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Guide for the Visual Inspection of Welds

Prepared by
AWS Committee on Methods of Inspection

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors
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Abstract

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



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Foreword

(This Foreword is not a part of ANSI/AWS B1.11-88, *Guide for the Visual Inspection of Welds*, but is included for information purposes only.)

Visual inspection (VI), 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 inspection methods require the use of eyesight to evaluate the conditions which are present; hence, the term *visual inspection*.

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

The Guide for the Visual Inspection 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, and personnel who need knowledge about basic visual inspection attributes, which would be essential, or desirable, for a particular process. Included in this guide are fundamental prerequisites for performing visual inspection, 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 ANSI/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 C1.1-66, *Recommended Practices for Resistance Welding*, AWS C1.3-70, *Recommended Practices for Resistance Welding of Coated Low Carbon Steels*, and AWS D8.7-78, *Specification for Automotive Weld Quality — Resistance Spot Welding*, published by the American Welding Society.

For the examination of brazed assemblies, refer to the *Brazing Manual*, 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 ANSI/AWS B1.10-86, *Guide for Nondestructive Inspection of Welds*, and in the AWS book *Welding Inspection*.

Comments and inquiries concerning this standard are welcome. They should be sent to the Technical Director, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

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Guide for the Visual Inspection of Welds

1. General Provisions

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 the precise duties and responsibilities defined in particular codes or specifications. Information relative to methods of visual examination (VI) applicable to weldments is provided. 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. In this regard, it is beneficial to consider certification such as that available from the American Welding Society under the certified welding inspector (CWI) program.

Adequate drawings and specifications relating to visual inspection should be supplied as part of the contract. In the absence of such requirements, the manufacturer should be requested to establish, in writing, details of the methods to be used, including methods of examination.

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. The scope of this guide includes an outline of the fundamental requisites for personnel performing visual inspection of welds, such as physical limitations or capabilities, as well as technical knowledge, training, experience, judgement, and certification.

The guide essentially provides an introduction to visual examination related to welding. These inspections 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 inspection may be performed by different people or organizations. Some of the people who may perform visual inspection at the appropriate sequence of welding include welders, welding supervisors, the contractor's welding inspector, the purchaser's examiner, or the regulatory inspector.

Also provided is a review of visual examination equipment aids routinely used, such as gages and lighting equipment recommendations. A section on records presents those aspects which may be considered necessary for formal documentation of visual inspection results. Finally, the guide suggests additional reading or reference, which may provide more detailed requirements for specific visual inspection applications.

2. Prerequisites

2.1 General. As with any other nondestructive inspection method, there are various prerequisites that should be considered prior to performing visual examination.

Some of the more common attributes to consider are discussed as follows.

2.2 Visual Acuity. One of the more obvious prerequisites is that the visual examiner 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 inspection is a requirement of many codes and specifications and is generally considered good practice. An eye examination by a qualified examiner is a prerequisite for certification by AWS as a Certified Welding Inspector (CWI) or a Certified Associate Welding Inspector (CAWI).

2.3 Equipment. Visual examination that requires the use of special tools or equipment will depend upon the application and possibly the degree of accuracy required for the inspection. Some tools may need special qualifications prior to use, as in the example of calibrations. 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 which comply with a particular code and specification, adequate for measuring to the accuracy of the acceptance criteria, or which satisfy the need of the inspection, should be used.

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. Both methods can be formal (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 judgement does not always come easily or readily. Sufficient time should be allowed for different individuals to properly grasp key points pertaining to: joint preparations, welding preheat, interpass temperature, weldment distortion, welding consumables, and other materials. Additionally, sufficient exposure to the many types of workmanship variances should be allowed.

2.5 Procedures. Development of standard procedures covering examination methodology and acceptance criteria is a consideration which may add considerably to consistency and accuracy. Such procedures are normally prepared by the employer and typically consist of detailed instructions which 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. Detailed specific examination factors can be included such as: workmanship, pictorials, attribute check lists, equipment requirements, and other items.

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. Certification is a testimony of qualification. The American Welding Society offers Certified Welding Inspector (CWI) and Certified Associate Welding Inspector (CAWI) programs. Other programs for the certification of visual welding inspectors may be used.

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.). Any personnel working or coming into contact with a welding environment should seek training in welding safety.

3. Fundamentals of Visual Inspection

3.1 General. Many programs instituted by the manufacturer or fabricator to control the quality of the products utilize visual examination as the primary, and in some instances the only, evaluative method of inspection. It can be an invaluable tool when properly applied. In addition to locating surface flaws, visual examination can be an excellent process control technique to help identify subsequent fabrication problems.

Visual examination is a method for identifying surface flaws and imperfections. Consequently, any conscientious quality control program consisting essentially of visual inspection should include a continual sequence of examinations performed during all phases of fabrication. This will allow visual inspection of the exposed surfaces as they occur in the fabrication sequence.

Discovery and repair of any defects at that time results in substantial cost reduction. It has been shown that a conscientious program of visual inspection occurring before, during, and after welding can result in discovery of the majority of all defects which would have been detected later using more extensive test methods. Fabricators realize the benefit of a well-disciplined visual inspection quality system.

The effectiveness of visual inspection is improved when a system is instituted which provides for coverage at all phases of the welding process (before, during, and

after welding). The sooner the examination process is introduced into the system, the better the coverage.

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

- (1) Review drawings and specifications.
- (2) Check qualification of procedures and personnel to be utilized.
- (3) Establish check points.
- (4) Set up a plan for the recording of results.
- (5) Review materials to be utilized.
- (6) Check for base metal discontinuities.
- (7) Check fit-up and alignment of weld joints.
- (8) Check preheat, if required.

If the inspector pays particularly close attention to these preliminary items, many problems which might occur later can be prevented. It is very important that the inspector knows exactly what requirements are to be met. Review of the governing documents will supply these data. Once these are reviewed, a system should be established to assure that accurate and complete records can be practically produced.

3.2.1 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 steps. This is of utmost importance on large construction projects or massive welded fabrications.

3.2.2 Welding Procedures. Another preliminary step which should occur is to assure that the applicable welding procedures comply with the job requirements. The proper documentation of the qualification or certifications of the individual welders should be reviewed as well. The drawings and specifications will dictate what base metals are to be joined and what filler metal will be utilized. For structural welding and other critical applications, welding is normally carried out in accordance with qualified procedures which record the essential variables of the process and by welders qualified for the process, material, and position to be welded. Additional procedural steps might be needed to accommodate certain materials. An example of a procedural step is that where low-hydrogen electrodes are specified, storage facilities as recommended by the manufacturer are required.

3.2.3 Base Materials. Prior to welding, identification of the material type and a thorough examination of the specific base metals should be made. If a discontinuity, such as a plate lamination, is present and remains undetected, it may affect the overall structural integrity

of the weldment. Many times a lamination will be visible along a plate edge, especially on an oxygen-cut edge.

3.2.4 Joint Fit-Up. For a weld, the most critical part of the base material is that area which has been prepared to accept weld metal in some form of joint shape. The importance of the joint fit prior to welding cannot be stressed enough. Therefore, the visual examination of joint fit-up is of highest priority. 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

All of these factors could have a direct bearing on the resultant weld quality. If the fit-up is poor, then the weld will most likely be of substandard quality as well. 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 for fillet welds exhibits an excessive root opening, the size of the required fillet weld should be increased by the amount of root opening present. So, if the inspector knows that this situation exists, the drawing or weld joint can be marked accordingly, and final determination of weld size compliance can be correctly interpreted.

3.3 During Welding. During welding, there are a number of items which require control so that the resulting weld will be satisfactory. Visual examination is the primary method for controlling this aspect of the fabrication. It can prove to be a valuable process control tool. Some of the aspects of fabrication which can be checked include:

- (1) Quality of weld root bead
- (2) Joint root preparation prior to welding the second side
- (3) Preheat and interpass temperatures
- (4) Sequence of weld passes
- (5) Subsequent layers for apparent weld quality
- (6) Cleaning between passes
- (7) Conformance with the applicable procedure; i.e. voltage, amperage, heat input, speed.

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

3.3.1 Weld Root Pass. Perhaps the most critical part of any weld is the weld root pass. Problems which exist at this point in the progression combine to make the successful completion of the balance of the weld difficult to accomplish. Consequently, a great many defects which are later discovered in a weld are associated with the weld root bead. Good visual inspection following the application of the weld root bead will help to improve the situation. Another critical joint root condition exists whenever second side treatment is applied to a double-welded joint. This usually includes removal of slag and other irregularities by chipping, thermal gouging, or grinding. Once this removal process has been accomplished, examination of the excavated area prior to welding the second side is required. This is to assure that all discontinuities have been removed. The size or shape of the groove may have to be altered to allow for suitable access to all surfaces.

3.3.2 Preheat and Interpass Temperatures. Preheat and interpass temperatures can be critical and, if specified, be measured. The limits are often described as a minimum, a maximum, or as both. Also, to help in controlling the amount of heat in the weld zone, the sequence and placement of the individual passes can be important. The inspector should always be conscious of the extent and location of any distortion or shrinkage caused by the welding heat. Many times, corrective measures can be taken as the welding heat progresses to alleviate the problem.

3.3.3 Between Layer Examination. To evaluate the quality of the weld as work progresses, it is wise to examine each layer visually to judge its integrity. 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. Many of these items may be addressed in the applicable welding procedure. In that case, visual inspection performed during the welding is basically a check to determine if there is compliance with the requirements of the welding procedure.

3.4 After Welding. Many people feel that visual inspection commences once the welding has been completed. However, if all of the previously discussed steps have been taken before and during welding, this final phase of visual inspection will be accomplished easily. It will simply provide a check to be sure that the steps taken have resulted in a satisfactory weld. Some of the various items which require attention after welding has been completed are

- (1) Final weld appearance
- (2) Final weld size
- (3) Weld length

- (4) Dimensional accuracy
- (5) Amount of distortion
- (6) Post-weld heat treatment

The basic purpose of final weld inspection is to assure the weld's quality. Therefore, visual examination of several things are required. Most codes and specifications describe the extent of the discontinuities that are acceptable, and many of these can occur on the surface of the completed weld.

3.4.1 Discontinuities. Typical discontinuities found in welds are

- (1) Porosity
- (2) Incomplete fusion
- (3) Incomplete joint penetration
- (4) Undercut
- (5) Overlap
- (6) Cracks
- (7) Slag inclusions
- (8) Excessive reinforcement

While code requirements may permit limited amounts of some of these discontinuities, cracks, and incomplete fusion defects are almost never allowed. For structures exposed to cyclic or fatigue loading, the criticality of these surface discontinuities is increased. In conditions such as these, visual examination of the surface may be the most important inspection which can be performed. The existence of undercut, overlap, and improper contour results in stress raisers; fatigue loading can cause premature failures which propagate from these naturally occurring transitions. That is why, many times, the proper contour of a weld can be much more important than the actual weld size, since a slightly undersized weld, free of abrupt surface irregularities, could perform more satisfactorily than a weld of adequate size exhibiting a poor contour.

To determine if compliance has been attained, the examiner should check to see if all welds meet drawing requirements for size and location. Fillet weld sizes can be determined by using one of several types of weld gages to provide a more efficient and accurate measurement of size. Groove welds should be measured for proper reinforcement on both sides of the joint. Some conditions may require the fabrication of special weld gages.

3.4.2 Post Weld Heat Treatment. Due to size, shape, or base metal type, postweld heat treatment may be specified in the welding procedure. This may involve only the application of heat at or near the interpass temperature range to provide a postweld condition that will aid in metallurgical control of the final weldment properties. Heating at the interpass temperature will not affect the microstructure, except in rare cases. Some

conditions may require the accomplishment of a thermal stress relief treatment. Here, the weldment is gradually heated at a prescribed rate to the stress relief range of approximately 1100° to 1200°F, (590° to 650°C) for most carbon steels. After holding at this temperature for about one hour for each inch of base metal thickness, the weldment is allowed to cool to about 600°F (315°C) at a controlled rate. The inspector may be responsible for monitoring this operation to assure that the procedure requirements have been met.

3.4.3 Final Dimensional Examination. Another measurement that affects the performance of a weldment is its dimensional accuracy. If a welded part will not fit an assembly, it may be useless, even though the weld is of adequate quality. Welding heat will distort the base metal, and can alter overall component dimensions. Therefore, dimensional examination after welding may be required to determine the weldment's fitness for its intended use.

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 inspection after the weld is completed is limited to the surface condition of the weld. Discovery of subsurface defects requires that a visual examination be supplemented by other NDE methods.

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 not necessarily a defect. Discontinuities are

rejectable only if they exceed specification requirements in terms of type, size, distribution, or location. A rejectable discontinuity is referred to as a defect. By definition, a defect is a discontinuity whose size, shape, orientation, or location makes it detrimental to the useful service of the part in which it occurs. Discontinuities may be found in the weld metal, heat affected zone, or base metal of many weldments. Four basic weld joints are considered in this guide: butt, T, corner, and lap.

Weld and base metal discontinuities of specific types are more common when certain welding processes and joint details are used. An example is the tungsten inclusion, which only occurs in welds made using gas tungsten arc welding. Other conditions, such as 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. Other documents may use different terminology for some of these discontinuities; however, whenever possible, the approved AWS terminology, as found in ANSI/AWS A3.0, *Standard Welding Terms and Definitions*, should be used to eliminate confusion. An example of additional terminology occurs in ANSI/AWS D1.1, *Structural Welding Code — Steel*. There, "fusion-type discontinuity" is a general term which is used to describe a number of various discontinuities, including: slag inclusions, incomplete fusion, incomplete joint penetration, and similar elongated discontinuities in fusion welds. Another type of discontinuity is caused by loss of shielding gas, see Figure 1. These discontinuities are of general interest to owners, designers, and fabricators.

4.2 Porosity. Porosity is characterized by cavity type discontinuities formed by gas entrapment during solidification. The discontinuity formed is generally spherical but may be cylindrical. Often, porosity is an indication

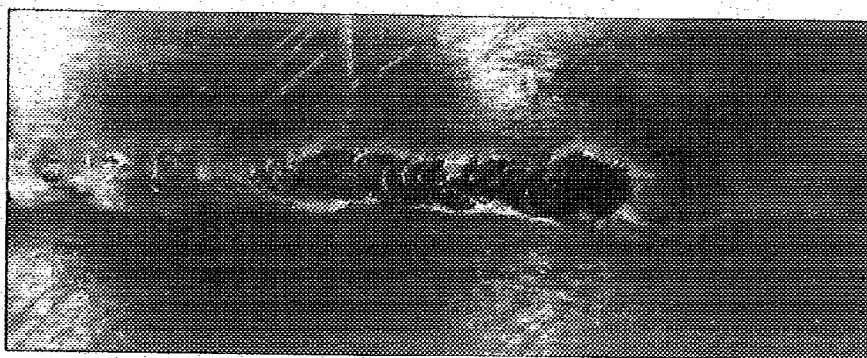


Figure 1 — Surface Oxidation (Sugaring) in a Stainless Steel Gas Tungsten Arc Weld

that the welding process is not being properly controlled, or that the base metal or filler metal is contaminated, or that the base metal is of a composition incompatible with the welding filler metal and process.

4.2.1 Scattered Porosity. Scattered porosity is porosity widely distributed in a single weld bead or in several beads of a multiple pass weld. Porosity will be present in a weld if the welding technique, or materials used or the conditions of the weld joint preparation, lead to gas formation and entrapment. If welds cool slowly enough to allow gas to pass to the surface before weld solidification, there will generally be no porosity in the weld. Figure 2 illustrates the presence of scattered porosity.

4.2.2 Cluster and Linear Porosity. Cluster porosity is a localized group of pores. It often results from improper starting or stopping of the welding pass. Conditions causing arc blow can also result in cluster porosity. Linear porosity is a number of pores which are aligned. It often occurs along the weld interface, the weld root, or an inter-bead boundary, and develops by contamination that causes gas to be liberated at those

locations. An example of linear porosity, with an accompanying longitudinal crack, is shown in Figure 3.

4.2.3 Piping Porosity. Piping porosity (also referred to as wormhole or elongated porosity) is a term for elongated gas discontinuities. Piping porosity in fillet welds extends from the weld root toward the weld face. When a few pores are seen in the weld face, careful excavation will often show that there are many subsurface pores that do not extend all the way to the weld face. Figure 4 is an illustration of some surface pores which, when excavated, were determined to be piping porosity.

4.3 Incomplete Fusion. Incomplete fusion is termed as fusion which does not occur over the entire base metal surfaces intended for welding and between all adjoining weld beads. Figure 5 depicts incomplete fusion which has occurred at various locations in the weld. Figure 6 shows incomplete fusion pictorially that would not be apparent during visual inspection, but would be detected by radiography or ultrasonic examination.



Figure 2 — Scattered Porosity

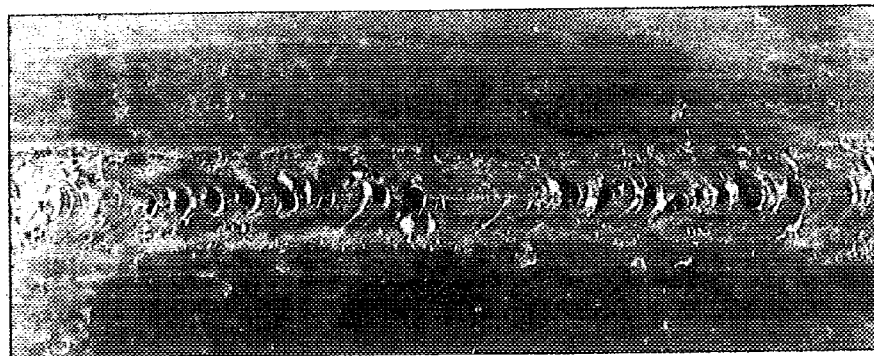


Figure 3 — Linear Porosity with Crack

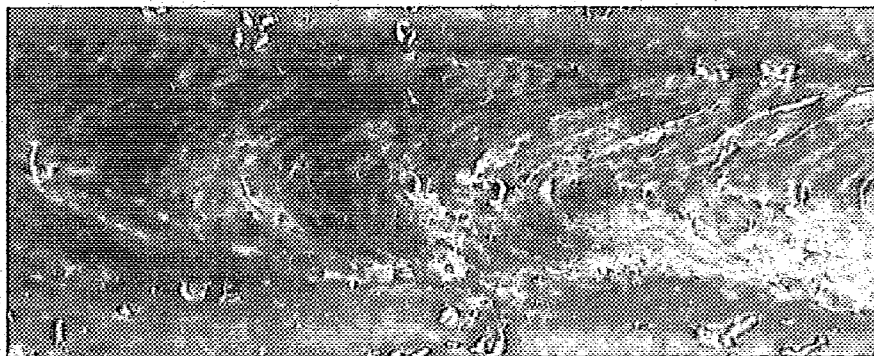


Figure 4 — Surface Appearance of Piping Porosity

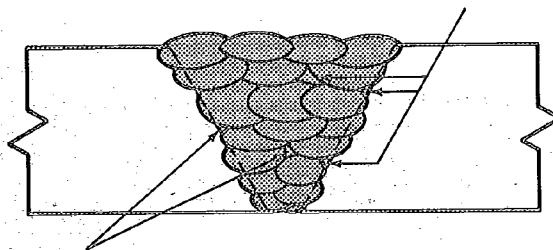


Figure 5 — Various Locations of Incomplete Fusion

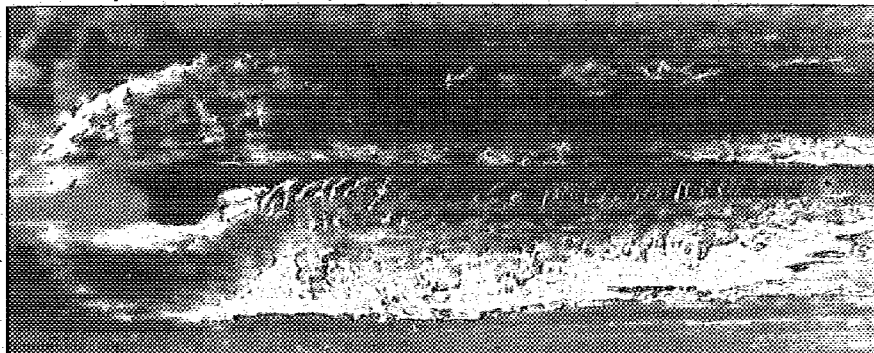


Figure 6 — Incomplete Fusion

Incomplete fusion can result from insufficient heat input or the improper manipulation of the welding electrode. While it is a discontinuity more commonly associated with weld technique, it could also be caused by the presence of contaminants on the surface being welded.

Figure 7 shows an example of incomplete fusion occurring at the groove face of a flux cored arc weld in steel. Figures 8 and 9 show the presence of incomplete fusion (cold lap) between individual weld beads and between the weld and base metals. These conditions were found in gas metal arc welds in aluminum.



Figure 7 — Incomplete Fusion at the Groove Face

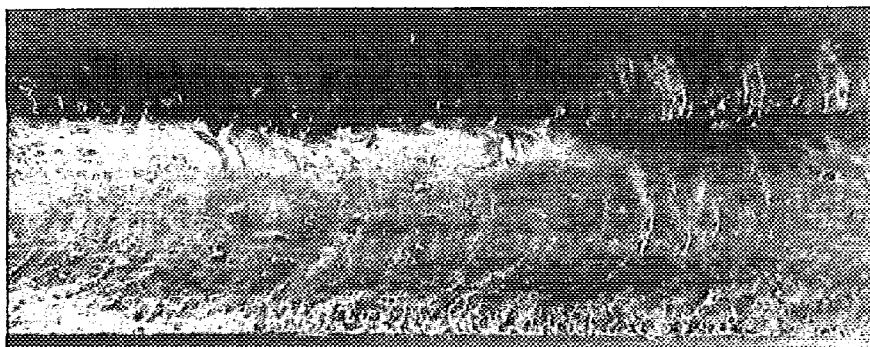


Figure 8 — Incomplete Fusion Between Weld Beads

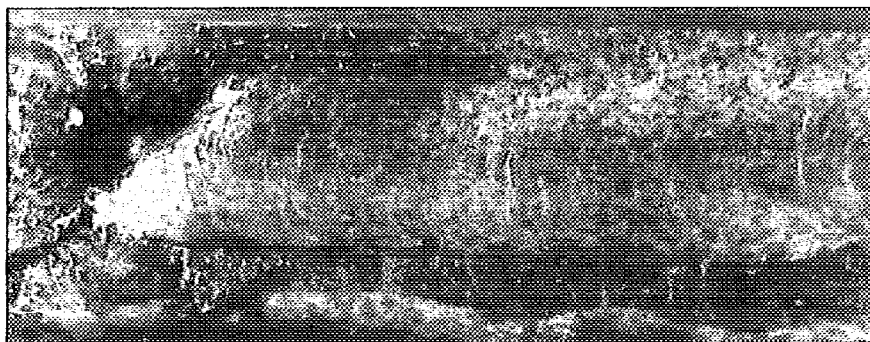


Figure 9 — Incomplete Fusion Between the Weld and Base Metal

4.4 Incomplete Joint Penetration. Incomplete joint penetration is defined as penetration by weld metal that does not extend for the full thickness of the base metal in a joint with a groove weld. Figure 10 depicts some conditions which are classified as incomplete joint penetration. The condition shown for the single V-groove weld will only be evident using visual examination if there is access to the weld root side. The condition shown on the double bevel T-joint will not be evident on the completed weld, except at the starts and stops.

Incomplete joint penetration may result from insufficient welding heat, improper lateral control of the welding arc, or improper joint configuration. Some welding processes have greater penetrating ability than others and would therefore be less susceptible to this problem. Many designs call for back gouging the weld root with subsequent welding on that same side to ensure that there are no areas of incomplete joint penetration or incomplete fusion. Pipe welds are especially vulnerable to these discontinuities, since the joint is usually inaccessible for welding from the root side. Often a backing ring or consumable insert is employed to aid welders in such cases (see Figure 11). Figure 12 is a photograph depicting incomplete joint penetration at the weld root.

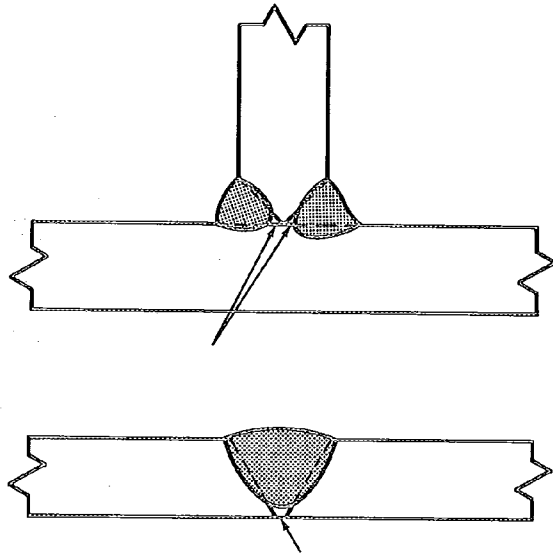


Figure 10 — Incomplete Joint Penetration

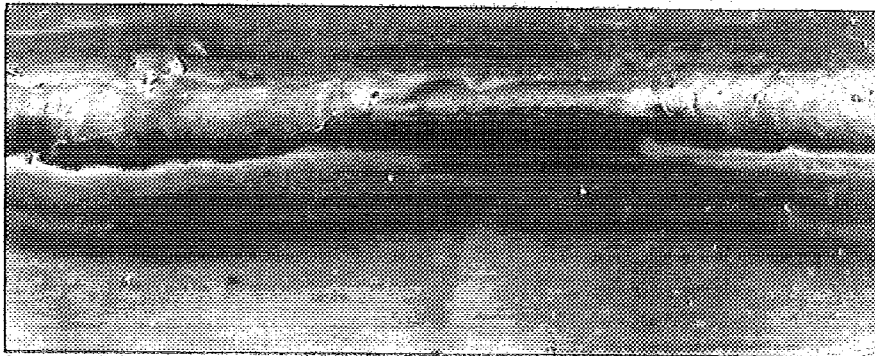


Figure 11 — Incomplete Fusion with Consumable Insert

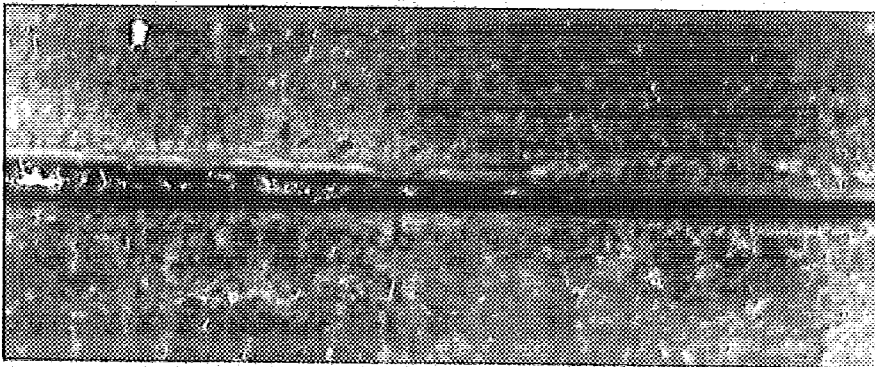


Figure 12 — Incomplete Joint Penetration

4.5 Undercut. Undercut creates a transition which should be evaluated for a reduction in cross section, and for stress concentrations or notch effect when fatigue is a consideration. Undercut, controlled within the limits of the specification, is not usually considered a weld defect. Undercut is generally associated with improper welding techniques or weld parameters, excessive welding currents or voltages, or both. Figure 13 shows the common configurations of undercut. Figure 14 is a photograph of undercut at the toe of a fillet weld in steel.

4.6 Underfill. Underfill is a depression on the weld face or root surface extending below the adjacent surface of the base metal. Underfill is usually defined as a condition where the total thickness through a weld is less than the thickness of the adjacent base metal. It results

from the failure of a welder or welding operator to completely fill the weld joint when called for in the job specifications, and is rarely acceptable. Figure 15 illustrates the configurations of underfill. A nonstandard term for underfill at the root surface of a pipe weld is "internal concavity." Figure 16 shows the presence of underfill in a flux cored arc weld in steel.

4.7 Overlap. Overlap is the protrusion of weld metal beyond the weld toe, or weld root. It can occur as a result of poor control of the welding process, improper selection of the welding materials, or improper preparation of materials prior to welding. If there are tightly adhering oxides on the base metal that interfere with fusion, overlap will often result. Figure 17 depicts overlap conditions.

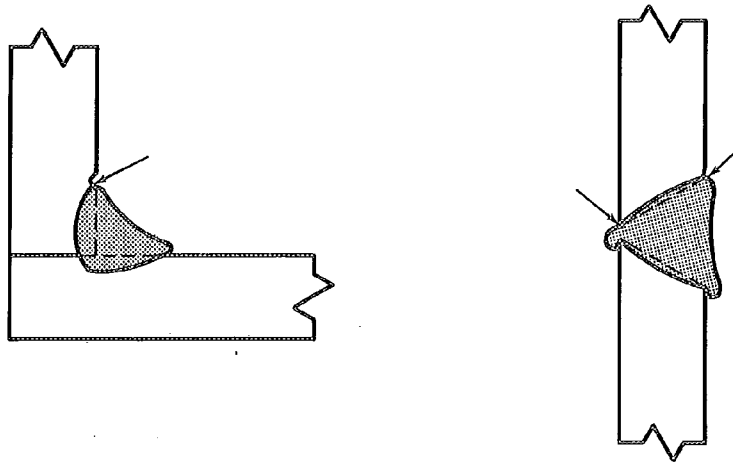


Figure 13 — Examples of Undercut



Figure 14 — Undercut at Fillet Weld Toe

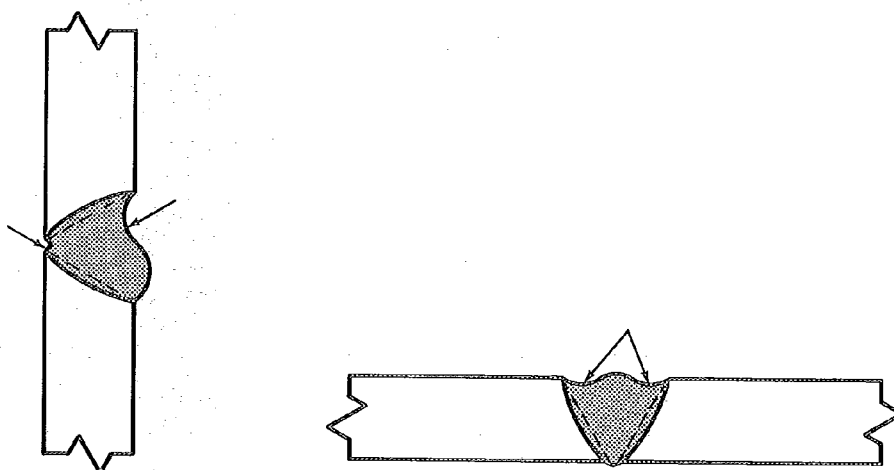


Figure 15 — Underfill

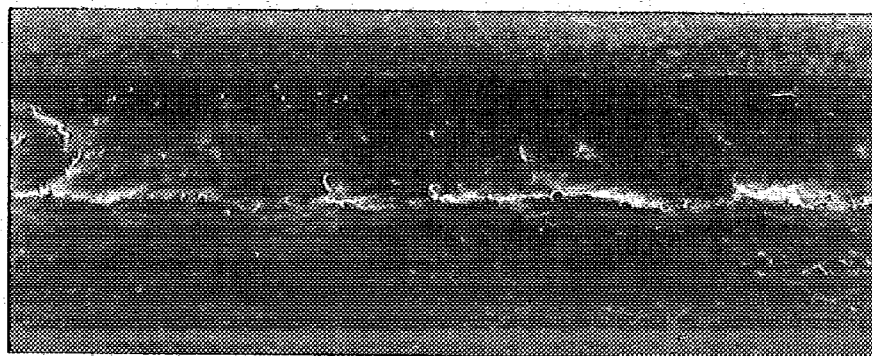


Figure 16 — Underfill Using Flux Cored Arc Welding in Steel

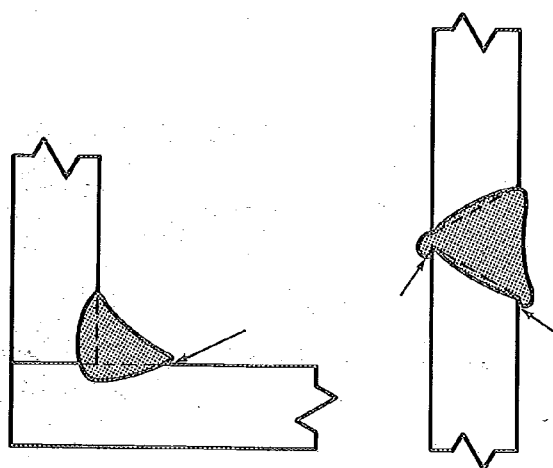


Figure 17 — Overlap

Overlap is a surface discontinuity that forms a mechanical notch, and is nearly always considered rejectable. An illustration of overlap is shown in Figure 18.

4.8 Laminations. Laminations are flat, generally elongated, base metal discontinuities found in the central thickness area of wrought products. An example is depicted in Figure 19.

Laminations may be completely internal, and are then only detected nondestructively by ultrasonic testing. They may also extend to an edge or end where they are visible at the surface and may be detected by visual, penetrant, or magnetic particle testing. They may also be revealed when exposed by cutting or machining operations.

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 bars and plates. Some laminations are partially forge welded along their interface by the high temperatures

and pressures of the rolling operation. Tight laminations will sometimes conduct sound across the interface and, therefore, may not be fully evaluated by ultrasonic testing.

4.9 Seams and Laps. Seams and laps are longitudinal base metal discontinuities sometimes found in forged and rolled products, or both. They differ from laminations in that they propagate to the rolled surface even though they may run in a lamellar direction (parallel to the rolled surfaces) for some portion of their length. When one of these discontinuities lies parallel to the principal stress, it is not generally considered to be a critical flaw. However, 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 and should be avoided.

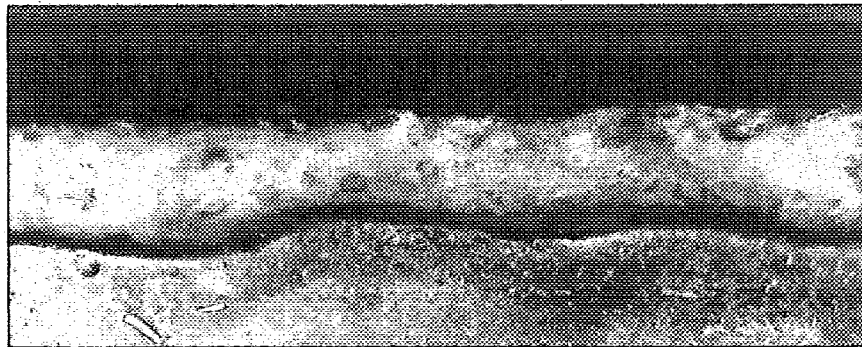


Figure 18 — Overlap



Figure 19 — Laminations

4.10 Cracks. Cracks form in the weld and base metal when localized stresses exceed the ultimate strength of the material. Cracking may occur at elevated temperatures during weld metal solidification, or after solidification, when the weldment has equalized in temperature. Cracking is generally associated with stress amplification near discontinuities in welds and base metal, or near notches associated with the weld joint design. High residual stresses are generally present, and hydrogen embrittlement is often also a contributor to crack formation. Welding related cracks are generally brittle in nature, exhibiting little plastic deformation at the crack boundaries. Figure 20 depicts the various types and locations of weld zone cracks, some of which will not be visible during visual examination of the weld surface.

Cracks can be classified as either hot cracks or cold cracks. Hot cracks develop at elevated temperatures. They form on solidification of the metal at tempera-

tures near the melting point. Cold cracks develop after solidification is complete. Cracking associated with hydrogen embrittlement, commonly referred to as "delayed cracking," is a form of cold cracking. Hot cracks propagate along grain boundaries. Cold cracks propagate both along grain boundaries and through grains.

4.10.1 Orientation. Crack orientation may be termed longitudinal or transverse, depending on the crack direction with respect to the weld axis. 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 the weld metal or a toe crack in the heat affected zone of the base metal. Transverse cracks lie perpendicular to the weld axis. These may be limited in size and confined to the weld metal or they may propagate from the weld into the adjacent heat affected zone and into the base metal. In some weldments, transverse cracks will form

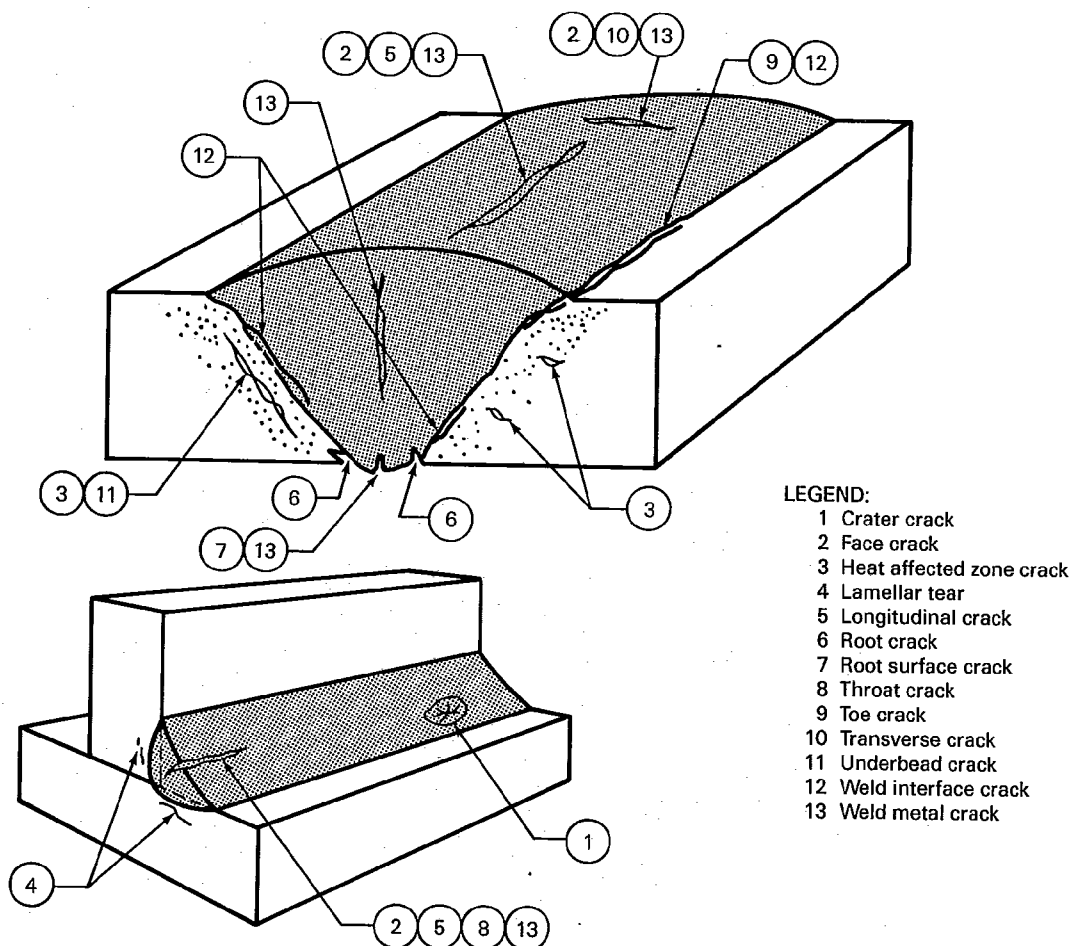


Figure 20 — Various Types of Cracks

in the heat affected zone and not in the weld. Longitudinal cracks in welds, made by machine welding, are commonly associated with high welding speeds and are sometimes related to porosity that does not show at the weld face. Welds having high depth to width ratios may also be susceptible to longitudinal cracking due to the resulting solidification patterns. Longitudinal cracks in small welds between heavy sections are often the result of rapid cooling rates and high restraint. Cold transverse cracks are generally the result of longitudinal shrinkage stresses acting on hard weld metal of low ductility. Figure 21 shows, schematically, the appearance of both longitudinal and transverse cracks. Figure 22 is

a photograph of a longitudinal crack which has propagated along the weld between pores of linear porosity. Figure 23 shows two transverse weld metal cracks occurring in a multipass gas metal arc weld in a high strength steel weldment.

4.10.2 Throat Cracks. Throat cracks are longitudinal cracks in the weld face in the direction of the weld axis. They are generally, but not always, hot cracks. An example of a throat crack in a fillet weld is shown in Figure 24.

4.10.3 Root Cracks. Root cracks are longitudinal cracks in the weld root. They are generally hot cracks.

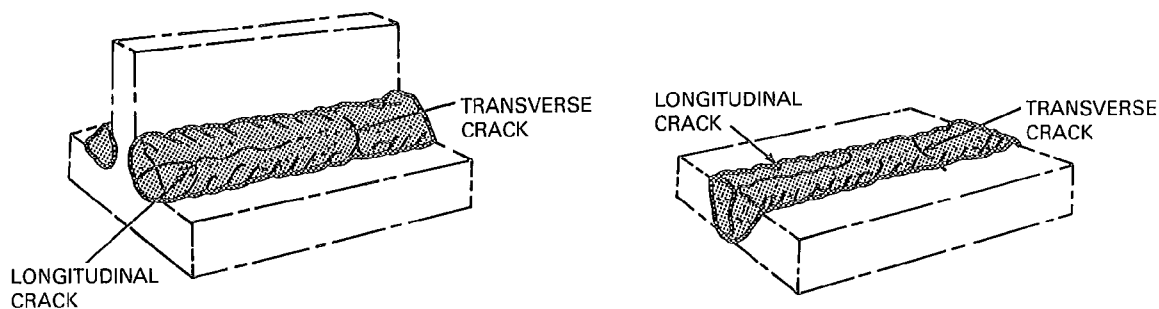


Figure 21 --- Longitudinal versus Transverse Cracks

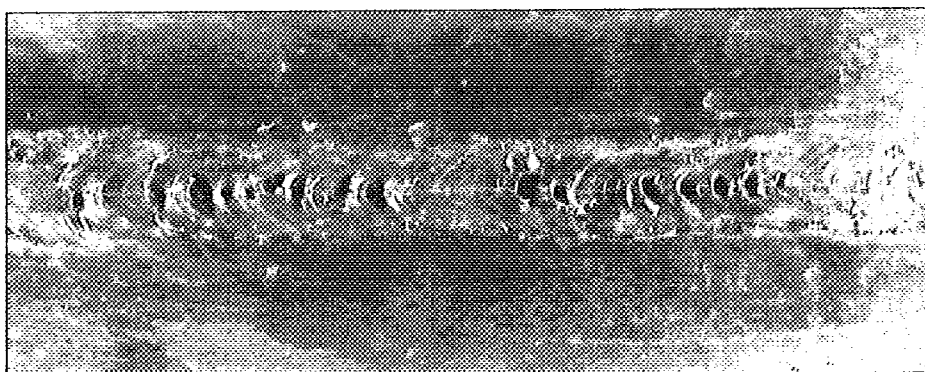


Figure 22 --- Longitudinal Crack and Linear Porosity

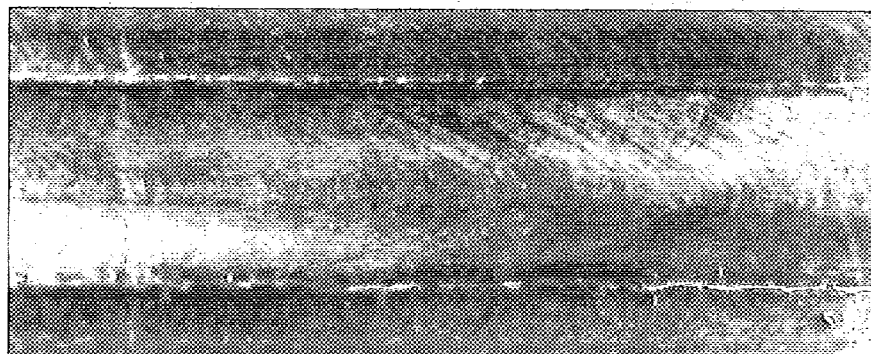


Figure 23 — Transverse Cracks

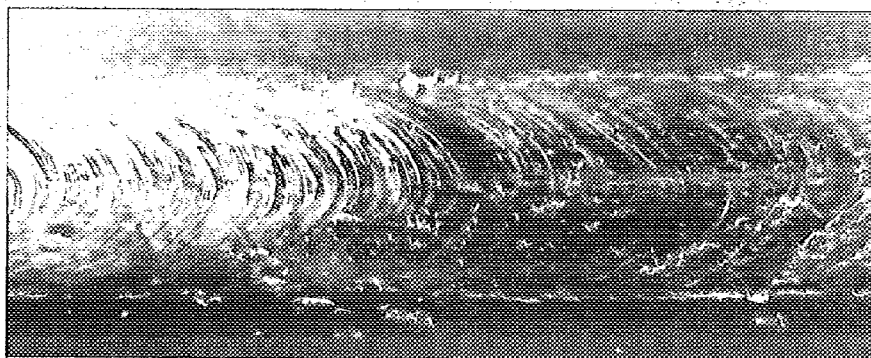


Figure 24 — Throat Crack

4.10.4 Crater Cracks. Crater cracks occur in the weld crater and are formed by improper termination of the welding arc. A nonstandard term for crater cracks is star crack though they may have other shapes. Crater cracks are shallow hot cracks usually forming a multi-pointed star-like cluster. Figure 25 shows a crater crack occurring in an aluminum gas tungsten arc tack weld. In Figure 26 another aluminum gas tungsten arc weld is pictured, where the exiting crater crack propagated into a longitudinal throat crack around the circumference of the circular fillet weld.

4.10.5 Toe Cracks. Toe cracks are generally cold cracks. They initiate and propagate from the weld toe where restraint stresses are highest. Abrupt profile changes at the toe caused by excessive convexity or

weld reinforcement can amplify stresses, making the weld toe a more likely area for cracking to occur. Figure 27 shows the appearance of toe cracks in a T-joint, and Figure 28 shows a photograph of a toe crack.

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 heat affected zone cannot accommodate the shrinkage stresses that are imposed by welding.

4.10.6 Underbead and Heat Affected Zone Cracks. Underbead and heat affected zone cracks are generally cold cracks that form in the heat affected zone of the

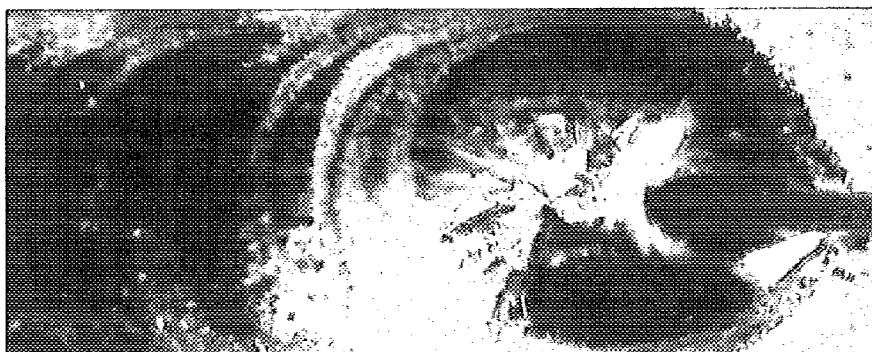


Figure 25 — Crater Crack



Figure 26 — Longitudinal Cracks Propagating from Crater Crack

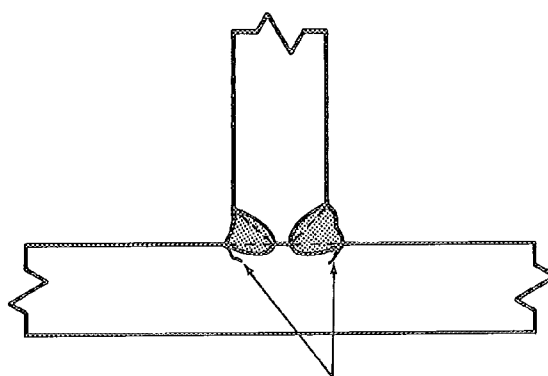


Figure 27 — Toe Cracks

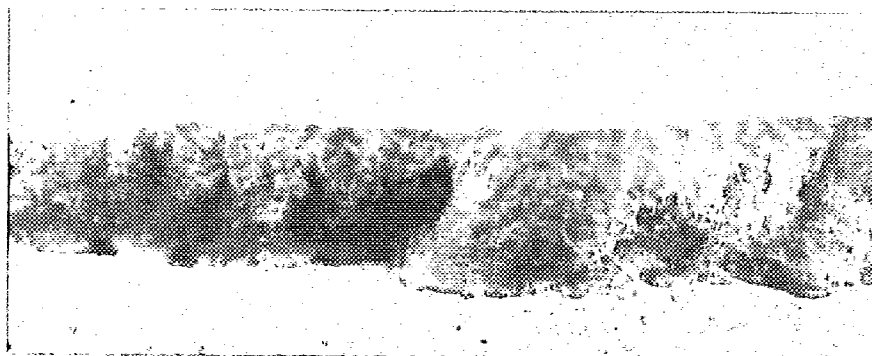


Figure 28 — Toe Cracks

base metal. Underbead and heat affected zone cracks can be either longitudinal or transverse. They are found at regular intervals under the weld and also outline boundaries of the weld where residual stresses are highest. Underbead cracks can become a serious problem when the following three elements are present simultaneously:

- (1) Hydrogen
- (2) Crack-susceptible microstructure
- (3) Stress

Figure 29 depicts the occurrence of underbead cracking, which cannot be detected by visual examination, except if the material is sectioned.

4.11 Slag Inclusion. Slag inclusions are nonmetallic solid material entrapped in weld metal or between weld metal and base metal. Slag inclusions are regions within the weld cross section or at the weld surface where the once-molten flux used to protect the molten metal is mechanically trapped within the solidified metal. This solidified slag represents a portion of the weld's cross section where the metal is not fused to itself. This can result in a weakened condition which could impair the serviceability of the component. Although normally thought of as being subsurface discontinuities, inclusions may also appear at the weld surface, as seen in Figure 30. Like incomplete fusion, slag inclusions can occur between the weld and base metal or between individual weld passes. In fact, slag inclusions are often associated with incomplete fusion.

4.12 Weld Reinforcement. Weld reinforcement is weld metal in excess of the quantity required to fill a groove weld. It is that amount of weld metal in a groove weld that is above the base metal surface, as shown in Figure 31.

All weld reinforcement produces a notch effect at the weld toe. Weld reinforcement, when excessive, does not add to the strength of the weld but may act as a stress raiser to amplify the applied stress. Greater reinforcements are associated with reduced reentrant angles, which result in greater notch effects. Reinforcements which are excessive tend to produce significant notch effects at the toe of the weld, which act as stress raisers and can produce cracking in service.

4.13 Convexity and Concavity. Convexity is the maximum distance from the face of a convex fillet weld perpendicular to a line joining the weld toes. Convexity, as shown in Figure 32, is a term applied to a fillet weld. Like weld reinforcement, when the amount of this convexity is excessive, the notch created at the weld toe could result in toe cracking. During welding, excessive convexity can occur in the intermediate beads of multi-pass welds which may inhibit the cleaning process and may lead to slag inclusions or incomplete fusion. Figure 33 depicts the presence of convexity.

Concavity is the maximum distance from the face of a concave fillet weld perpendicular to a line joining the weld toes. Concavity is only considered detrimental when it results in an undersized weld. See Figure 34.

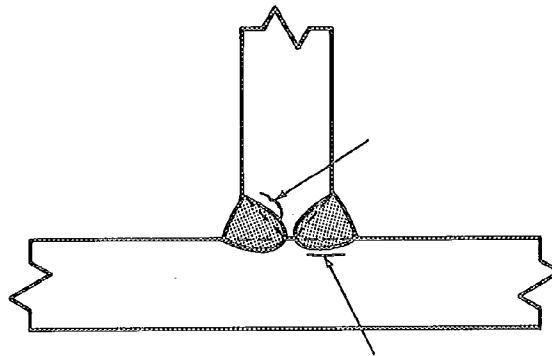


Figure 29 — Underbead Cracks

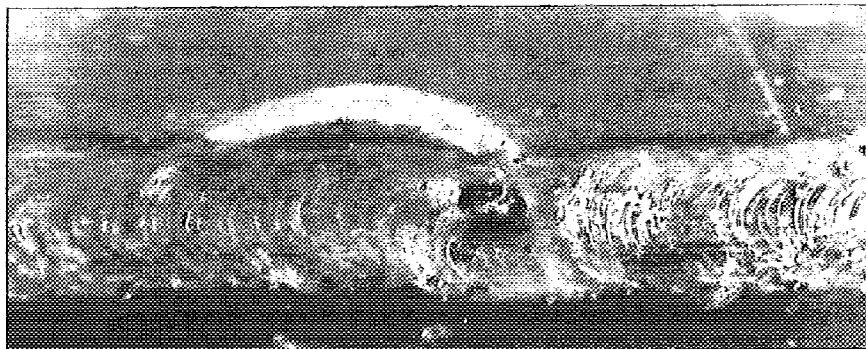


Figure 30 — Slag Inclusion

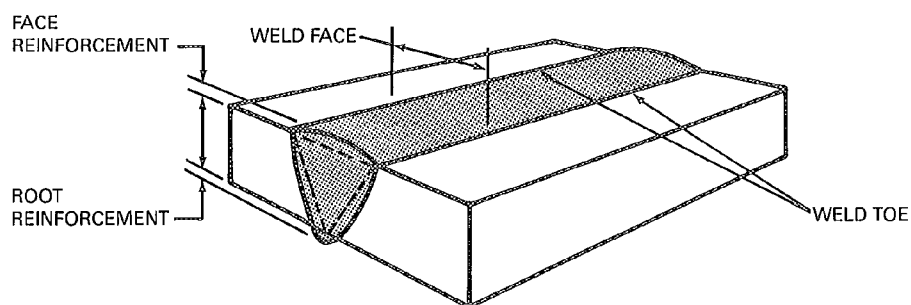


Figure 31 — Weld Reinforcement

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 which is melted and then rapidly cooled due to the massive heat sink created by the surrounding base metal. Arc strikes are not desirable and often not acceptable, as they could lead to cracking during the cooling process or under fatigue conditions.

4.15 Spatter. Spatter consists of metal particles expelled during fusion welding that do not form a part of the weld. Those particles that are actually attached to the base metal adjacent to the weld are the most disconcerting form of spatter. Particles which are thrown away from the weld and base metal are, by definition, spatter. In total, spatter is particles of metal which comprise the difference between the amount of filler metal melted and the amount of filler metal actually deposited in the weld joint.

Normally, spatter is not considered to be a serious flaw unless its presence interferes with subsequent oper-

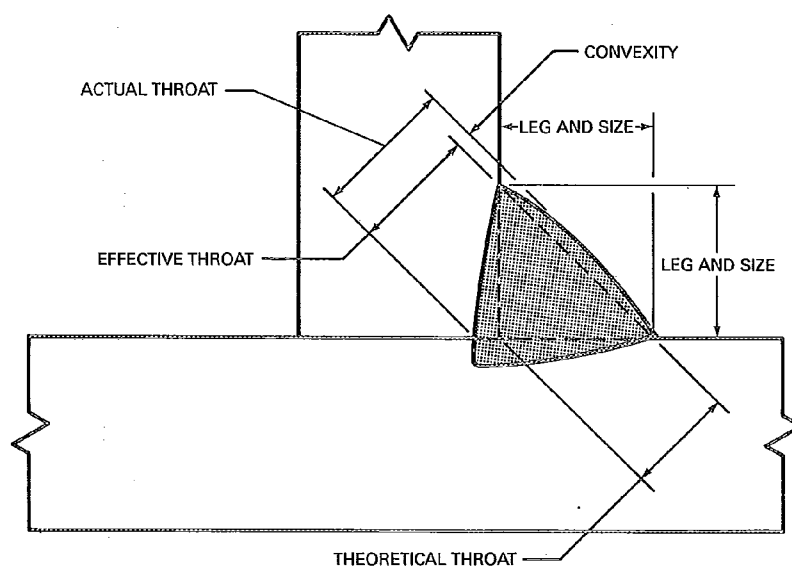


Figure 32 — Convex Fillet Weld

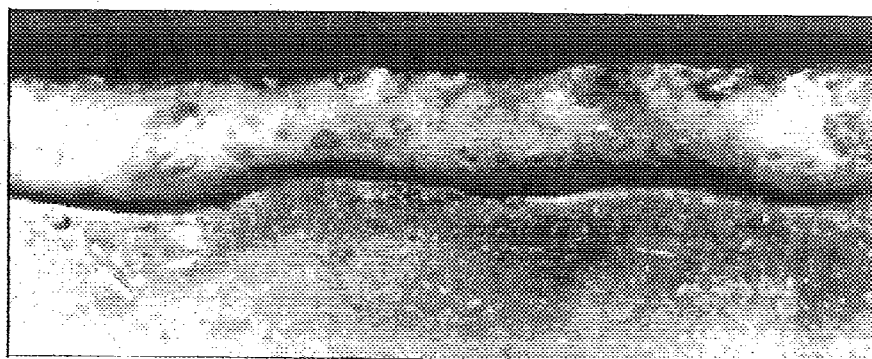


Figure 33 — Convexity

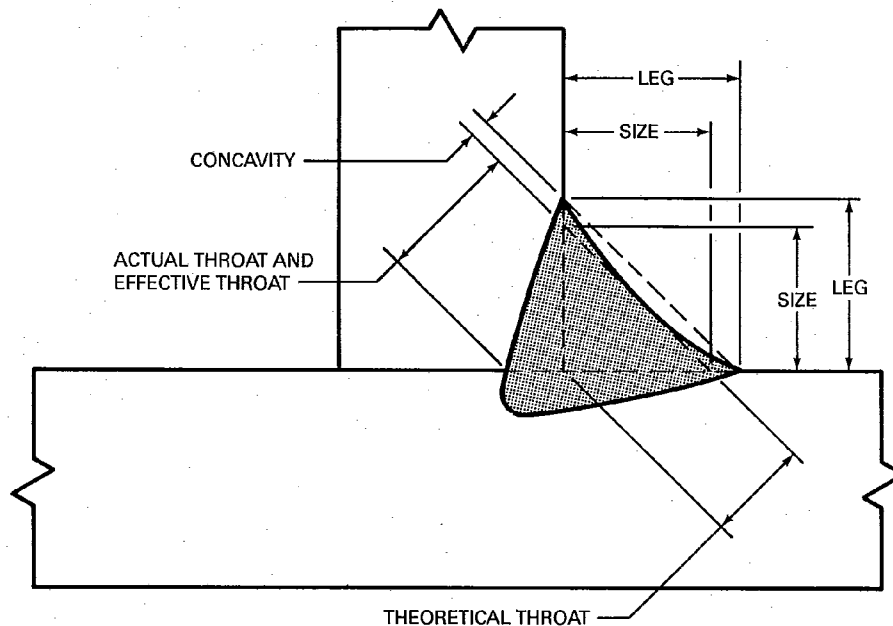


Figure 34 — Concave Fillet Weld

ations, especially nondestructive testing, or the serviceability of the part. It might be indicative of the welding process being out of control, however. See Figure 35.

5. Examination Equipment

5.1 Introduction. There are numerous examination devices used in the welding inspectors trade. This section will survey some of the tools and gages most frequently used in visual welding inspection. The tools covered by this section are:

- (1) Ammeters
- (2) Temperature sensitive crayons
- (3) Surface contact thermometers
- (4) Weld gages
- (5) Fiberscopes and borescopes
- (6) Ferrite gages

The section also details how to determine whether there is proper lighting for examination.

5.1.1 Handling of Examination Equipment. In order to assure continued accuracy of examination equipment, it is important to avoid careless or abusive treat-

ment. Instruments should be kept free of dust, moisture, or fingerprints, and, therefore, should be wiped off before being put away. Care should be exercised to avoid scratches or nicks on contact surfaces, dial faces, and graduations. Gages should be treated with a light dressing oil applied with a soft, lint free cloth prior to storage.

When it is necessary to remove a gage before reading a measurement, the lock should be engaged and the gage carefully removed. A gage should never be forced on or off a work piece. The face of the gage should not be rocked against the work piece, as rocking tends to produce uneven wear of the gage.

5.1.2 Calibration 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 Bureau of Standards. Calibration is generally documented on a permanent record, and a certification label is then attached to the instrument indicating the date the instrument is again due to be calibrated.

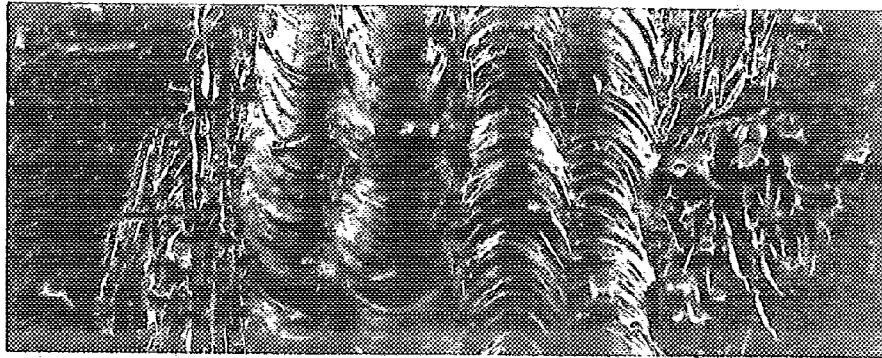


Figure 35 — Spatter

An effective calibration system should assure the recall and calibration of all precision measuring devices under its control on a pre-established periodic schedule. Prior to using a controlled measuring device, the inspector should assure that there is a calibration certification label and that the calibration due date has not passed. Any gage which has passed its expiration date should be calibrated and certified prior to use.

In addition to calibration labels, all controlled measuring devices should have its own unique serial number. The serial number allows for calibration traceability in case a calibration tag inadvertently falls off. A serial number is imperative for small gages and devices that are unable to bear a calibration tag or label.

5.2 Ammeters. An ammeter of the tong test type is a unique, portable instrument that will measure current flowing in a circuit without making an electrical connection to it. This is an efficient way to verify the amperage that is being used during welding (check welding procedure). By placing the jaws of the tong tester around a conductor carrying current, a reading in amperes can be obtained, as shown in Figure 36.

5.3 Temperature Sensitive Crayons. Temperature sensitive crayons are frequently used to give an approximate temperature indication. A crayon mark is made across the metal in the area to be checked; for example, when using a 500 degree crayon, the temperature of the piece will be at least 500 degrees when the crayon mark melts. This measurement usually should be made within one inch (25 mm) of the weld on the base metal. Crayon marks should never be made directly on the weld because of possible contamination. This is illustrated in Figure 37.

5.4 Surface Contact Thermometers. The surface thermometer provides a direct indication of the surface temperature of pipe or other joint members. The thermometer's permanent magnet will attach it to ferrous base metal, but the thermometer should be otherwise attached to nonferrous base metal. Temperature readings should be taken very close to the weld area, preferably within three inches of the weld on either side, as shown in Figure 38.

The pyrometer is an electrical instrument which offers direct indication of temperature. Pyrometers are often used when the temperature measured might exceed the limits of mercury thermometers or other type thermometers. The point of the probe is placed on the work and temperature is read from the scale or digital 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 the crayon discussed previously. Figure 39 illustrates the use of a pyrometer.

5.5 Weld Gages

5.5.1 Fillet Weld Gage. The fillet weld gage offers a quick means of measuring most fillet welds, of $\frac{1}{8}$ in. (3.2 mm) through 1 in. (25 mm) in size. It measures both convex and concave fillet welds. To measure a convex fillet weld, the blade representing the specified fillet weld size with the concave curve should be selected. As seen in Figure 40, the lower edge of the blade is placed on the base plate with the tip of the blade moved to the upright member.

To measure a concave fillet weld, the blade representing the specified fillet weld size with the double concave curve should be selected, as shown in Figure 41. After placing the lower edge of the blade on the base plate with the tip touching the upright member, the projec-

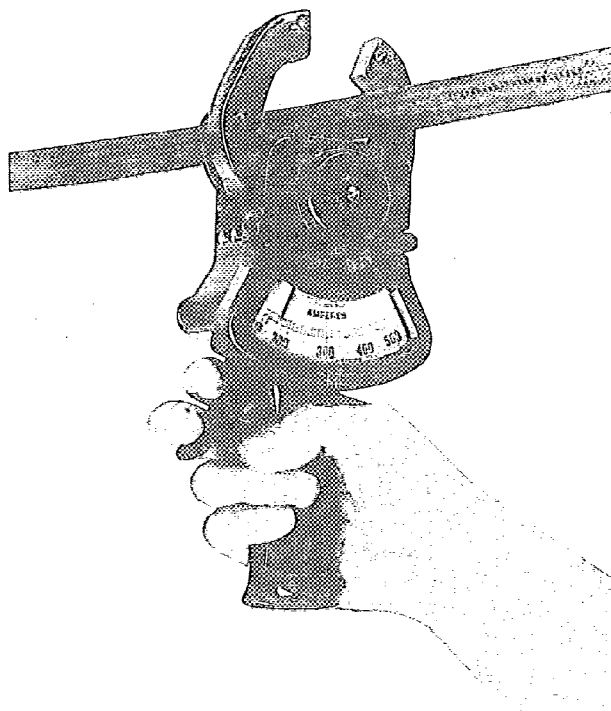


Figure 36 — Tong Test Ammeter

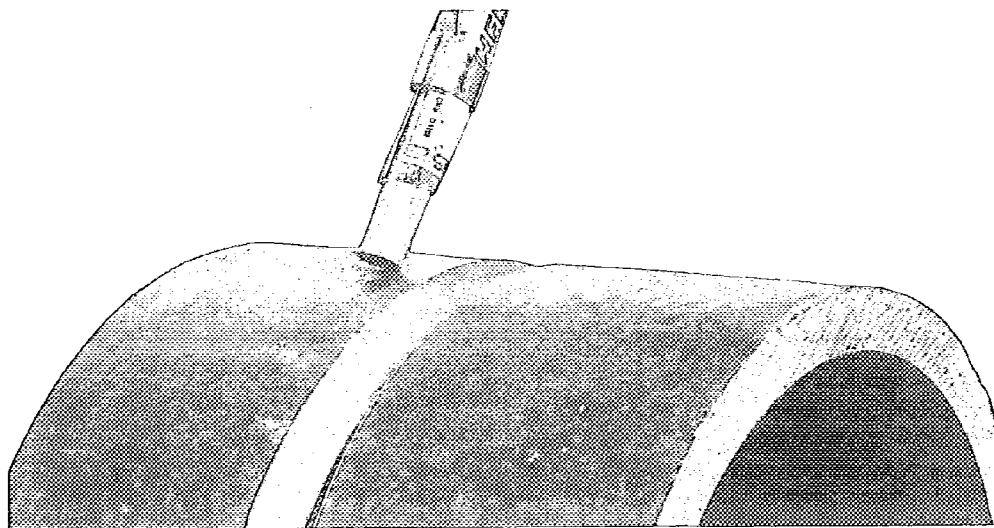


Figure 37 — Temperature Sensitive Crayon

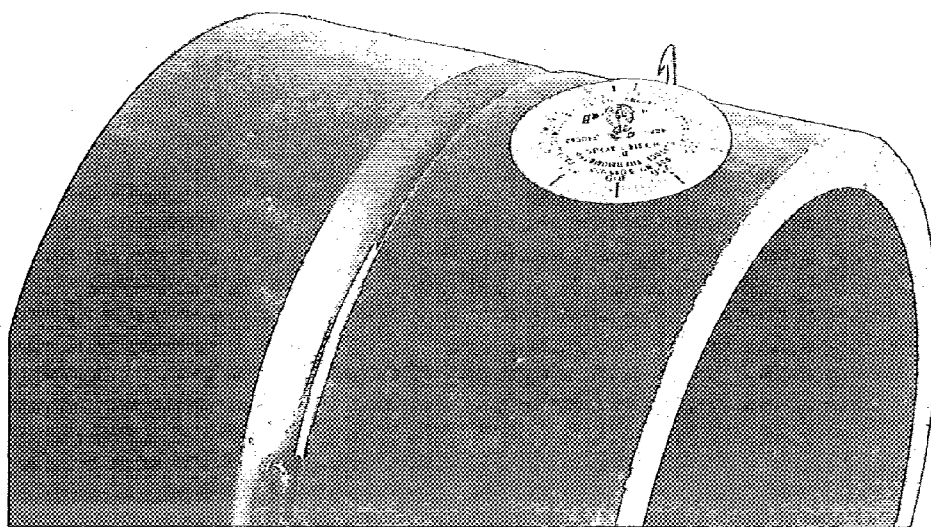


Figure 38 — Surface Contact Thermometers

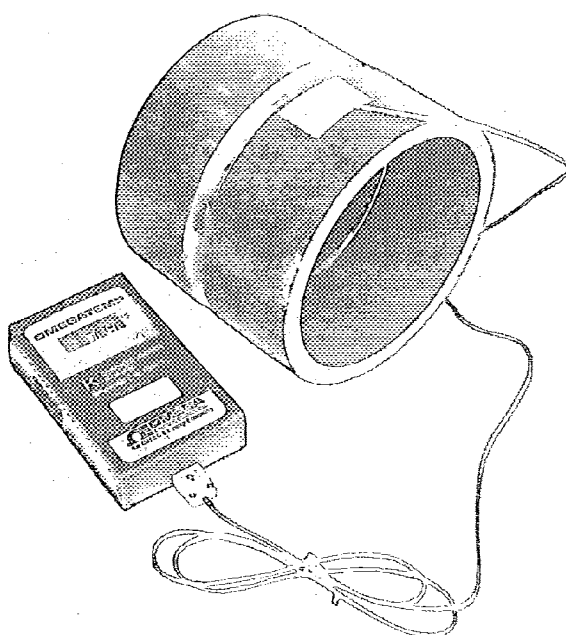


Figure 39 — Pyrometer

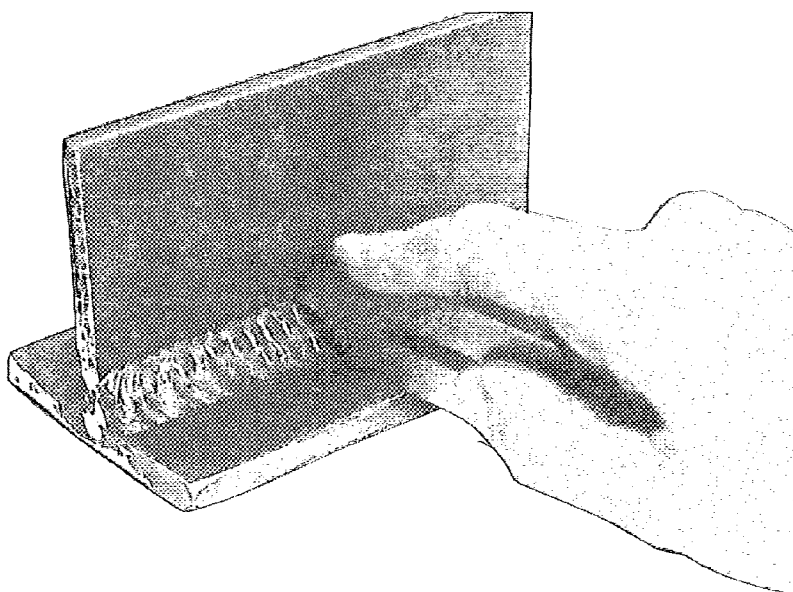


Figure 40 — Evaluating a Convex Fillet Weld

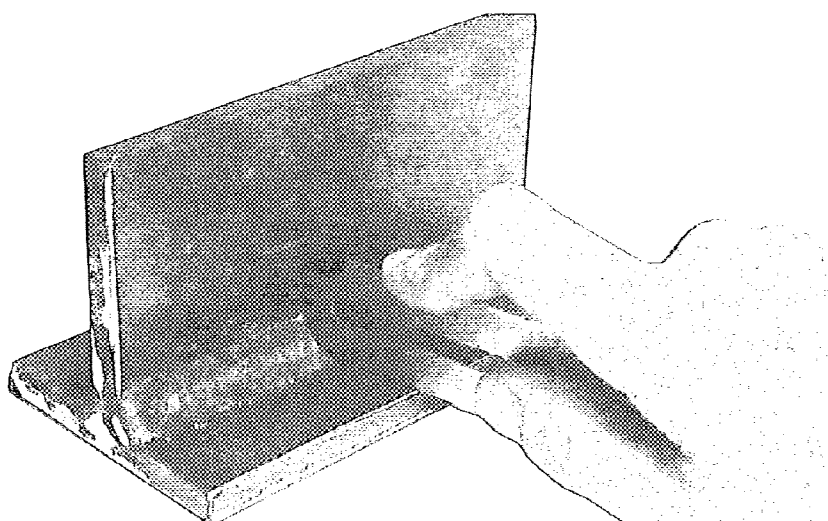


Figure 41 — Evaluating a Concave Fillet Weld

tion formed by the double curve should just touch the center of the weld face. This will measure throat size for the specified weld size. However, if the center portion of the gage does not touch the weld, the weld has insufficient throat size.

5.5.2 Multipurpose Gage. There are several multipurpose welding gages available on the market today. A multipurpose gage is capable of performing many mea-

surements, such as measuring convex and concave fillet welds, weld reinforcement, and root opening. The use of all the numerous and various gages available cannot all be detailed here; therefore, the instructions with each gage should be followed carefully. Figure 42 illustrates one of these gages being used to measure a fillet weld.

5.5.3 Taper Gage. The taper gage is inserted into the opening of a joint to measure root opening (gap). The

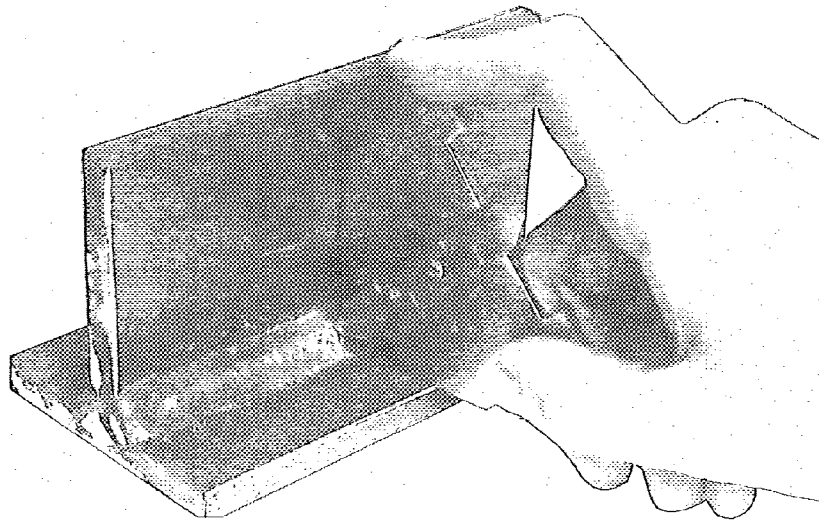


Figure 42 — A Multipurpose Gage

root opening measurement is taken from the gage at the point where the gage becomes snug in the joint as illustrated in Figure 43.

5.5.4 Hi-Lo Gage. The Hi-Lo gage, also called a mismatch gage, is used to measure the internal alignment of a pipe joint. After the gage has been inserted and adjusted, the thumb screw is tightened, and the tool is removed for measurement of misalignment. This is shown in Figure 44.

5.6 Fiberscopes and Borescopes. These are fiberoptic instruments ideal for weld examination where there is restricted access. A flexible fiberscope is basically an optical instrument. This allows the inspector to look into small holes and around corners. These units are also available with magnifying lenses; images can be projected on a screen, and the results stored. Figure 45 illustrates the use of a borescope.

5.7 Ferrite Gages. The presence of a small fraction of the magnetic delta ferrite phase in an otherwise austenitic (nonmagnetic) weld metal has a pronounced influence in the prevention of both centerline cracking and fissuring. The amount of delta ferrite in as-welded weld metal is largely, but not completely, controlled by a balance in the weld metal composition between the ferrite-promoting elements and the austenite-promoting elements. When welding austenitic stainless steel, with insufficient delta ferrite structure, the weld metal has a tendency to develop small cracks or fissures. These

small fissures tend to be located transverse to the weld interface in weld beads and base metal that were reheated to near the melting point.

There are several ferrite gages which will determine the amount of magnetic delta ferrite phase present. The American Welding Society has published A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*. Portable ferrite gages or indicators are designed for on-site use. Ferrite content of the weld metal is indicated in ferrite numbers (FN), and may be bracketed between two values. This provides sufficient control in most applications where minimum ferrite content or a ferrite range is specified. A ferrite gage is shown in Figure 46.

5.8 Lighting. The inspector should have adequate illumination, either natural or artificial, while performing visual examination. This may be determined using a fine line, approximately 1/32 in. (0.8 mm) in width, drawn on a 18 percent neutral grey card. The card should be placed near the area under examination; if this fine line is distinctly visible, the inspector may consider this as a demonstration of adequate illumination. Generally, a flashlight will provide sufficient lighting. Some codes specify minimum foot candles of illumination that are required while performing visual inspection; for example, 15fc (16 lx) for general examination, and a minimum of 50fc (54 lx) for the detection of small discontinuities.

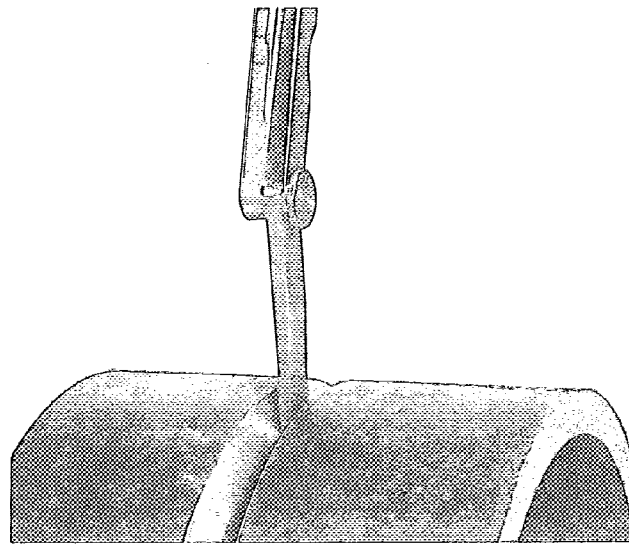


Figure 43 — A Taper Gage

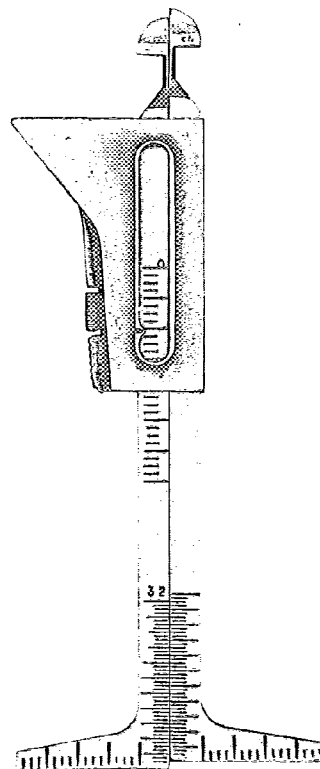


Figure 44 — Hi-Lo Mismatch Gage

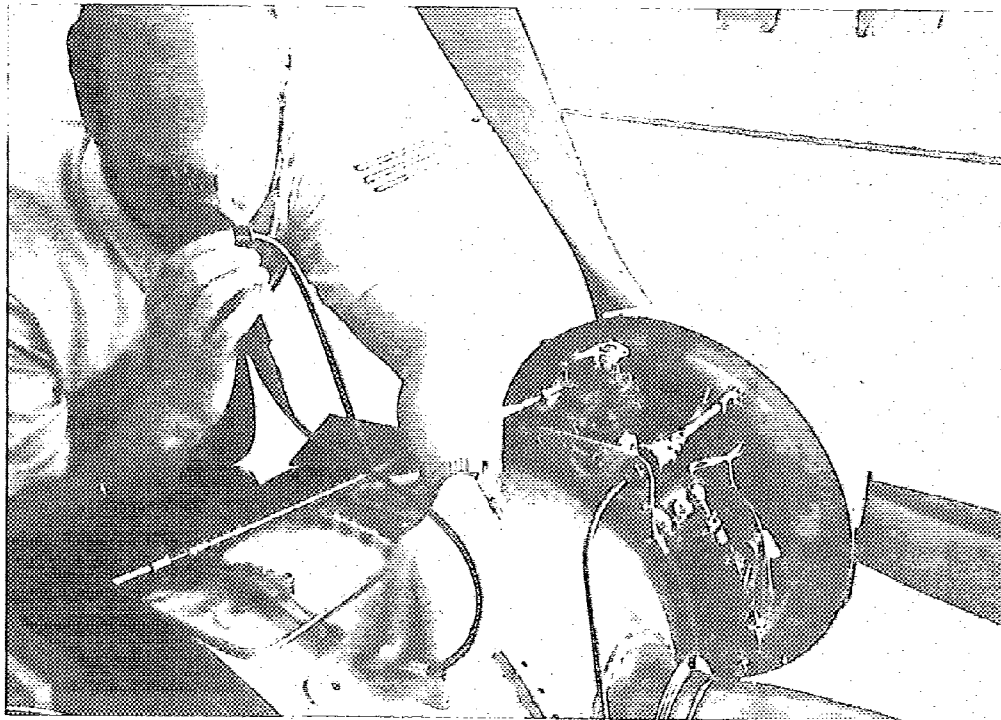


Figure 45 — A Fiberscope in Use

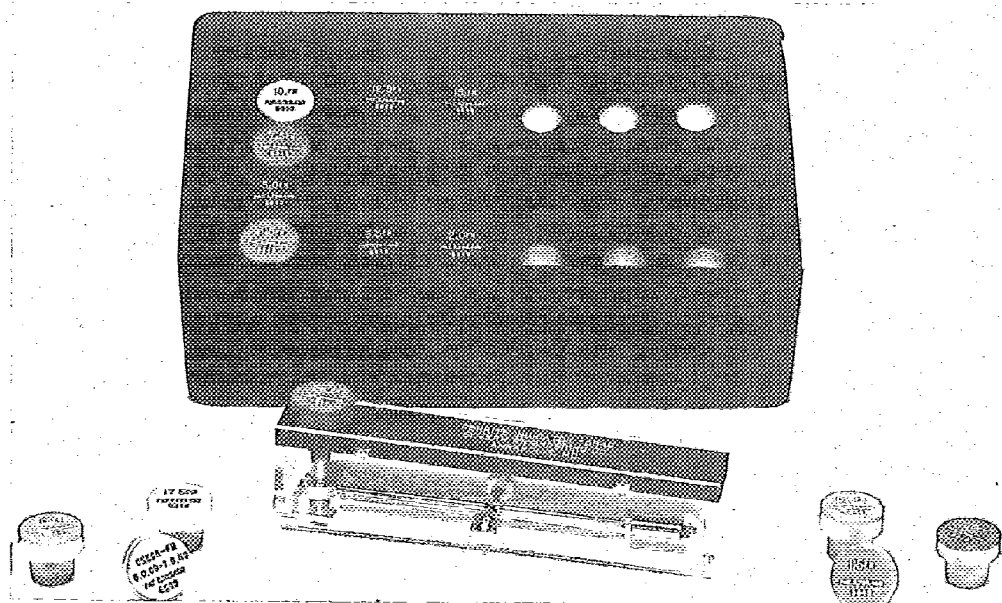


Figure 46 — Ferrite Indicator (Severn Gage)

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 a very important function.

An inspector should be able to maintain adequate records. Inspectors should be able to write clear and concise reports so that superiors will have no difficulty understanding reasons for past decisions if they are reviewed later. Inspection reports should be concise, yet complete enough to be clear to a reader unfamiliar with the product inspected. 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 may also require 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 fabricator's signature should be prepared by the fabricator rather than the inspector.

Records should be in as much detail as necessary. The inspector should comment on the general character of the work, how well it stayed within prescribed tolerances, difficulties that occurred, and any defects. 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.

It should be remembered that facts well known at the time of the writing may not be recalled so clearly, completely, or accurately later. Check lists can be used to document inspection points during fabrication. Lack of explanatory information and documentation can result in costly delays.

Appendix A

Typical Industry Standards

(This Appendix is not a part of ANSI/AWS B1.11-88, *Guide for the Visual Inspection of Welds*, but is included for information purposes only.)

Listed below are some of the standards used in the welding industry for fabrication and examination or inspection. They are listed here by name of category and society.

Category	Society	Title
Pressure Vessel	ASME 345 E. 47th Street New York, NY 10017	Code, Boiler & Pressure Vessel Section V, Nondestructive Examination
Piping	American National Standards Institute (ANSI) 1430 Broadway New York, New York 10018	B31.1 — Power Piping B31.3 — Chemical Plant and Petroleum Refinery Piping B31.4 — Liquid Petroleum Transportation Piping Systems
	American Petroleum Institute (API) 1220 L Street NW Washington, DC 20005	Standard 1104 — Standard for Welding of Pipelines and Related Facilities
Structural	American Institute of Steel Construction (AISC) 400 N. Michigan Avenue Chicago, Illinois 60611	Quality Criteria and Inspection Standards, 2nd Edition Specifications for the Designing, Fabrica- tion and Erection of Safety Related Structures for Nuclear Facilities
	American Welding Society (AWS) 550 N.W. LeJeune Road P.O. Box 351040 Miami, Florida 33135	D1.1 — Structural Welding Code — Steel D1.2 — Structural Welding Code — Aluminum D1.3 — Structural Welding Code — Sheet Steel D1.4 — Structural Welding Code — Reinforcing Steel
Shipbuilding	American Bureau of Shipping (ABS) 45 Eisenhour Drive Paramus, New Jersey 07652	Rules for Building and Classing Steel Vessels, Section 43

Appendix B

Supplementary Reading Material

(This Appendix is not a part of ANSI/AWS B1.11-88, *Guide for the Visual Inspection of Welds*, but is included for information purposes only.)

American Society for Metals. Nondestructive Inspection and Quality Control, ASM *Metals Handbook*, Vol. II, 8th Ed. Metals Park, Ohio: American Society for Metals.

American Welding Society. *Guide for the Nondestructive Inspection of Welding*, B1.10-86. Miami, Florida: American Welding Society, 1986.

_____. *Standard Welding Terms and Definitions*, A3.0-85. Miami, Florida: American Welding Society, 1985.

_____. *Symbols for Welding and Nondestructive Testing*, A2.4-86. Miami, Florida: American Welding Society, 1986.

_____. *Welding Handbook*, Vol. I, 8th Ed. Miami, Florida: American Welding Society, 1987.

_____. *Welding Inspection*, 2nd Ed., Miami, Florida: American Welding Society, 1980.

McMaster, R. C. Ed. *Nondestructive Testing Handbook*, 2nd Ed., Columbus, Ohio: The American Society for Nondestructive Testing.