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Guide for the Visual Examination of Welds

American Welding Society

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Guide for the Visual Examination of Welds

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Prepared by
AWS Committee on Methods of Inspection

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This guide contains information to assist in the visual examination of welds. Included are sections on prerequisites, fundamentals, surface conditions, and equipment. Sketches and full-color photographs illustrate weld discontinuities commonly found in welds.

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Foreword

(This Foreword is not a part of AWS B1.11:2000, *Guide for the Visual Examination of Welds*, but is included for information purposes only.)

Visual examination (VT), as used in this guide, is a nondestructive method whereby a weldment, the related base metal, and particular phases of welding may be evaluated in accordance with applicable requirements. All visual examination methods require the use of eyesight to evaluate the conditions which are present; hence, the term *visual* examination.

The use of gauges and other tools is supplemental to the main method, and these are treated only as adjuncts to visual examination of weldments.

The Guide for the Visual Examination of Welds has been prepared by the AWS Committee on Methods of Inspection to serve as a simple tutorial source of basic information concerning visual examination of welds. It is not the intent of this document to present the *only* approved methods for conducting visual examination. Some typical standards are listed in this document. It is intended that the material presented be useful to engineers, designers, educators, inspectors, and other welding personnel who need knowledge about basic visual examination attributes, which would be essential, or desirable, for a particular process. Included in this guide are fundamental prerequisites for performing visual examination, steps in performing visual examination at various stages of welding, and also typical examples of visual examination, discontinuities and conditions, equipment supplements and aids, records, and other reference sources which may be helpful. Terminology used throughout this guide has been established in AWS A3.0, *Standard Welding Terms and Definitions.*

This guide is intended as an instructive reference. The codes or specifications applicable to any particular weldment always take precedence over the generalized material contained herein, should any conflict arise between the two. The text has been written in general terms and does not include all the conditions applicable to a specific instance. Examples given are general and are used only for the purpose of illustration.

This material can be used as a training text for inspectors. Although the information generally relates to the arc welding processes, most of it applies to weldments fabricated by other fusion welding processes, for which these methods may be required.

For the examination of resistance welded assemblies, refer to AWS C1.1, *Recommended Practices for Resistance Welding, AWS C1.3, Recommended Practices for Resistance Welding Coated Low Carbon Steels*, and AWS D8.7, *Recommended Practices for Automotive Weld Quality—Resistance Spot Welding*, published by the American Welding Society.

For the examination of brazed assemblies, refer to the *Brazing Handbook*, also published by the American Welding Society.

For those who need more detailed information than this guide provides, bibliographies or complete books on the subjects covered in each chapter may be found in good technical libraries. The many specifications and codes that are listed, and have been used as illustrative examples, may also be consulted for more detailed information.

Basic information on other nondestructive examination methods is contained in AWS B1.10, *Guide for Nondestructive Examination of Welds*, and in the AWS book, *Welding Inspection*.

Comments and inquiries concerning this standard are welcome. They should be sent to the Secretary, B1 Committee on Methods of Inspection, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Guide for the Visual Examination of Welds

1. General

1.1 Application. Information contained in this guide applies to the general duties and responsibilities of visual inspectors of weldments and is useful to them in carrying out their duties and responsibilities defined in particular codes or specifications. This document is primarily intended for those who are responsible for the final acceptance of weldments. However all welders, supervisors, technicians, and engineers who are required to routinely inspect work performed by them or under their authority will benefit from the use of this document. This document will provide general guidelines for the visual examination of weldments.

The inspector should be knowledgeable concerning each of the principles and methods of examination required on a particular weldment. It is the responsibility of those charged with the administration and supervision of inspection to make certain that the principles and methods set forth are properly understood and uniformly applied. This responsibility also includes the qualification and certification of inspectors, where such certification is required by codes, specifications, or civil laws. AWS QC1, *Standard for AWS Certification of Welding Inspectors*, indicates the importance AWS assigns to visual examination.

Contract documents should specify the requirements for visual examination. In the absence of such requirements, the manufacturer should be requested to establish, in writing, the extent and the methods of examination to be required.

Acceptance standards should be clearly understood by both the manufacturer and the buyer before any welding is started. This is not only to make more effective use of the examination methods but to prevent disagreement over whether a weldment is satisfactory and in accordance with the contract specifications.

1.2 Scope. This guide includes an outline of the fundamental prerequisites for personnel performing visual examination of welds. Such prerequisites include physical limitations or capabilities, as well as technical knowledge, training, experience, judgment, and certification.

This guide essentially provides an introduction to visual examination of welding. These examinations fall into three categories based on the time they are performed, as follows: (1) prior to welding, (2) during welding, and (3) after welding. An extensive treatment is provided on weld surface conditions, including reference to frequently used terminologies associated with *preferred* and *nonpreferred* conditions. Visual examination may be performed by different people or organizations. Personnel performing welding examination include welders, welding supervisors, the contractor's welding inspector, the purchaser's examiner, or the regulatory inspector. For the purpose of simplicity, these individuals referred to as visual inspectors in the remainder of this standard in that they perform visual inspection. Fabrication documents, contract specifications, and regulatory agencies may specify who performs final inspections.

Also provided is a review of visual examination equipment aids routinely used, such as gauges and lighting equipment. Formal documentation of visual examination results is contained in Section 6, Records. Finally, the guide suggests additional reading or references, that may provide more detailed requirements for specific visual examination applications.

1.3 Safety and Health. This technical document does not address all welding and health hazards. Pertinent information can be found in ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and other safety-related documents including federal, state, and local regulations.

1.4 References. The following documents are cited in this document. Copies may be obtained from the American Welding Society.

(1) AWS A3.0, *Standard Welding Terms and Definitions*

(2) AWS A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*

(3) AWS A5.4, *Specification for Stainless Steel Welding Electrodes for Shielded Metal Arc Welding*

(4) AWS D10.11, *Root Pass Welding and Gas Purging of Piping*

(5) AWS QC-1, *Standard for AWS Certification of Welding Inspectors*

(6) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

2. Prerequisites

2.1 General. As with any other nondestructive examination method, there are various prerequisites that should be considered prior to performing visual examination. Some of the more common attributes to consider are discussed in the following paragraphs.

2.2 Visual Acuity. One of the more obvious prerequisites is that the visual inspector should have sufficient visual acuity to perform an adequate inspection. Consideration should be given to sufficient near and far vision with natural or corrected vision. A documented periodic visual acuity examination is a requirement of many codes and specifications, and is generally considered good practice.

2.3 Equipment. Visual examination may require the use of special tools or equipment. The tools or equipment depend upon the application and the degree of accuracy required. Some tools may need to be calibrated prior to use. Although this guide presents an outline of visual examination aids, there are many different concepts and other variations of equipment. As a general rule, those tools should be used that: (1) comply with the project requirements, (2) are adequate for the intended accuracy, and (3) satisfy the need of the inspection.

2.4 Experience and Training. Another obvious prerequisite is that the visual inspector should have sufficient knowledge and skill to perform the examination successfully and meaningfully. Knowledge and skill can be imparted or obtained through the educational and training processes. Either method can be performed in a classroom or on the job. The variety of methods and processes of imparting or obtaining knowledge and skill are many, but the art of good judgment does not always come easily or readily. Sufficient time should be allowed for individuals to properly grasp key points pertaining to the following: (1) joint preparations, (2) welding preheat, (3) interpass temperature, (4) weldment distortion, (5) welding consumables, (6) base materials, and (7) workmanship standards.

2.5 Procedures. Development of standard procedures covering examination methodology and acceptance criteria results in consistency and accuracy. Such procedures are normally prepared by the employer and typically consist of detailed instructions that interrelate the various fabrication processes, the customer's detailed requirements, and baseline inspection criteria. Items such as *who* performs an inspection, *when* to perform an inspection, *how* to perform an examination, and *where* to perform an examination are typically included in the procedure. As a minimum the standard procedures should include the following: workmanship standards, check lists, and examination equipment requirements.

When written procedures are not available, inspectors may be asked to work directly with codes and specifications.

2.6 Certification Programs. To provide assurance that visual inspectors are qualified (that is, sufficient prerequisites are obtained and maintained), it may be desirable to have visual inspection personnel formally certified. Contract documents, fabrication standards, or regulatory agencies may require special qualifications for visual inspectors. Several standards developers offer certification programs for visual inspectors such as AWS QC1, *Standard for Certification of Welding Inspectors*.

2.7 Safety. Visual inspectors should receive sufficient indoctrination on welding safety practices. There are many potential safety hazards present (electricity, gases, fumes, ultraviolet light, heat, etc.). All personnel working in or exposed to a welding environment should seek training in welding safety.

3. Fundamentals of Visual Examination

3.1 General. Visual examination reveals surface flaws, and is a valuable indication of weld quality. It is a simple, accessible, low-cost inspection method, but it requires a trained inspector. Additionally, it can be an excellent process-control tool to help avoid subsequent fabrication problems and evaluate workmanship.

Visual examination only identifies surface discontinuities. Consequently, any conscientious quality control program should include a sequence of examinations performed during all phases of fabrication. An inspection plan should establish hold points that allow for visual examination prior to subsequent operations.

A conscientious program of visual inspection before and during welding may reduce costs by revealing surface defects early in the fabrication process.

3.2 Prior to Welding. Prior to welding, some typical action items requiring attention by the visual inspector should include the following:

(1) Review drawings and specifications
(2) Check procedure and performance qualifications
(3) Establish hold points if required
(4) Establish documentation plan
(5) Review material documentation
(6) Examine base material
(7) Examine fitup and alignment of joints
(8) Review storage of welding consumables

If the inspector pays particular attention to these preliminary items, many problems that might occur later can be prevented. It is important that the inspector review the governing documents to determine the job requirements. A system should be established to assure that accurate and complete records are produced.

3.2.1 Review Drawings and Specifications. The inspector should either have copies of the drawings and specifications, or have access to them, and should review them periodically. Information to be gained includes: weld details, material requirements, inspection requirements, dimensions, and qualification requirements.

3.2.2 Check Procedure and Performance Qualifications. The inspector should review welding procedures and welder qualification records to assure the qualifications meet the requirements of the job specification.

3.2.3 Establish Hold Points. Consideration should be given to the establishment of hold points or check points where an examination is to occur prior to the accomplishment of any further fabrication. Hold points should be established for inspection of work which will become inaccessible for inspection because it will be covered by subsequent work.

3.2.4 Establish Documentation Plan. It may be necessary to record some inspection results. This documentation will provide data needed for final acceptance.

3.2.5 Review Material Documentation. The inspector should verify that the correct material was ordered, received, and used during fabrication.

3.2.6 Examine Base Materials. Prior to welding, the base materials should be examined for unacceptable discontinuities such as laminations, seams, laps, and cracks.

3.2.7 Examine Joint Fit-Up and Alignment. Joint fit-up and alignment are critical to the production of a sound weld. Items that may be considered prior to welding include:

(1) Groove angle
(2) Root openings
(3) Joint alignment
(4) Backing
(5) Consumable insert
(6) Joint cleanliness
(7) Tack welds
(8) Preheat (when required)

All of these factors could have a direct bearing on the resultant weld quality. If the fitup is poor, it should be corrected prior to welding. Extra care taken during the joint assembly can greatly improve welding effectiveness. Sometimes, examination of the joint prior to welding will reveal irregularities within code limitations, but these become areas of concern and can be watched carefully during later steps. For example, if a T-joint exhibits the maximum root opening, the size of the required fillet weld may be increased by the actual amount of root opening. Inspectors will only know of such a condition if they checked the fit. The drawing or weld joint should be marked accordingly, so that the correct weld size can be verified during final inspection.

3.2.8 Review Storage of Welding Consumables. Welding consumables should be stored in accordance with the manufacturer's recommendations, applicable codes, and contract requirements.

3.3 During Welding. During welding, some typical action items requiring attention by those responsible for weld quality should include the following:

(1) Check preheat and interpass temperatures
(2) Check conformance to Welding Procedure Specification (WPS)
(3) Examine weld root pass
(4) Examine weld layers
(5) Examine second side prior to welding

Any of these factors, if ignored, could result in discontinuities that could cause serious quality degradation.

3.3.1 Check Preheat and Interpass Temperatures. When required by the reference code, contract documents, or the Welding Procedure Specification, preheat and interpass temperatures should be verified by the inspector. See 5.4, Temperature Measuring Devices, for equipment used to check temperatures.

3.3.2 Check Conformance with Welding Procedure Specification. Verify that the welding operation is in compliance with the Welding Procedure Specification. Such variables as consumables, wire feed speed, joint design, electrical characteristics, and technique among others should be verified.

3.3.3 Examine Weld Root Pass. A great many defects that are discovered in a weld are associated with the weld root bead. Good visual examination following the application of the weld root bead should expose the problem for correction.

3.3.4 Examine Weld Layers. To evaluate the weld as work progresses, it is wise to visually examine each layer. This also provides a check to determine if adequate cleaning is being accomplished between passes. This may help to alleviate the occurrence of slag inclusions in the final weld.

3.3.5 Examine Second Side Prior to Welding. Critical joint root conditions may exist on the second side of a double-welded joint. This area should be examined after removal of slag and other irregularities. This is to assure that all discontinuities have been removed and that the contour of the excavation provides access for subsequent welding.

3.4 After Welding. Following welding, some typical action items requiring attention by the visual inspector should include the following:

(1) Examine weld surface quality
(2) Verify weld dimensions
(3) Verify dimensional accuracy
(4) Review subsequent requirements

3.4.1 Examine Weld Surface Quality. Visually examine weld surface and verify that the weld contour concavity and convexity meet acceptance criteria required by the contract documents. Workmanship standards may address such items as surface roughness, weld spatter, and arc strikes. Most codes and specifications describe the type and size of discontinuities that are acceptable. Many of these discontinuities can be found by visual examination of the completed weld. The following are typical discontinuities found at the surface of welds:

(1) Porosity
(2) Incomplete fusion
(3) Incomplete joint penetration
(4) Undercut
(5) Underfill
(6) Overlap
(7) Cracks
(8) Metallic and nonmetallic inclusions
(9) Excessive reinforcement

3.4.2 Verify Weld Dimensions. To determine if compliance has been obtained, the inspector should check to see if all welds meet drawing requirements for size, length, and location. Fillet weld sizes can be determined by using one of several types of weld gauges to be discussed later. Groove welds should be filled to the full cross section of the joint, or as specified, and the weld reinforcement should not be excessive. Some conditions may require the use of special weld gauges to verify these dimensions.

3.4.3 Verify Dimensional Accuracy. Final inspection of a fabricated weldment should verify that the dimensions are in accordance with the drawing.

3.4.4 Review Subsequent Requirements. Review the specification to determine if additional procedures are required. Such procedures may include postweld heat treatment, nondestructive examination, proof testing, and others. The welding inspector when responsible for final acceptance should verify that each of these subsequent operations was performed.

4. Weld Surface Conditions

4.1 General. This section is concerned only with discontinuities, which may or may not be classed as defects (rejectable) depending on requirements of individual specifications or codes. The intent is informational and instructional, and meant to assist in the identification of discontinuities. Discontinuities can occur at any location in the weld. Visual examination after welding is limited to the surface condition of the weld. Discovery of subsurface discontinuities requires that a visual examination be supplemented by other nondestructive examination (NDE) methods.

A discontinuity is an interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect. Discontinuities are rejectable only if they exceed specification requirements in terms of type, size, distribution, or location. A defect is a discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. The term *defect* designates rejectability.

Weld and base-metal discontinuities of specific types are more common when certain welding processes and joint details are used. Attendant conditions, such as high restraint and limited access to portions of a weld joint, may lead to a higher than normal incidence of weld or base-metal discontinuities. For example, highly restrained weld joints are more prone to cracking.

Each general type of discontinuity is discussed in detail in this section. Other documents may use different terminology for some of these discontinuities; however, whenever possible, the approved AWS terminology, as found in AWS A3.0, *Standard Welding Terms and Definitions*, should be used to eliminate confusion. An example of additional terminology occurs in AWS D1.1, *Structural Welding Code—Steel*. There, *fusion-type discontinuity* is a general term which is used to describe a number of discontinuities, including: slag inclusions, incomplete fusion, incomplete joint penetration, and similar elongated discontinuities in fusion welds.

4.2 Porosity. Porosity is a cavity-type discontinuity formed by gas entrapment during solidification or in a thermal-spray deposit. The discontinuity formed is generally spherical and may be elongated. A common cause of porosity is contamination during welding.

Generally, porosity is not considered to be as detrimental as other discontinuities, due to its shape, since it doesn't result in the creation of a severe stress concentration. Porosity is an indication that the welding parameters, welding consumables, or joint fitup were not 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 an indicator regarding the apparent quality of a weld, without being considered a severe discontinuity. Important information regarding the cause of the problem is provided by describing both the shape and orientation of individual pores or the geometric array of adjacent pores.

An example of this utility is the distinction between elongated porosity and piping porosity. Both have lengths greater than their width, but they differ because of their orientation with respect to the weld axis. They also differ in terms of how they were caused.

By providing this additional detail, an inspector is giving more information than a standard will normally require, but it can be helpful in determining what corrective action to take.

4.2.1 Scattered Porosity. Figure 1 illustrates scattered porosity which is uniformly distributed throughout the weld metal.

4.2.2 Cluster Porosity. Cluster porosity is a localized array of porosity having a random geometric distribution.

4.2.3 Piping Porosity. Figure 2 illustrates piping porosity which is a form of porosity having a length greater than its width that lies approximately perpendicular to the weld face. Piping porosity may also be referred to as *wormhole porosity.*

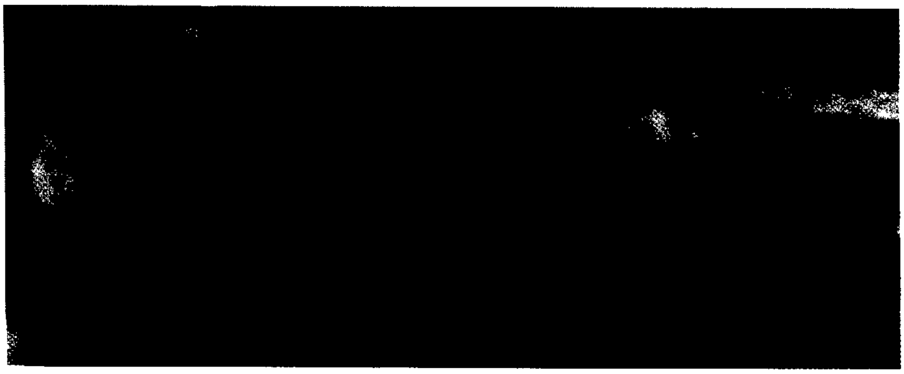

Figure 1—Scattered Porosity

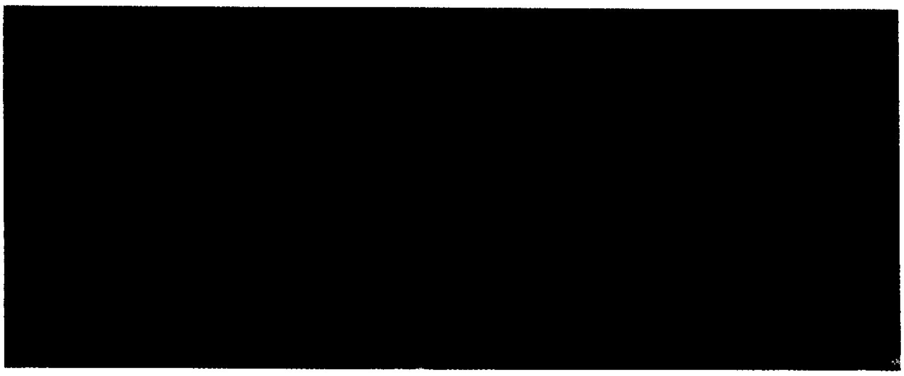

Figure 2—Surface Appearance of Piping Porosity

4.2.4 Aligned Porosity. Figure 3 illustrates aligned porosity which is a localized array of porosity oriented in a line. The pores may be spherical or elongated. Aligned porosity is sometimes referred to as *linear porosity.*

4.2.5 Elongated Porosity. Figure 4 illustrates elongated porosity which is a form of porosity having a length greater than its width that lies approximately parallel to the weld axis. It shows elongated porosity formed between the slag and the weld metal surface. Such porosity could also be formed below the surface of the weld metal.

4.3 Incomplete Fusion. Incomplete fusion is a weld discontinuity in which fusion did not occur between weld metal and fusion faces or adjoining weld beads. Examples of incomplete fusion are shown in Figures 5–9. It is the result of improper welding techniques, improper preparation of the base metal, or improper joint design. Deficiencies causing incomplete fusion include insufficient welding heat or lack of access to all fusion faces, or both. Unless the weld joint is properly cleaned the tightly adhering oxides can interfere with complete fusion, even when there is proper access for welding and proper welding heats are used.

4.4 Incomplete Joint Penetration. Incomplete joint penetration is a joint root condition in which weld metal does not extend through the joint thickness. The unpenetrated and unfused area is a discontinuity described as incomplete joint penetration. Examples of incomplete joint penetration are illustrated in Figures 10–12. Incomplete joint penetration may result from insufficient welding heat, improper joint design (e.g., thickness the welding arc cannot 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, backgouging may be specified before welding the second

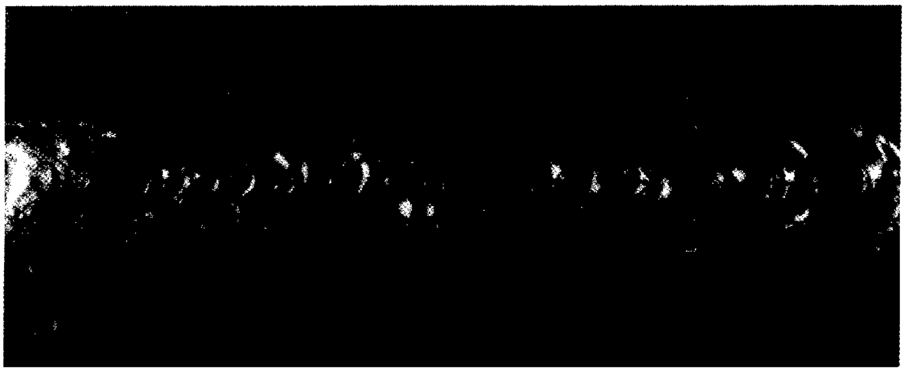

Figure 3—Aligned Porosity with Crack

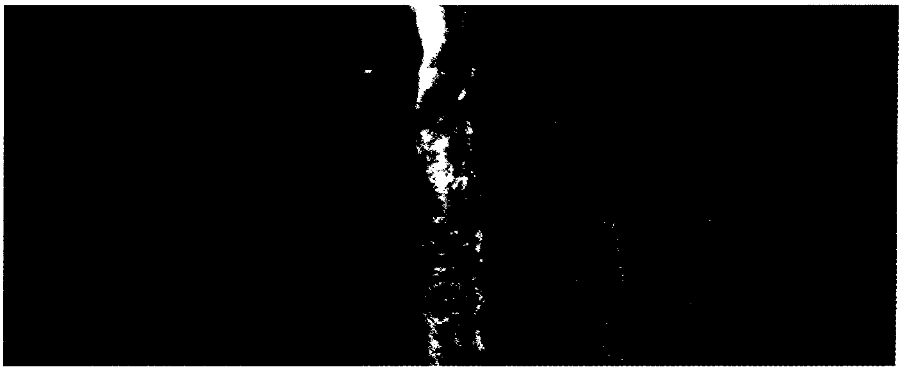

Figure 4—Elongated Porosity

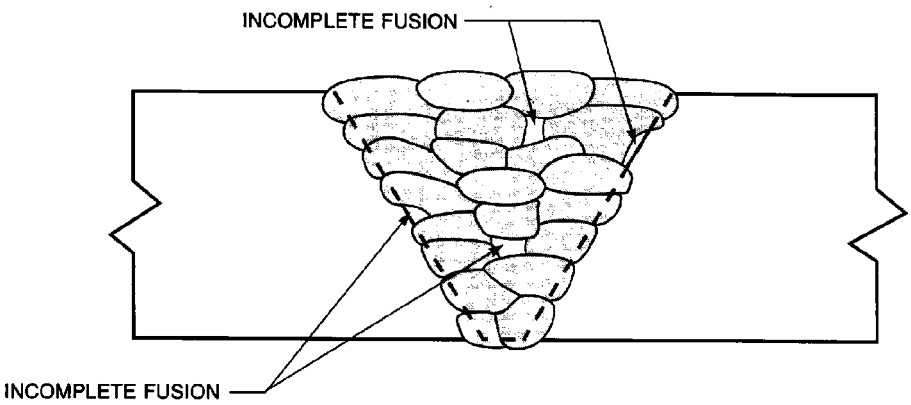

Figure 5—Various Locations of Incomplete Fusion

Figure 6—Incomplete Fusion

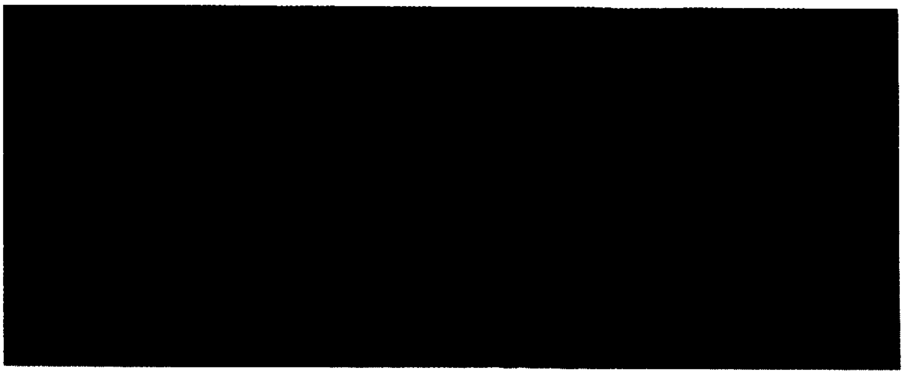

Figure 7—Incomplete Fusion at the Groove Face

Figure 8—Incomplete Fusion Between Weld Beads

Figure 9—Incomplete Fusion Between the Weld and Base Metal

side to ensure that there is no incomplete joint penetration. Pipe welds are especially vulnerable to this type of discontinuity, since the inside of the pipe is usually inaccessible. Designers may employ a backing ring or consumable inserts to aid welders in such cases. Welds that are required to have complete joint penetration are commonly examined by some nondestructive method.

4.5 Undercut. 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. Examples of undercut are illustrated in Figures 13 and 14. When undercut is controlled within the limits of specifications it is not considered a weld defect. Undercut is generally associated with either improper welding techniques or excessive welding currents, or both.

4.6 Underfill. Underfill is a condition in which the weld face or root surface of a groove weld extends below the adjacent surface of the base metal. It results from the failure of the welder to completely fill the weld joint. Examples of underfill are illustrated in Figures 15 and 16.

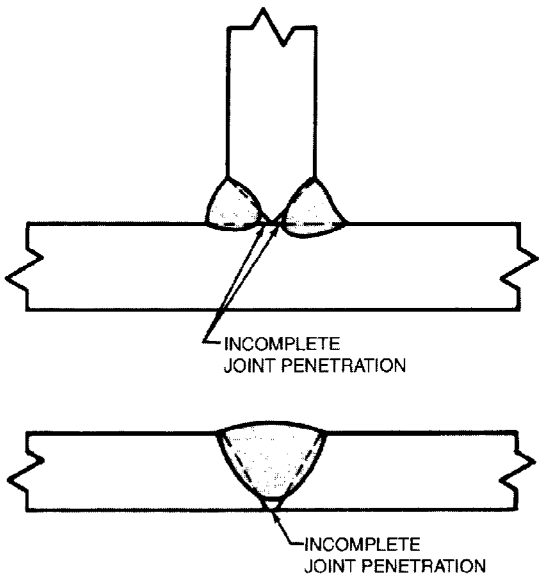

Figure 10—Incomplete Joint Penetration

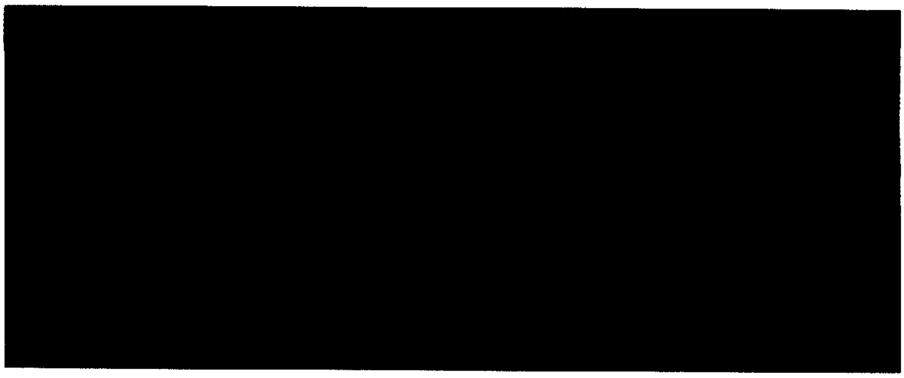

Figure 11—Incomplete Joint Penetration with Consumable Insert

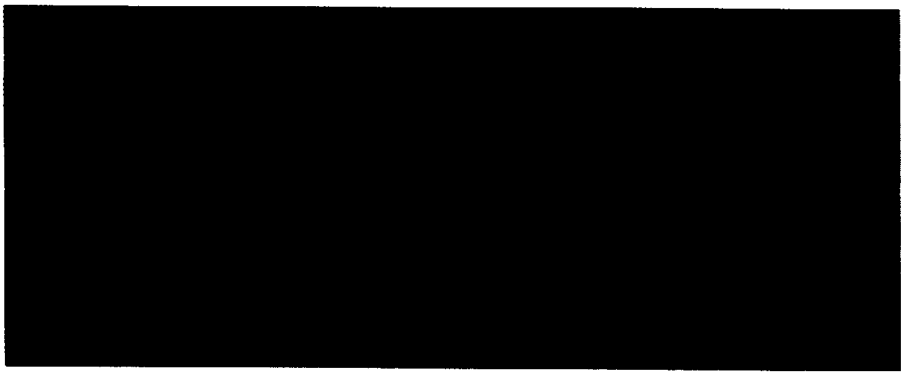

Figure 12—Incomplete Joint Penetration

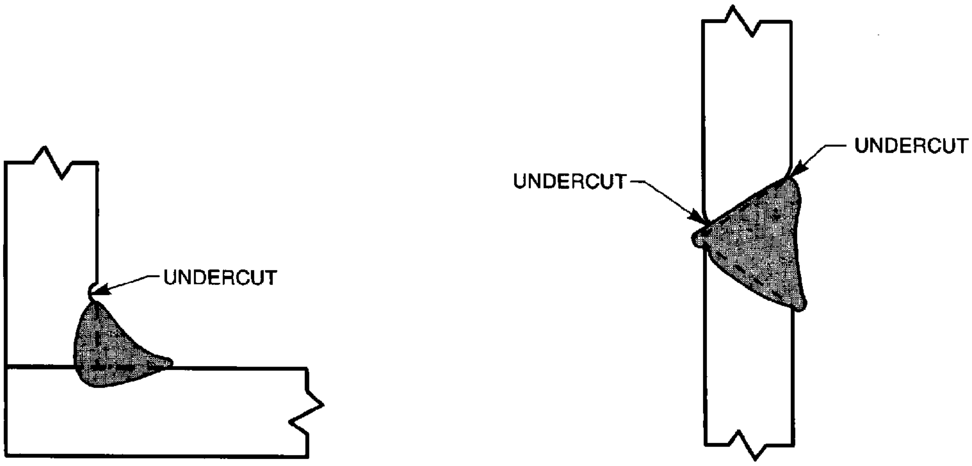

Figure 13—Examples of Undercut

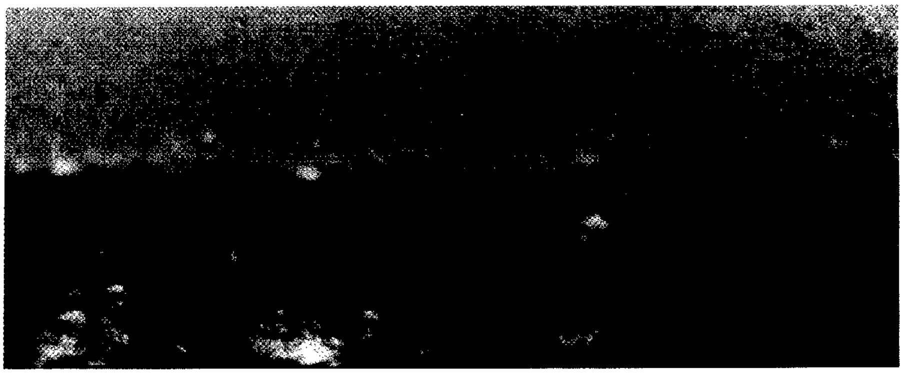

Figure 14—Undercut at Fillet Weld Toe

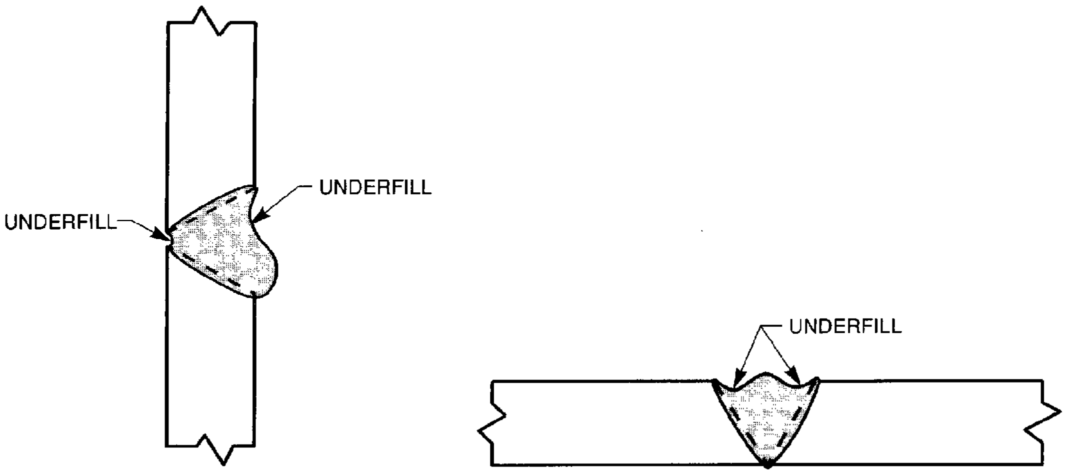

Figure 15—Underfill

Figure 16—Underfill Using Flux Cored Arc Welding in Steel

4.7 Overlap. Overlap is the protrusion of unfused weld metal beyond the weld toe or weld root. Overlap is a surface discontinuity that forms a mechanical notch and is nearly always considered rejectable. Two common causes of overlap may be insufficient travel speed and improper preparation of the base metal. Examples of overlap are illustrated in Figures 17 and 18.

4.8 Lamination. Lamination is a type of base-metal discontinuity with separation or weakness generally aligned parallel to the worked surface of a metal.

Laminations are formed when gas voids, shrinkage cavities, or nonmetallic inclusions in the original ingot, slab, or billet are rolled.

Laminations may be completely internal and are usually detected nondestructively by ultrasonic examination. They may also extend to an edge or end, where they are visible at the surface and may be detected by visual, liquid penetrant, or magnetic-particle examination. They may be found when cutting or machining exposes internal laminations. A lamination exposed by oxyfuel gas cutting is shown in Figure 19.

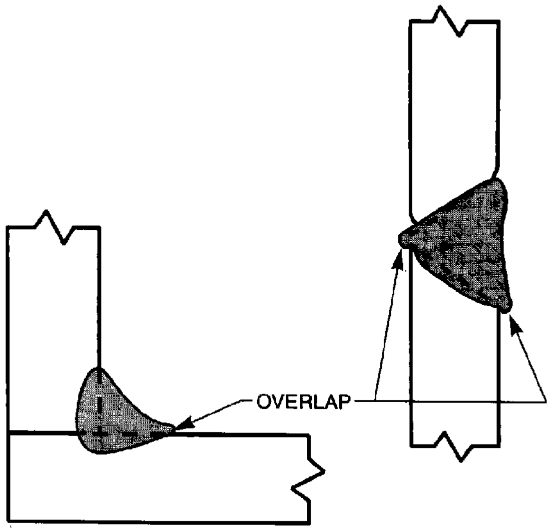

Figure 17—Overlap

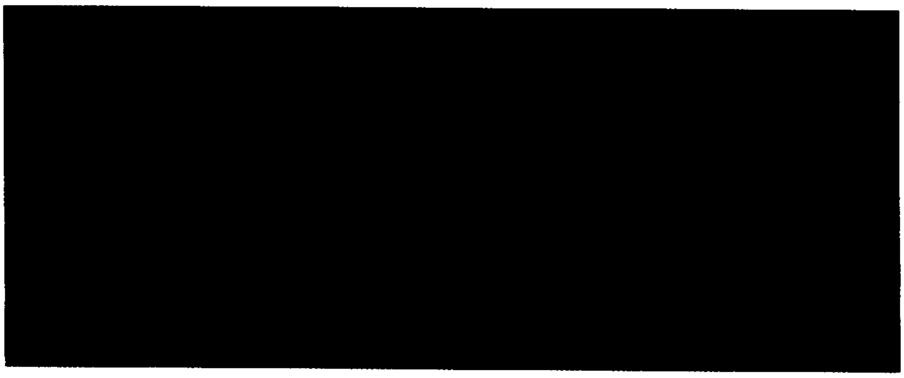

Figure 18—Overlap

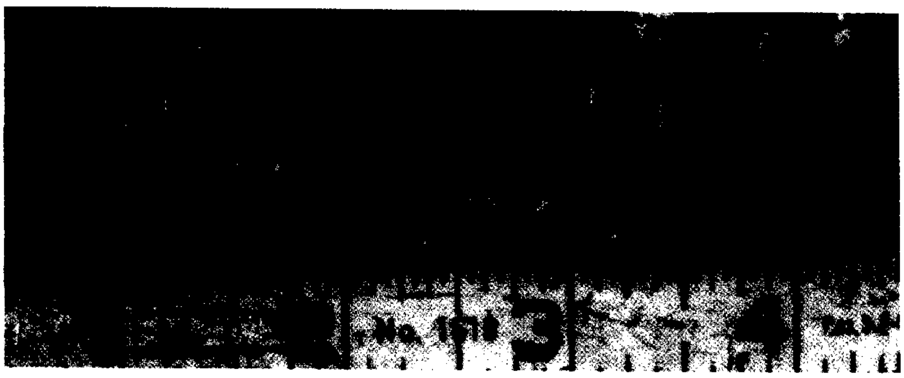

Figure 19—Laminations

A delamination is the separation of a lamination under stress.

4.9 Seams and Laps. Seams and laps are base metal discontinuities that may be found in rolled, drawn, and forged products. They differ from laminations in that they appear on the surface of the worked product. The criticality of seams and laps depend on their orientation, size, and the application of the weldment. While seams and laps are surface discontinuities, they may only be detected after fabrication operations such as bending, rolling, or sand blasting. Welding over seams and laps can cause cracking, porosity, or both.

4.10 Cracks. Cracks are defined as fracture-type discontinuities characterized by a sharp tip and high ratio of length and width to opening displacement. They can occur in weld metal, heat-affected zone, and base metal when localized stresses exceed the ultimate strength of the material. Cracking often initiates at stress concentrations caused by other discontinuities or near mechanical notches associated with the weldment design. Stresses that cause cracking may be either residual or applied. Residual stresses develop as a result of restraint provided by the weld joint and thermal contraction of the weld following solidification. Welding related cracks exhibit little plastic deformation. Some crack types are illustrated in Figure 20.

If a crack is found during welding, it should be completely removed prior to additional welding. Welding over a crack rarely eliminates the crack.

4.10.1 Orientation. Cracks may be described as either longitudinal or transverse, depending on their orientation.

When a crack is parallel to the weld axis it is called a *longitudinal crack* regardless of whether it is a centerline crack in weld metal or a toe crack in the base metal heat-

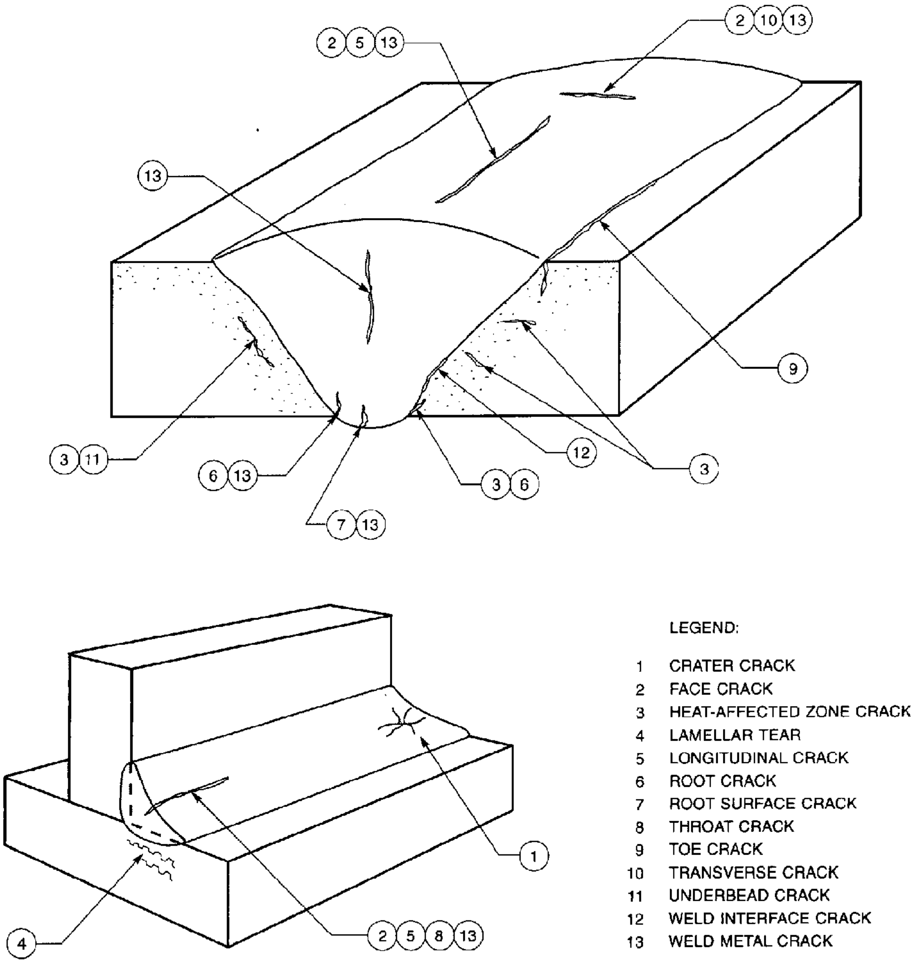

Figure 20—Types of Cracks

affected zone. Longitudinal cracks are illustrated in Figure 21 and shown in Figure 22. Longitudinal cracks in small welds between heavy sections are often the result of high cooling rates and high restraint. In submerged arc welding they are commonly associated with high welding speeds or may be related to porosity problems that do not show at the surface of the weld. Longitudinal heat-affected-zone cracks are usually caused by dissolved hydrogen.

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 further into the base metal. In some weldments, transverse cracks will form in the heat-affected zone and not in the weld.

Transverse cracks are generally the result of longitudinal shrinkage stresses acting on weld metal of low ductility. Weld metal hydrogen cracking can be oriented in the transverse direction. Transverse cracks are shown in Figure 23.

4.10.2 Crack Types. Cracks can generally be classified as either hot cracks or cold cracks. Hot cracks develop during solidification and are the result of insufficient ductility at high temperature. Hot cracks propagate between grains in the weld metal or at the weld interface.

Cold cracks develop after solidification is complete. In carbon and low-alloy steels, cold cracks can occur in either the weld metal, heat-affected zone, or base metal, and are usually the result of dissolved hydrogen. The cracks can form hours or even days after the weld is completed. Cold cracks propagate both between grains and through grains.

4.10.2.1 Throat Cracks. Throat cracks are longitudinal cracks oriented along the throat of fillet welds. A

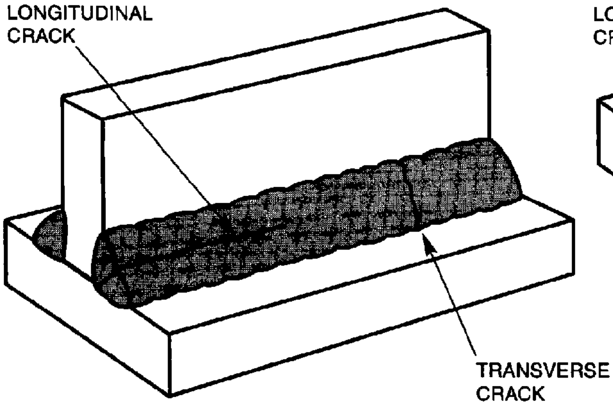

Figure 21—Longitudinal vs. Transverse Cracks

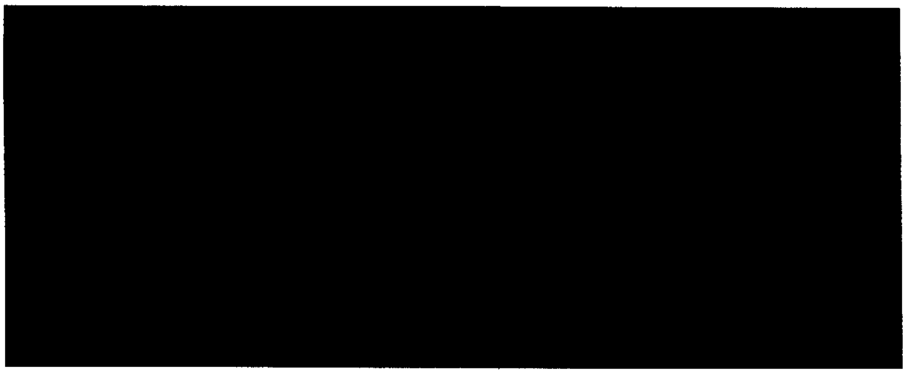

Figure 22—Longitudinal Crack and Linear Porosity

throat crack is shown in Figure 24. They are generally, but not always, hot cracks.

4.10.2.2 Root Cracks. Root cracks are longitudinal cracks at the weld root or in the root surface. They may be hot or cold cracks. Root cracks are illustrated in Figure 20.

4.10.2.3 Crater Cracks. Crater cracks occur in the crater of a weld when the welding is improperly terminated. They are sometimes referred to as *star cracks*, though they may have other configurations. A crater crack is shown in Figure 25. Crater cracks are hot cracks usually forming a pronged starlike network. Crater cracks are found most frequently in materials with high coefficients of thermal expansion, for example austenitic stainless steel and aluminum. However, the occurrence of any such cracks can be minimized or prevented by filling the crater to a slightly convex shape prior to terminating the arc. Longitudinal cracks may initiate from a crater crack. Such a crack is shown in Figure 26.

4.10.2.4 Toe Cracks. Toe cracks, Figures 27 and 28, are generally cold cracks. They initiate and propagate from the weld toe where shrinkage 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 ductility of the base metal cannot accommodate the shrinkage stresses that are imposed by welding.

4.10.2.5 Underbead and Heat-Affected-Zone Cracks. Underbead and heat-affected-zone cracks are generally used interchangeably. Underbead and heat-affected-zone cracks are generally cold cracks that form in the heat-affected zone of the base metal. Typical underbead cracks are illustrated in Figure 29. Underbead cracks can occur when three elements are present simultaneously:

(1) Hydrogen

(2) A microstructure of relatively low ductility

(3) High residual stress

Figure 23—Transverse Cracks

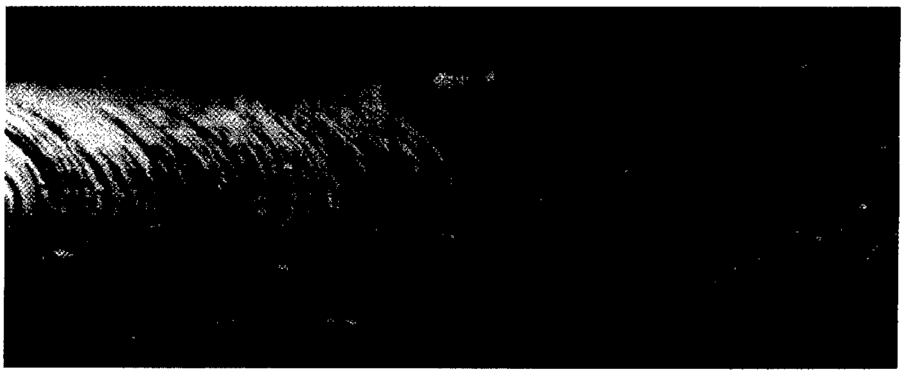

Figure 24—Throat Crack

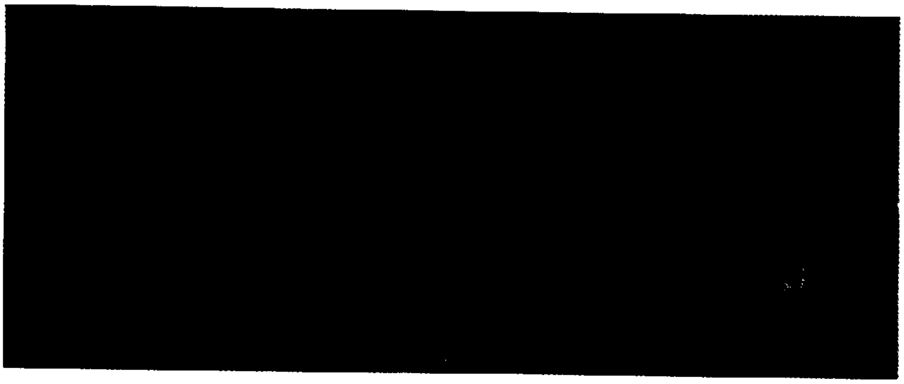

Figure 25—Crater Crack

Figure 26—Longitudinal Cracks Propagating from Crater Crack

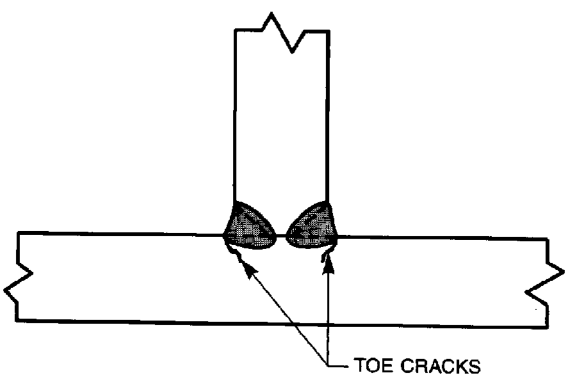

Figure 27—Toe Cracks

Underbead and heat-affected-zone cracks can be both longitudinal and transverse. They are found in the heat-affected zone and are not always detectable by visual examination. Underbead cracks are found primarily in fillet welds, but they can also occur in groove welds.

4.11 Slag Inclusions. Slag inclusions are nonmetallic products resulting from the mutual dissolution of flux and nonmetallic impurities in some welding and brazing processes. A slag inclusion is shown in Figure 30.

In general, slag inclusions can be found in welds made with any arc welding process that employs flux as a shielding medium. In general, slag inclusions result from improper welding techniques, the lack of adequate access for welding the joint, or improper cleaning of the weld between passes. Due to its relatively low density

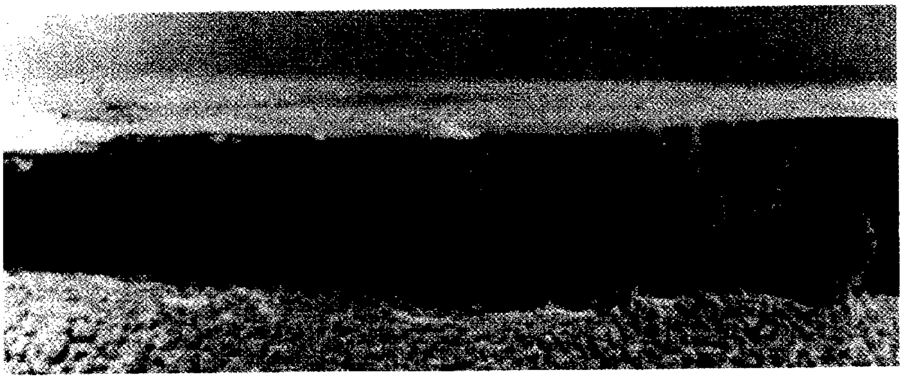

Figure 28—Toe Cracks

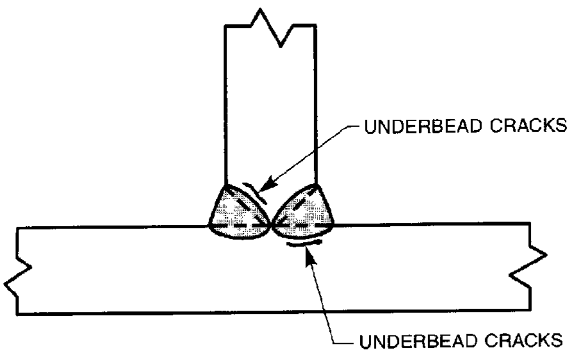

Figure 29—Underbead Cracks

and melting point molten slag will normally flow to the surface of the weld pass. Sharp notches in the weld interface or between passes often cause slag to be entrapped under the molten weld metal. The release of slag from the molten metal will be expedited by any factor that tends to make the metal less viscous or retard its solidification, such as high-heat input.

4.12 Excessive Reinforcement. In groove welds, weld reinforcement is weld metal in excess of the quantity required to fill a joint. Weld reinforcement can be located at either the weld face or weld root surface, and is called *face reinforcement* and *root reinforcement*, respectively. Examples of weld reinforcement are illustrated in Figure 31. Excessive weld reinforcement is undesirable because it creates high stress concentrations at the toes of the weld. This condition results from over welding.

4.13 Convexity and Concavity. Convexity, illustrated in Figure 32, is the maximum distance from the face of a convex fillet weld perpendicular to a line joining the weld toes. A weld exhibiting convexity is shown in Figure 33. Excessive convexity like excessive weld reinforcement can introduce undesirable stress concentrations at the weld toes.

Concavity, illustrated in Figure 34, is the maximum distance from the face of a concave filled weld to a line joining the weld toes. The size of a concave fillet weld is related to its throat dimension. The measured leg size will be greater than the true weld size.

4.14 Arc Strikes. An arc strike is a discontinuity consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any part of a weld or base metal resulting from an arc. Arc strikes result when the arc is initiated on the base-metal surface away from the weld joint, either intentionally or accidentally. When this occurs, there is a localized area of the base-metal surface that is melted and then rapidly cooled due to the massive heat sink created by the surrounding base metal. Arc strikes are not desirable and are unacceptable, as they could contain cracks.

4.15 Spatter. Spatter consists of metal particles expelled during fusion welding that do not form a part of the weld. Only that spatter that adheres to the base metal is of concern to the visual inspector.

Normally, spatter is not considered to be a serious flaw unless its presence interferes with subsequent operations, especially nondestructive examination, or the serviceability of the part. It might be indicative of the welding process being out of control, however. An example of spatter is shown in Figure 35.

4.16 Melt-Through. Melt-through is visible root reinforcement produced in a joint welded from one side. Several conditions of melt-through are illustrated in Figure

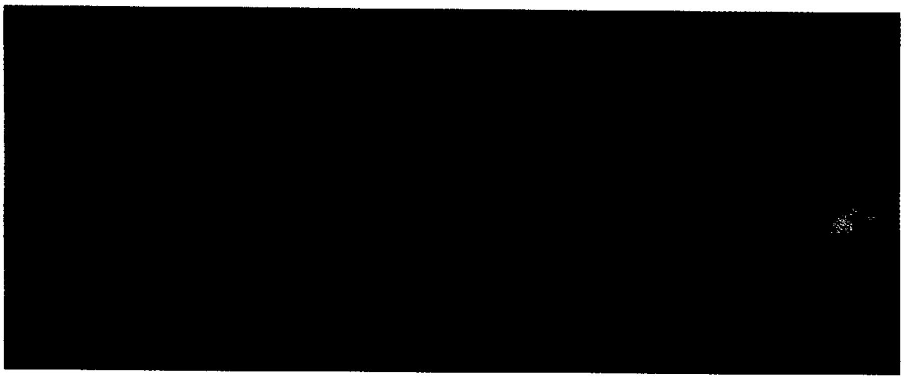

Figure 30—Slag Inclusions

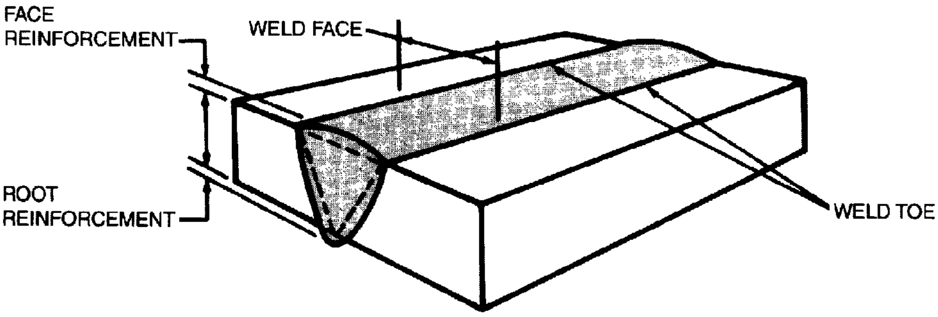

Figure 31—Weld Reinforcement

36. Melt-through is generally acceptable unless it results in excessive root reinforcement.

4.17 Weld Size. Weld size is a measure of a critical dimension, or a combination of critical dimensions of a weld. The required weld size should be shown on the detail drawings. Weld size for various welds are defined and illustrated in AWS A3.0, *Standard Welding Terms and Definitions*.

4.18 Surface Oxidation. Surface oxidation of stainless steels and nickel alloys occurs whenever these alloys are exposed to the atmosphere while above 1000°F (540°C) known as *sugaring* when it becomes heavy. When titanium and zirconium are exposed to the atmosphere at high temperature, they may develop discoloration from straw color to blue to black. Any discoloration darker than slight yellowing indicates extreme contamination of the base metal. These conditions may be avoided by keeping these metals protected by an inert gas anytime they are heated above 800°F (430°C). In piping, this is called purging, and specific direction on how to do purging of piping is covered in AWS D10.11, *Root Pass Welding and Gas Purging of Piping*. Surface oxidation occurs during gas shielded arc welding when the gas shield is lost or inadequate. Excessive surface oxidation, sometimes called sugaring, is shown in Figure 37.

5. Examination Equipment

5.1 Introduction. There are numerous examination devices that may be used in welding inspection. This section surveys some of the tools and gauges most frequently used in visual welding inspection. The tools covered by this section are the following:

(1) Linear measurement devices
(2) Temperature-indicating materials
(3) Surface contact thermometers

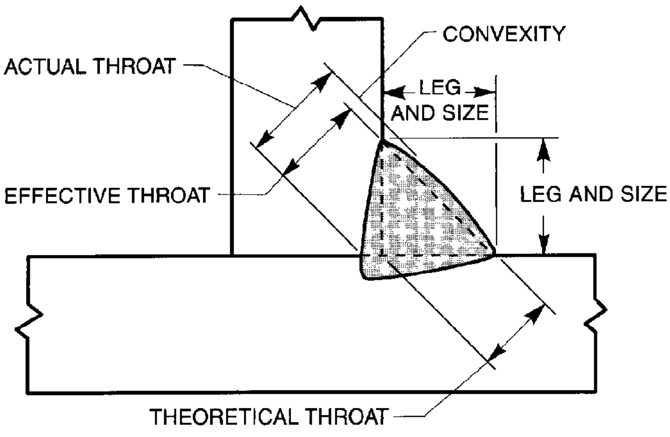

Figure 32—Convex Fillet Weld

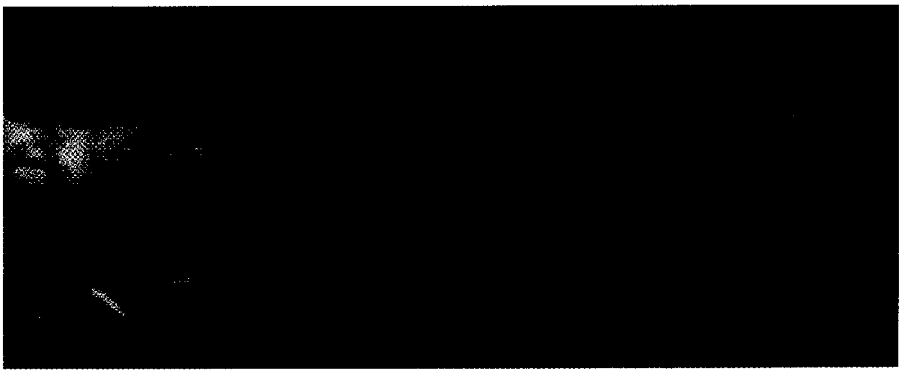

Figure 33—Convexity

(4) Weld gauges
(5) Fiberscopes and borescopes
(6) Ferrite gauges
(7) Light sources
(8) Ammeters

5.2 Calibration and Handling of Examination Equipment. Some industries require the use of calibrated measuring instruments. Calibration is the comparison of a measuring instrument with a reference standard of a closer tolerance and known accuracy. This comparison is generally made to a standard whose accuracy is traceable to the National Institute for Standards and Technology. Calibration is generally documented on a permanent record, and a calibration label may be attached to the instrument indicating the date the instrument is again due to be calibrated.

An effective calibration system should assure the recall and calibration of all precision measuring devices under its control on a preestablished periodic schedule. Prior to using a controlled measuring device, the inspector should assure that the calibration is current. Any gauge whose calibration date has expired should be calibrated prior to use.

To assure continued accuracy it is important to avoid careless or abusive treatment of examination equipment.

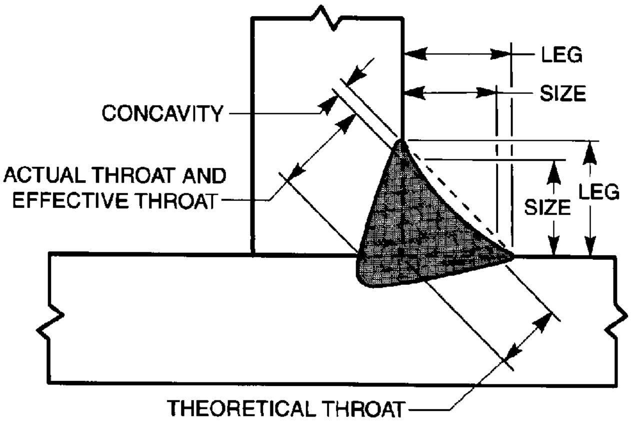

Figure 34—Concave Fillet Weld

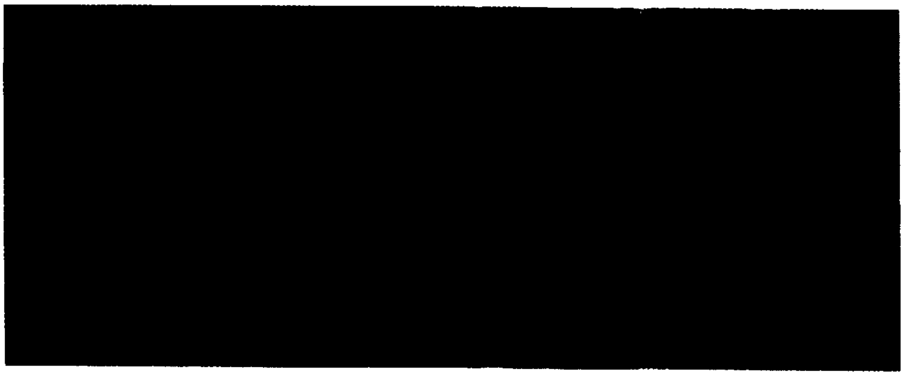

Figure 35—Spatter

Care should be exercised to avoid scratches or nicks on contact surfaces, dial faces, and graduations. Instruments should be kept free of dust, moisture, or fingerprints, and, therefore, should be wiped off before being put away. Equipment should be handled and stored in accordance with manufacturers recommendations.

5.3 Linear Measuring Devices. Devices such as tape measures, micrometers, calipers, and rulers are used for measuring weldment dimensions.

5.4 Temperature-Measuring Devices

5.4.1 Temperature-Indicating Materials. Temperature-indicating materials are frequently used to give an approximate temperature indication. A mark is made across the metal in the area to be checked. For example, when using a 500°F (260°C) indicator, the temperature of the piece will be at least 500°F (260°C) when the mark melts. This is illustrated in Figure 38.

5.4.2 Surface Contact Thermometers. The surface thermometer provides a direct indication of the surface temperature of the workpiece. The magnet of the surface thermometer holds fast to ferromagnetic base metals. A surface contact thermometer is shown in Figure 39.

5.4.3 Surface Contact Pyrometers. The electrical pyrometer is an instrument which offers direct indication of

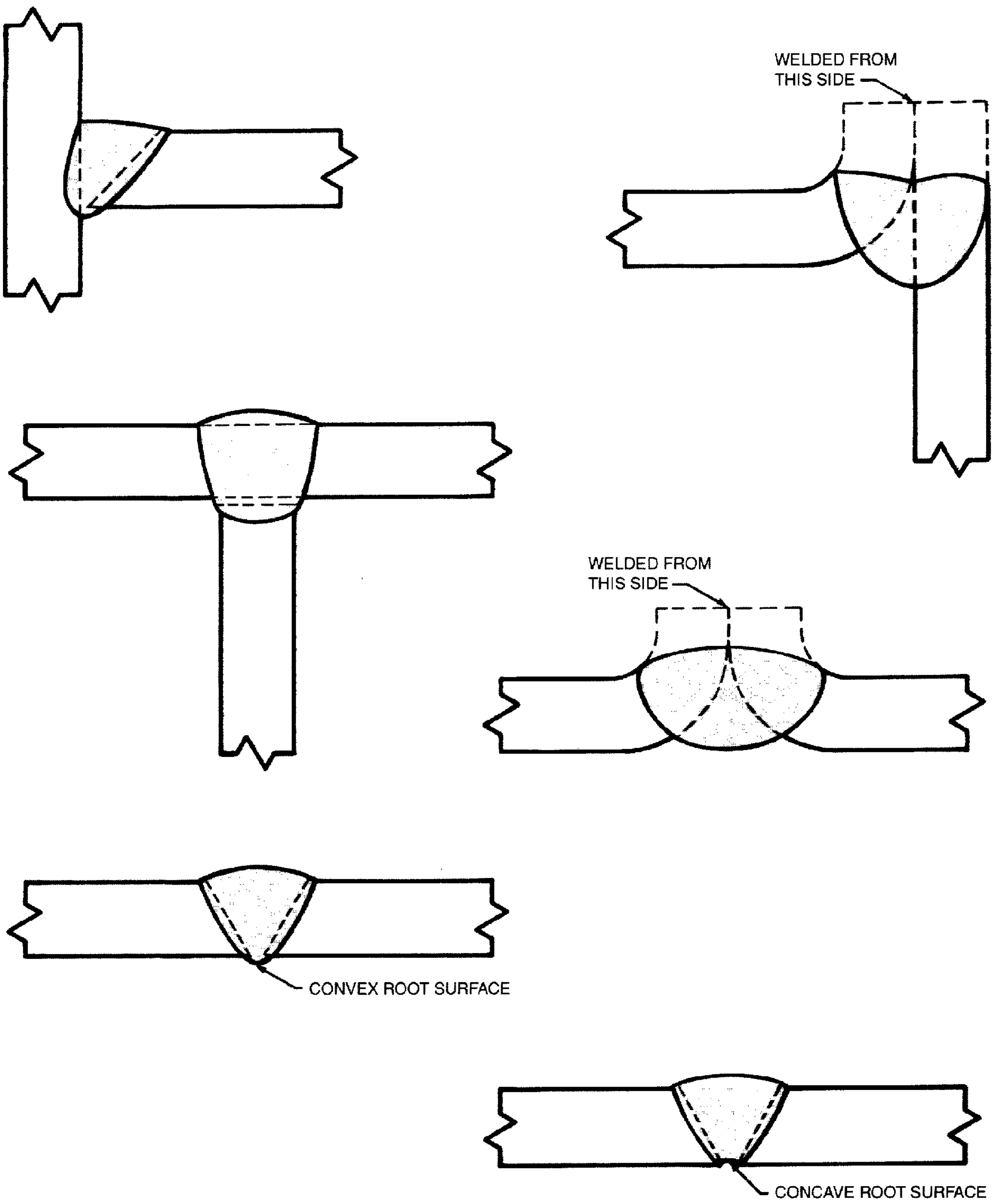

Figure 36—Melt-Through

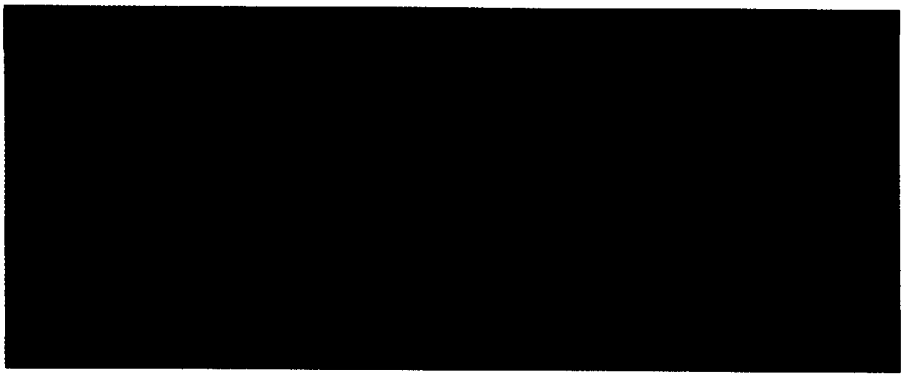

Figure 37—Surface Oxidation (Sugaring) in a Stainless Steel Gas Tungsten Arc Weld

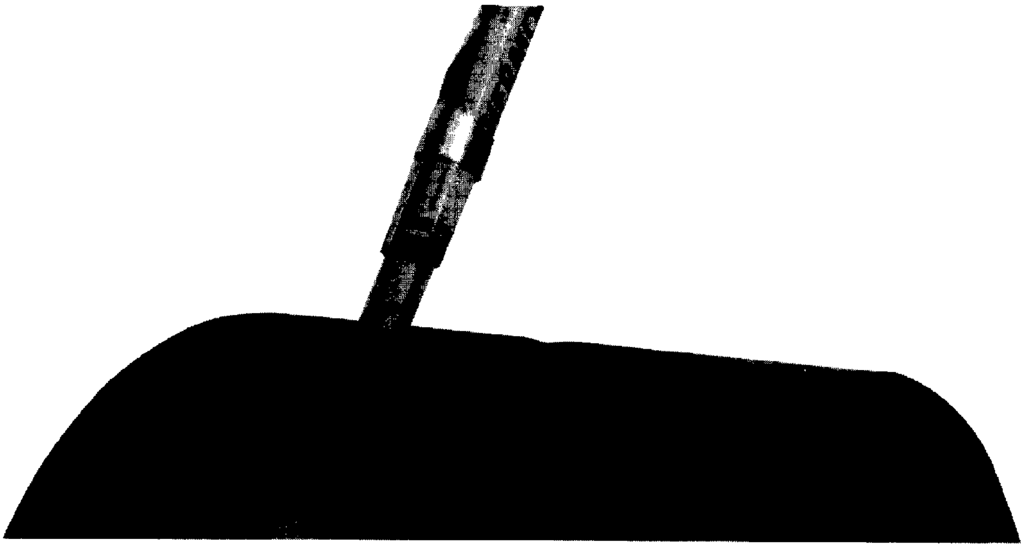

Figure 38—Temperature-Sensitive Crayon

temperature. It is often used when the temperature measured might exceed the limits of mercury or other type thermometers. The point of the probe is placed on the work, and the temperature is read from the scale. Some devices have a button that can be depressed to hold the reading, if desired. These types of instruments give a more accurate indication than either the surface thermometer, or temperature-indicating materials discussed previously. Figure 40 illustrates the use of an electrical pyrometer.

5.5 Weld Gauges

5.5.1 Fillet Weld Gauge. The fillet weld gauge offers a quick means of measuring most fillet welds, of 1/8–1 in. (3.2–25 mm) in size. Both legs of fillet welds should be measured. Fillet weld gauges measure both convex and concave fillet welds.

To measure a convex fillet weld, the blade representing the specified fillet weld size with the single curve should be selected. As shown in Figure 41, the lower edge of the blade is placed on one of the base plates with the tip of the blade moved to the other member.

To measure a concave fillet weld, the blade representing the specified fillet weld size with the double curve should be selected, as shown in Figure 42. After placing the lower edge of the blade on the base plate with the tip touching the upright member, the projection formed by the double curve should just touch the center of the weld

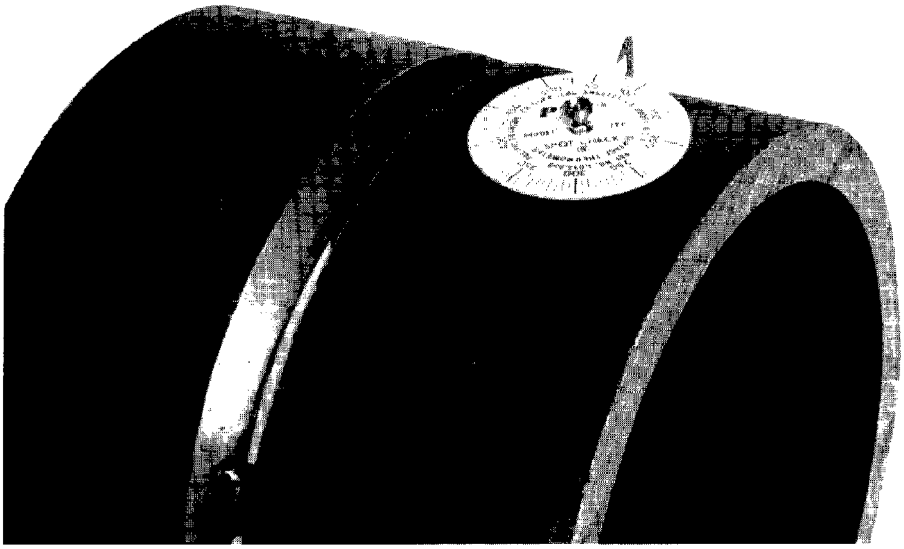

Figure 39—Surface Contact Thermometers

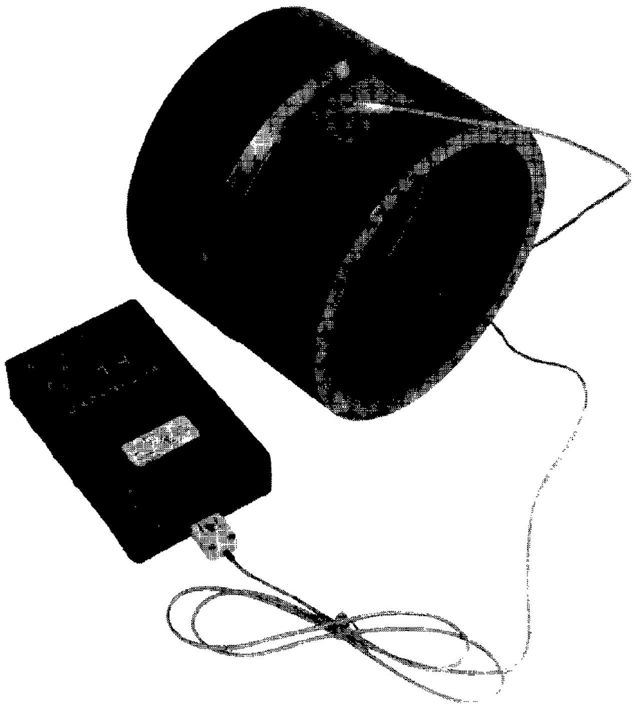

Figure 40—Pyrometer

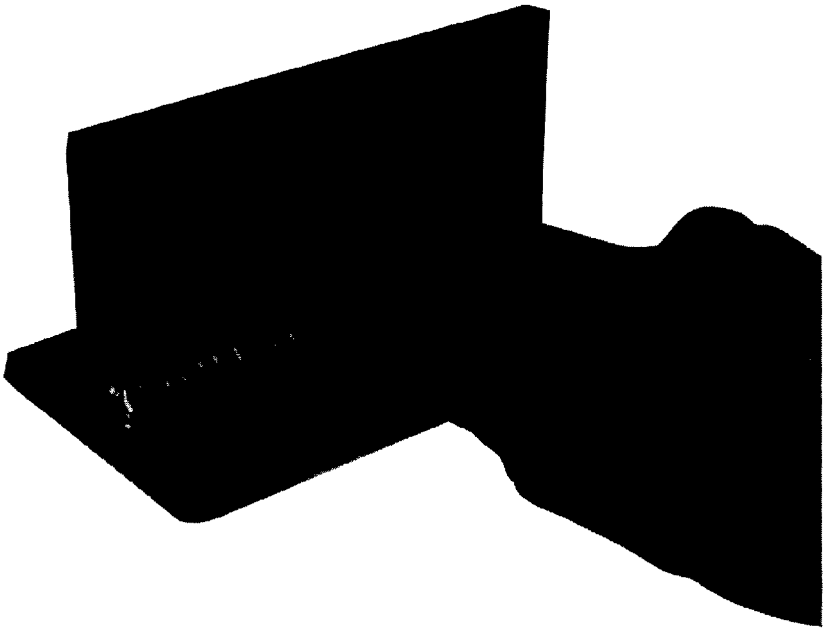

Figure 41—Evaluating a Convex Fillet Weld

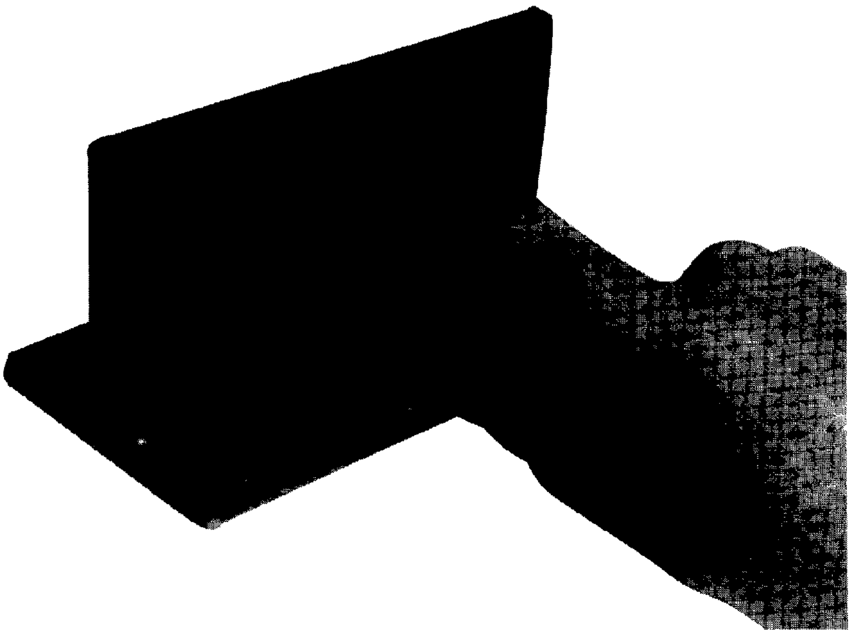

Figure 42—Evaluating a Concave Fillet Weld

face. This will measure throat size for the specified weld size. However, if the center portion of the gauge does not touch the weld, the weld has insufficient throat size.

5.5.2 Multipurpose Gauge. There are numerous multipurpose welding gauges available. A multipurpose gauge is capable of performing many measurements, such as measuring convex and concave fillet welds, weld reinforcement, and root opening. The use of all the numerous and various gauges available cannot all be detailed here; therefore, the instructions packed with each gauge should be carefully followed. Figure 43 illustrates one of these gauges being used to measure a fillet weld.

5.5.3 Taper Gauge. The taper gauge is inserted into the opening of a joint to measure root opening (gap). The root opening measurement is taken from the gauge at the point where the gauge becomes snug in the joint as illustrated in Figure 44.

5.5.4 Hi-Lo Gauge. The Hi-Lo gauge, also called a *mismatch gauge*, is used to measure the internal alignment of a pipe joint. After the gauge has been inserted and adjusted, the thumb screw is tightened, and the tool is removed for measurement of misalignment. This is shown in Figure 45.

5.6 Fiberscopes and Borescopes. These are optical instruments ideal for weld examination where there is restricted access. A fiberscope has a flexible construction, and a borescope is rigid. These instruments allow the inspector to look into small holes or around corners. These units may be combined with lenses and cameras, allowing the images to be projected and recorded. Figure 46 illustrates the use of a fiberscope.

5.7 Ferrite Gauges. Austenitic stainless steel weld metal forms microcracks when it does not contain a sufficient amount of a magnetic phase known as delta ferrite. The amount of delta ferrite can be predicted if the chemical composition of the weld metal is known. This methodology is discussed in detail in AWS A5.4, *Specification for Stainless Steel Welding Electrodes for Shielded Metal Arc Welding*. In addition, ferrite in production welds can be measured using one of several magnetic comparator devices, (ferrite gauges) some of which are rugged and highly portable. Ferrite is measured in Ferrite Numbers (FN), and the gauges can be calibrated in accordance with AWS A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*. Typically, a minimum of 3 FN is adequate to preclude microcracking, although the specific requirements should be provided in the contract documents for the work. A ferrite gauge is shown in Figure 47.

5.8 Light Source. The inspector should have adequate illumination, either natural or artificial, while performing visual examination. Some codes specify minimum lighting requirements. For example, a fine line approximately

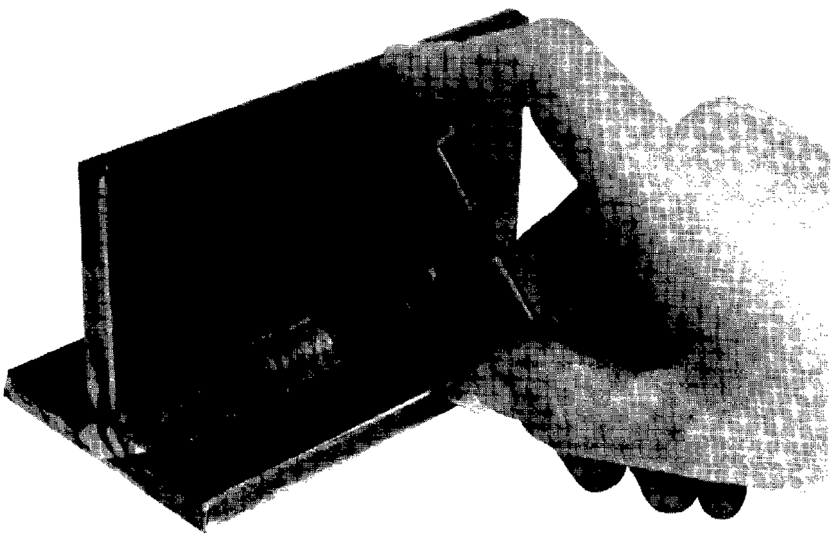

Figure 43—A Multipurpose Gauge

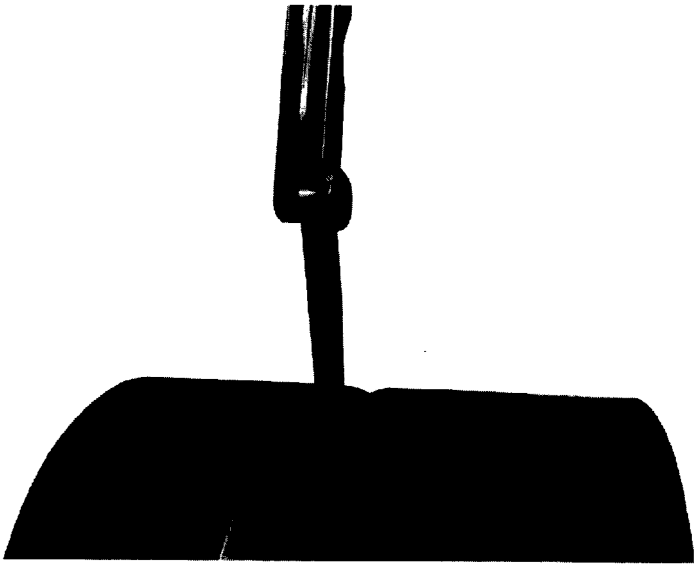

Figure 44—A Taper Gauge

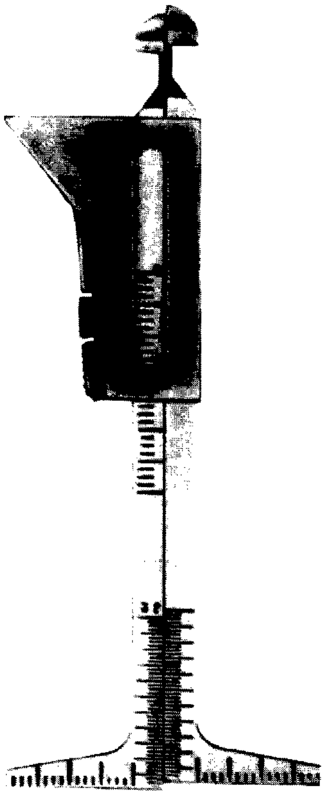

Figure 45—Hi-Lo Mismatch Gauge

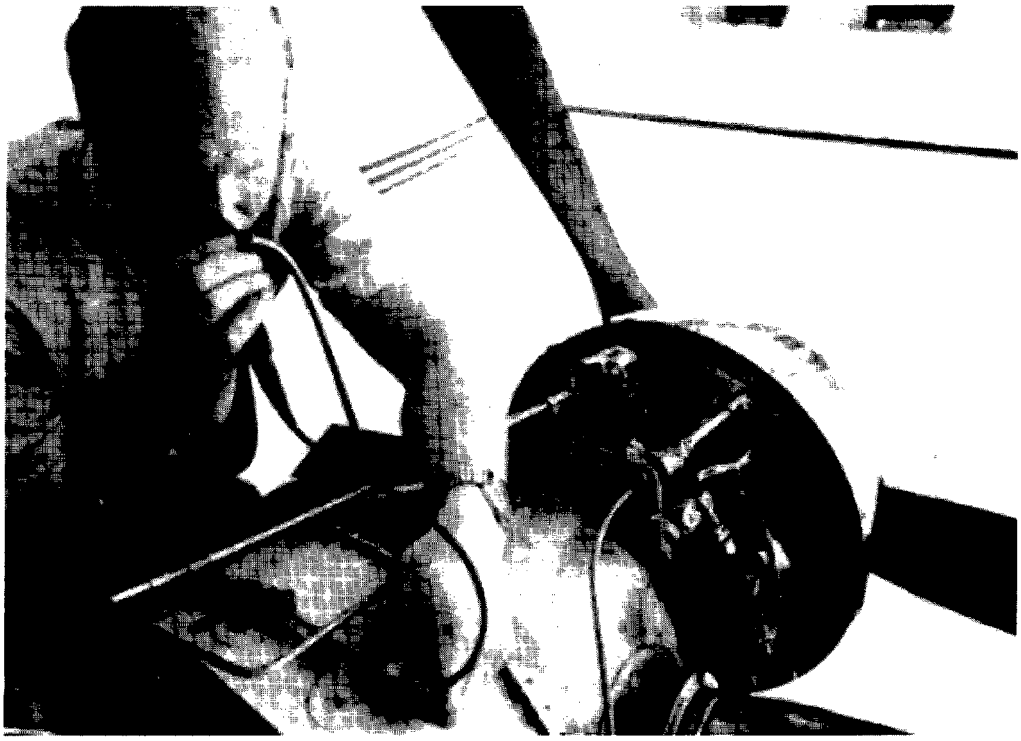

Figure 46—A Fiberscope in Use

Figure 47—Ferrite Indicator (Ferritescope)

1/32 in. (0.8 mm) in width, drawn on a 18% neutral-gray card should be distinctly visible for the lighting to be adequate. Other codes specify minimum footcandles (fc) of illumination that are required while performing visual inspection; for example, 15 fc (16 lux) for general examination, and a minimum of 50 fc (54 lux) for the detection of small discontinuities. If ambient light conditions are inadequate, auxiliary lighting such as a flashlight should be used.

5.9 Ammeters. A tong-type ammeter is a unique, portable instrument that measures current flowing in a circuit without making an electrical connection to it. This is an efficient way to verify that the welding current is within the range specified by the welding procedure. A reading in amperes can be obtained by placing the jaws of the tong tester around a current-carrying conductor, as shown in Figure 48.

Figure 48—Tong Test Ammeter

6. Records

As with any type of inspection, once completed, any defective area should be identified in some manner to assure that it will be located and repaired properly. Many methods are available, so specific conditions may dictate which marking system would be most effective. One method commonly used is to record type, size, and location of any defects so that they can be located, identified, and repaired. Perhaps more effective, however, is the identification of the defective area by marking directly on the part. Some conditions may require utilization of both methods. Whatever method is used, it is all part of an important function.

An inspector should be able to maintain adequate records, and should be able to write clear and concise reports so that others will understand past decisions if they are reviewed later. In preparing the records, the most basic facts should be included, even though they are well known and understood at the time of writing, since they may not be remembered so clearly later. Thus, good records not only protect the inspectors who wrote them, they also help in adhering to a policy of uniform standards.

Any work performed under a specification or code that requires inspection, examination, or tests also requires records. However, whether required or not, the inspector should keep adequate records.

It is also the inspector's duty to examine all records for completeness and accuracy in accordance with specified requirements and to make certain that they are available when needed.

Any records that require the inspector's signature should be prepared by the inspector.

Records should be in as much detail as necessary. The inspector should comment on the general workmanship, the problems incurred, and the resolution of unacceptable conditions. Any repair should be explained. Copies of these records should go to all persons entitled to receive them, and a copy should be kept for the inspector's own files.

Annex A
List of Standards Commonly Used in the Welding Industry

(This Annex is not a part of AWS B1.11:2000, *Guide to the Visual Examination of Welds*, but is included for information purposes only.)

American Society of Mechanical Engineers[1] (ASME). *Boiler and Pressure Vessel Code*. ASME, New York, N.Y.

———. B31.1, *Power Piping*; B31.3, *Chemical Plant and Petroleum Refinery Piping*; B31.4, *Liquid Petroleum Transportation Piping Systems*. ASME, New York, N.Y.

American Petroleum Institute[2] (API). Standard 1104, *Standard for Welding of Pipelines and Related Facilities*. API, Washington, D.C.

American Welding Society[3] (AWS). D1.1, *Structural Welding Code—Steel*. AWS, Miami, Fla.

———. D1.2, *Structural Welding Code—Aluminum*. AWS, Miami, Fla.

———. D1.3, *Structural Welding Code—Sheet Steel*. AWS, Miami, Fla.

———. D1.4, *Structural Welding Code—Reinforcing Steel*. AWS, Miami, Fla.

———. D9.1, *Sheet Metal Welding Code*. AWS, Miami, Fla.

1. ASME documents are available from ASME International, Three Park Avenue, New York, NY 10016.
2. API documents are available from the American Petroleum Institute, 1220 L Street NW, Washington, DC 20005.
3. AWS documents are available from the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

———. D3.6, *Specification for Underwater Welding*. AWS, Miami, Fla.

———. QC-1, *Standard for AWS Certification of Welding Inspectors*. AWS, Miami, Fla.

———. QC-2, *Recommended Practice for the Training, Qualification and Certification of Welding Inspectors Specialist and Welding Inspector Assistant*. AWS, Miami, Fla.

American Institute of Steel Construction[4] (AISC). *Quality Criteria and Inspection Standards*, 2nd Edition. AISC, Chicago, Ill.

———. *Specifications for the Designing, Fabrication and Erection of Safety-Related Structures for Nuclear Facilities*. AISC, Chicago, Ill.

American Bureau of Shipping[5] (ABS). *Rules for Building and Classing Steel Vessels*, Section 43. ABS, New York, N.Y.

Navy specifications.[6] Mil-Std.-248, Mil-Std.-278.

4. AISC documents are available from the American Institute of Steel Construction, 400 N. Michigan Avenue, Chicago, IL 60611.
5. ABS documents are available from the American Bureau of Shipping, Two World Trade Center, 106th Floor, New York, NY 10048.
6. Navy specifications are available from the Naval Publication and Forms Center, 5801 Taber Avenue, Philadelphia, PA 19120.

Annex B
Supplementary Reading Material

(This Annex is not a part of AWS B1.11:2000, *Guide to the Visual Examination of Welds*, but is included for information purposes only.)

ASM International.[7] Nondestructive Evaluation and Quality Control, *Metals Handbook*, Vol. XVII, 9th Ed. Metals Park, Ohio: ASM International, 1989.

American Welding Society (AWS). B1.10, *Guide for the Nondestructive Examinationtion of Welds*. AWS, Miami, Fla.

———. A3.0, *Standard Welding Terms and Definitions*. AWS, Miami, Fla.

———. A2.4, *Symbols for Welding and Nondestructive Examination*. AWS, Miami, Fla.

———. ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*. AWS, Miami, Fla.

———. *Welding Handbook*, Vol. 1, 8th Ed. AWS, Miami, Fla., 1987.

———. *Welding Handbook*, Vol. 2, 8th Ed. AWS, Miami, Fla., 1991.

———. *Welding Handbook*, Vol. 3, 8th Ed. AWS, Miami, Fla., 1996.

———. *Welding Handbook*, Vol. 4, 7th Ed. AWS, Miami, Fla., 1998.

———. *Welding Inspection*, AWS, Miami, Fla., 1980.

The American Society for Nondestructive Testing (ASNT).[8] Visual and Optical Testing, *Nondestructive Testing Handbook*, Vol. 8, Second Ed. Columbus, Ohio: The American Society for Nondestructive Testing, 1993.

7. ASM documents may be obtained from ASM International, Materials Park, OH 44073-0002.

8. ASNT documents may be obtained from the American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, OH 43228.

Annex C
Guidelines for Preparation of Technical Inquiries for AWS Technical Committees

(This Annex is not a part of AWS B1.11:2000, *Guide to the Visual Examination of Welds*, but is included for information purposes only.)

C1. Introduction

The AWS Board of Directors has adopted a policy whereby all official interpretations of AWS standards will be handled in a formal manner. Under that policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

C2. Procedure

All inquiries must be directed to:

Managing Director, Technical Services
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

All inquiries must contain the name, address, and affiliation of the inquirer, and they must provide enough information for the committee to fully understand the point of concern in the inquiry. Where that point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and should also be in the format used here.

C2.1 Scope. Each inquiry must address one single provision of the Standard, unless the point of the inquiry involves two or more interrelated provisions. That provision must be identified in the Scope of the inquiry, along with the edition of the standard that contains the provisions or that the Inquirer is addressing.

C2.2 Purpose of the Inquiry. The purpose of the inquiry must be stated in this portion of the inquiry. The purpose can be either to obtain an interpretation of a Standard requirement, or to request the revision of a particular provision in the Standard.

C2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to quickly and fully understand the point of the inquiry. Sketches should be used when appropriate and all paragraphs, figures, and tables (or the Annex), which bear on the inquiry must be cited. If the point of the inquiry is to obtain a revision of the Standard, the inquiry must provide technical justification for that revision.

C2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry, or the wording for a proposed revision, if that is what inquirer seeks.

C3. Interpretation of Provisions of the Standard

Interpretations of provisions of the Standard are made by the relevant AWS Technical Committee. The secretary of the committee refers all inquiries to the chairman of the particular subcommittee that has jurisdiction over the portion of the Standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation will be an official interpretation of the Society, and the secretary will transmit the response to the inquirer and to the *Welding Journal* for publication.

C4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal.*

C5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS Standards should be limited to questions of a general nature or to matters directly related to the use of the Standard. The Board of Directors' Policy requires that all AWS Staff members respond to a telephone request for an official interpretation of any AWS Standard with the information that such an interpretation can be obtained only through a written request. The Headquarters Staff can not provide consulting services. The staff can, however, refer a caller to any of those consultants whose names are on file at AWS Headquarters.

C6. The AWS Technical Committee

The activities of AWS Technical Committees in regard to interpretations, are limited strictly to the Interpretation of provisions of Standards prepared by the Committee or to consideration of revisions to existing provisions on the basis of new data or technology. Neither the committee nor the Staff is in a position to offer interpretive or consulting services on: (1) specific engineering problems, or (2) requirements of Standards applied to fabrications outside the scope of the document or points not specifically covered by the Standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

AWS Document List

AWS Designation	Title
B1.10	Guide for the Nondestructive Examination of Welds
B1.11	Guide for the Visual Inspection of Welds

For ordering information, contact the AWS Order Department, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126. Telephones: (800) 334-9353, (305) 443-9353, ext. 280; FAX (305) 443-7559.