing symbol, the reference should be placed in the tail.

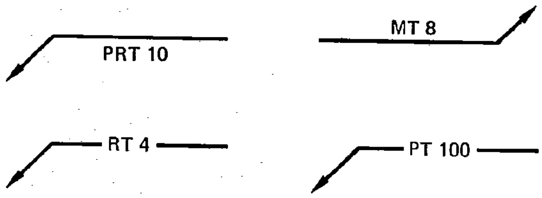


B3. Methods of Specifying Extent of Nondestructive Examination

B3.1 U.S. Customary and Metric Units. When it is necessary to show dimensions with nondestructive testing symbols, the same system of units that is the standard for drawings shall be used. Dual units should not be used on testing symbols. If it is desired to show conversions from metric to US customary or vice versa, a table of conversions may be included on the drawing. For guidance in drafting standards, reference is made to the ANSI Y14 Drafting Manual. For guidance on the use of metric (SI) units, reference is made to AWS A2.3, *Metric Practice Guide for the Welding Industry,* latest edition.

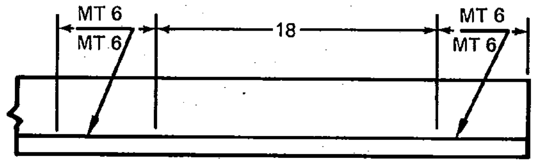
B3.2 Specifying Length of Section to be Tested

B3.2.1 Length Shown. To specify tests of welds on parts where only the length of a section need be considered, the length should be shown to the right of the basic test symbol.



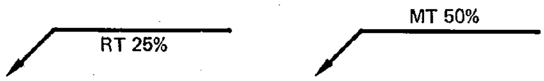
Dimensions in mm

B3.2.2 Location Shown. To show the exact location of a section to be tested as well as its length, dimension lines should be used.

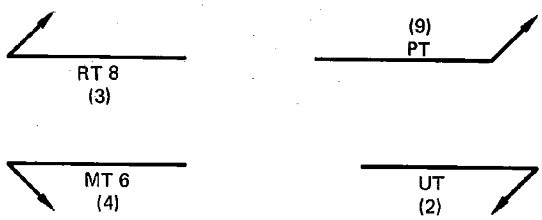


B3.2.3 Test of Full Length. When the full length of a part is to be tested, no length dimension need be shown on the testing symbol.

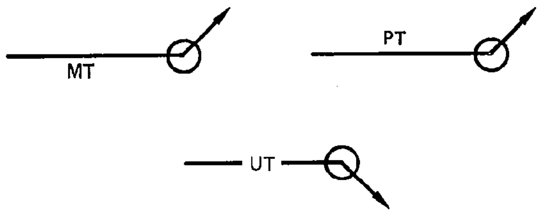
B3.2.4 Partial Testing. When less than 100 percent of the length of a weld or part is to be tested with locations to be selected by a specified procedure, the percentage of the length to be tested is indicated.



B3.3 Specifying Number of Tests. To specify a number of tests to be taken on a joint or part at random locations, the number of desired tests should be shown in parentheses.

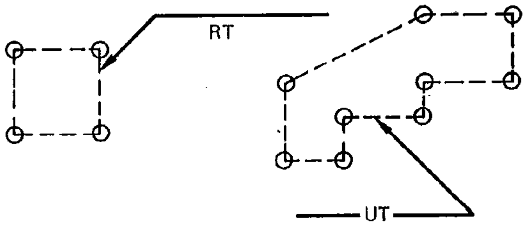


B3.4 Specifying Tests Made All Around A Joint. To specify tests to be made all around a joint, the test-all-around symbol shall be used.

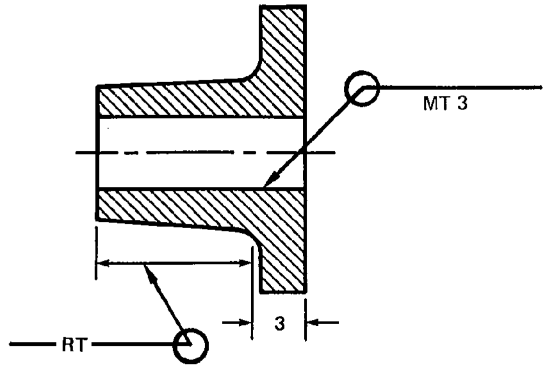


B3.5 Specifying Examination of Parts (Areas). When required, nondestructive examination of parts (areas) should be indicated by one of the following methods:

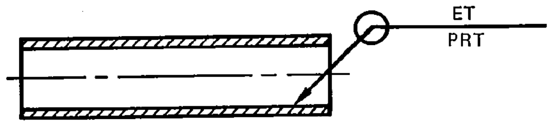
B3.5.1 Plane Areas. For nondestructive examination of an area represented as a plane on the drawing, the area to be examined should be enclosed by straight broken lines having a circle at each change of direction. The testing symbol specifying the kind of nondestructive test should be used in connection with these lines as shown below. When necessary, these enclosures should be located by coordinate dimensions.



B3.5.2 Areas of Revolution. For nondestructive testing areas of revolution, the area should be indicated by using the test-all-around symbol and appropriate dimensions. On the drawing below, the upper symbol indicates that the bore of the flange is to be subjected to a magnetic particle examination for a distance of three inches from the face, all the way around. The lower symbol indicates an area of revolution to be subjected to radiographic examination where dimensions are not available on drawing.



The symbols below indicate an area of revolution subject to an internal proof test and an external eddy current test. Since no dimensions are given, the entire length is to be tested.



B3.6 Acoustic Emission. Acoustic emission is generally applied to all or a large portion of a component, such as a pressure vessel or pipe. The symbol indicates application of AET to the component without specific reference to location of sensors. Arrows are not used and there is no significance to top of bottom replacement of the NDT symbol.