



Visual Inspection Workshop

Reference Manual
Fourth Edition 2008



American Welding Society

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**Published by
American Welding Society
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American Welding Society

550 N.W. LeJeune Road, Miami, FL 33126



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VISUAL INSPECTION OF WELDING

INTRODUCTION

Rationale

Inspection is traditionally considered a post-processing activity. A machine component may be turned to finished form and size—then inspected for conformance to the applicable drawing or specification. A garment is inspected after sewing and all the buttons and other features are in place. In these and similar instances, *visual inspection* is carried out after the production activities have been completed.

In the case of weldments, experience has shown that post-processing inspection, even when supplemented with nondestructive examination (NDE), gives no guarantee of suitability for intended service. However, consistent results over a considerable period of time have demonstrated the effectiveness of a preplanned sequence of visual inspections. If carried out at specific stages of weldment production, such programs give a high degree of assurance of meeting quality expectations—frequently without recourse to NDE.

With welding, the factors influencing quality may manifest themselves at any stage of the production operation. In many instances, quality is compromised even before welding commences. In most such circumstances, suitably timed visual inspection would have revealed the shortcoming at a stage when corrective action would be simple to implement and inexpensive to carry out.

Weld and weldment quality are determined by:

- Weldment and joint design
- Materials used in construction
- Welding procedures
- Manner of weld application
- Inspection program

Visual welding inspection provides the basis for the effective control of these determinants.

Workshop Aims

The aims of this workshop are to:

- Provide a basic understanding of the circumstances under which weld and weldment quality, or both, may be compromised.
- Offer a program of weld inspection that gives a high degree of assurance of meeting weld quality requirements for most fabricated products.
- Show how to develop and implement specific quality plans to meet all normal requirements for weld and weldment quality.

- Demonstrate and practice the techniques of visual inspection required to carry out effective weld quality control.

Quality

The term *quality* is widely used and applied. However, many times, the general concept of quality is misunderstood.

Quality is conformance to the applicable specification.

The required level of quality for a product or service is typically determined by the designer, based on suitability for service over the intended life span. All product variables must be specified in a manner that is capable of being measured. Dimensions are readily verified. Attributes such as surface finish, if significant, must be specified in terms allowing for precise determination or measurement.

In carrying out an inspection, the inspector's task is to compare the *actual* with the *required* or specified product dimensions. Appearance alone is rarely the determinant of product quality.

Terms and Definitions

Certain important terms are used in the inspection of welding that may or may not apply in other industries. These include:

- **Discontinuity**—any interruption in the uniformity of an object.
- **Defect**—a discontinuity that does not meet the required product specification.

In general, a discontinuity is described as any interruption in the uniform nature of an item. Therefore, a bump in a highway could be considered to be a type of discontinuity because it interrupts the smooth, uniform surface of the pavement. In welding, the types of discontinuities with which we are concerned are such things as cracks, porosity, undercut, incomplete fusion, etc.

Knowledge of these discontinuities is important to the welding inspector for a number of reasons. First, the inspector will be asked to visually inspect welds to determine the presence of any of these discontinuities. If any are discovered, the welding inspector must then be capable of describing their nature, location, and extent. This information will be required to determine whether or not that discontinuity requires repair, as described in the applicable job specifications.

If additional treatment is deemed necessary, the welding inspector must be capable of accurately describing the discontinuity to the extent that it can be satisfactorily corrected by production personnel.

Before describing these discontinuities, it is extremely important to understand the difference between a discontinuity and a defect. Too often, people mistakenly use the two terms interchangeably. As a welding inspector, you should strive to realize the distinction between the terms *discontinuity* and *defect*.

While a *discontinuity* is some feature which introduces an irregularity in an otherwise uniform structure, a *defect* is a specific discontinuity which can impair the suitability of that structure for its intended purpose. That is, a defect is a discontinuity of a certain type, and one which occurs in an amount great enough to render that particular object or structure unsuitable for its intended service based on criteria in the applicable code.

In order to determine if a particular discontinuity is actually a defect, there must be some standard which defines the acceptable limits of that discontinuity. When its size or concentration exceeds these limits, it is deemed a defect. We can therefore think of a defect as a “rejectable discontinuity.” So, if we refer to some feature as a defect, we are implying that it is rejectable and requires some further treatment to bring it into acceptable limits to a particular code. Depending on the intended service of the part in question, an existing discontinuity may or may not be considered to be a defect. Consequently, each industry uses specific codes or standards which describe the acceptable limits for those discontinuities which could affect the successful performance of various components.

A *code* by definition is “a body of laws, as of a nation, city, etc., arranged systematically for easy reference.” When a structure is built within the jurisdiction of a city or state, it must often comply with certain “building codes.” Since a code consists of laws having legal status, it will always be considered mandatory. Therefore, we will see text containing words such as “shall” and “will.” A specific code includes certain conditions and requirements for the item in question. Quite often it will also include descriptions of methods to determine if those conditions and requirements have been achieved.

The next document type to be covered will be the standard. The dictionary describes a *standard* as, “something established for use as a rule or basis of comparison in measuring or judging capacity, quantity, content, extent, value, quality, etc.” A standard is treated as a separate document classification; however, the term standard also applies to numerous types of documents, including codes and specifications. Other types of documents considered to be standards are procedures, recommended practices, groups of graphic symbols, classifications, and definitions of terms.

Some standards are considered to be mandatory. This means the information is an absolute requirement. A mandatory standard is precise, clearly defined and suitable for adoption as part of a law or regulation. Therefore, the welding inspector must make judgments based on the content of these standards. These mandatory standards use such words as “shall” and “will” because their requirements are not a matter of choice. Codes are examples of mandatory standards because they have legal status.

There are numerous standards that provide important information, but are considered to be nonmandatory. An example of a nonmandatory standard would be a recommended practice. They are nonmandatory because they may provide other ways in which objectives can be accomplished. Nonmandatory standards include words such as “should” and “could” in place of “shall” and “will.” The implication here is that the

information has been put forth to serve as a guideline for the performance of a particular task. However, it doesn't mean that something is rejectable just because it fails to comply with that guideline. Even though a standard may be considered nonmandatory, it still provides important information.

The final document classification to be discussed is the specification. This type is described as, "a detailed description of the parts of a whole: statement or enumeration of particulars, as to actual or required size, quality, performance, terms, etc." A specification is a detailed description or listing of required attributes of some item or operation. Not only are those requirements listed, but there may also be some description of how they will be measured.

Depending upon a specific need, specifications can exist in different forms. Companies often develop in-house specifications describing the necessary attributes of a material or a process used in their manufacturing operation. The specification may be used entirely within the confines of that company, or it may be sent to suppliers to detail exactly what the company wants to purchase. When these requirements are put into writing, there is more assurance that the item or service that is supplied will meet the quality expectations.

To advance the application and utilization of welding, the American Welding Society (AWS) has standardized requirements for welding inspectors. Certification of eligible persons is based on documented evidence of appropriate experience along with the achievement of a certain minimum level of competence in a 3-part examination.

Certified Welding Inspectors

An Inspector meeting AWS standards is designated a **Senior Certified Welding Inspector (SCWI)** or a **Certified Welding Inspector (CWI)**. SCWIs and CWIs are employed in a wide spectrum of industry and carry out a variety of tasks. While certain inspectors will have a wide range of situations with which to deal, others work in more specific areas of inspection. However, a knowledge of all facets of welding quality is required of SCWIs and CWIs to determine how the variables interact.

Visual Inspection

Key points about the visual inspection of welding should be recognized. These include:

- No inspection program will give an absolute guarantee as to weld and weldment suitability for intended service over the life of a product. However, by structuring an appropriate *inspection plan*, commercially realistic degrees of confidence in a welded product can be achieved.
- While visual inspection is highly effective in the control and assessment of weld and weldment quality, there is one obvious limiting factor. Visual inspections are confined to exposed surfaces—so subsurface discontinuities may not be detected. This is offset by structuring welding inspection programs to examine the minimum number of surfaces that will give the required degree of assurance.

- Nondestructive testing of welds and welding is an adjunct to the visual inspection program, not a substitute for it. The four NDE methods used in connection with welding each have their own areas of best application—along with limitations. Penetrant and magnetic particle testing are surface techniques, with the latter limited to ferromagnetic materials. Radiography is directional, ultrasonic examinations require smooth surfaces for transducer contact.

Safety and Health

This 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.

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1. CHAPTER #1—VISUAL INSPECTION OF WELDING

1.0 Aims of Chapter #1

This manual 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 manual 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 or fabricator's welding inspector, the purchaser's examiner, or the regulatory inspector. For the purpose of simplicity, these individuals are referred to as visual inspectors in the remainder of this manual in that they perform visual inspection. Fabrication documents, contract specifications, and regulatory agencies may specify who performs final inspection.

1.1 Application

Information contained in this manual 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 workbook 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 workbook. This workbook 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*, and AWS B5.1, *Specification for the Qualification 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 Weldment and Joint Design

Without question, the most significant factor in the quality of a welded product is the arrangement of parts to be welded. The relationship of members and the manner in which the loads are handled determines the local stresses. Likewise, the placement of joints has great significance. However, these last two matters are the designer's responsibility and are not the responsibility of the welding inspector.

Joint design is another matter, one in which the welding inspector is vitally concerned. In one sense, joint design, along with the procedure of welding, could be identified as the most significant factors in weld and weldment quality.

The most significant factors include, but are not limited to, those shown in Table 1.1.

Table 1.1—Welded Joint Design Determinants

DESIGN OF WELDED JOINTS
1. Welding and inspection access 2. Most cost-effective form 3. Minimize residual stresses

In most cases, joint design is proposed by the manufacturer and approved by the designer. Inappropriate joint designs are frequently imposed on manufacturers. In some instances, the welding inspector has a role to play in identifying potential problem areas during design. If that is the case, the inspector can have a positive input in to joint design taking into account joint accessibility. The initiation of the required corrective action through the appropriate channels should automatically follow.

Joint designs are specified in the applicable welding procedure specifications (WPSs). The practice of making pictorial joint representations on drawings is costly, counterproductive, and inaccurate.

1.3 Base Materials

While welding can be successfully used to make a wide range of welded joints in many materials, there are certain limitations. These include:

1. Not all metals are weldable. Of those that are, not all can be welded with the same degree of ease or using similar methods and procedures.
2. Welding has the potential to cause significant physical and metallurgical changes that may adversely affect the suitability for intended service of the welded product.

Designers who specify engineering materials for fabrication are generally aware of these limitations and call for the use of materials considered weldable. However, many fully weldable materials react differently to certain welding processes and

procedures of welding. As with design, this leaves the welding personnel with two important determinations to make.

Before welding, the compatibility of the base metal with the filler metals to be used and the welding process to be employed are verified. These are the main essential variables of the welding procedure and must be established by test. Where previously qualified welding procedures have been specified, only verification checks are necessary. In other circumstances, more comprehensive action will be required. The extent and scope of such action will be dictated by the prevailing situation.

1.4 Welding Procedures

Welding Procedure Specifications (WPSs) are a breakdown of the welding variables to be used to make one or more joints under certain circumstances. In a general sense, there can be a limitless number of such combinations. In practice, by using care and attention, it is possible for a relatively small number of WPSs to cover all the diverse situations that arise even when making complex weldments.

Over time, manufacturers of welded products build up a library of qualified welding procedures from which unique WPSs can be generated. In the event that there are no suitable qualified (or, if appropriate, prequalified) procedures available, it is necessary to carry out further qualification testing. The significant point is that this possibility allows time for appropriate action, together with the qualification of welding personnel if necessary.

1.5 Welding Fabrication

Welders are responsible for the welding on the component or structure being fabricated. There is an increasing requirement that the welders be qualified and certified in accordance with some Code or Standard. Welder certification attests to the skill and ability of a welder to weld specified types of joints in certain materials under a range of restricted conditions. These conditions typically include the welding process(es), type(s), and form(s) of base metal, and joint position along with the technique and progression of welding.

Welding inspectors verify that the welders, welding operators, or tackers are certified to weld with the procedures to be used during production. This gives warning of any additional requirements as far as welding personnel are concerned. It should be kept in mind that welder certification tests may or may not duplicate joints to be made in production.

The welding inspector checks the condition of the welding equipment and suitability of the base and filler metals. Welding inspectors are required to assure that welder skill is maintained throughout. Where there is evidence of reduced skill, requalification, or even retraining, may be necessary if substandard work persists.

1.6 Inspection

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

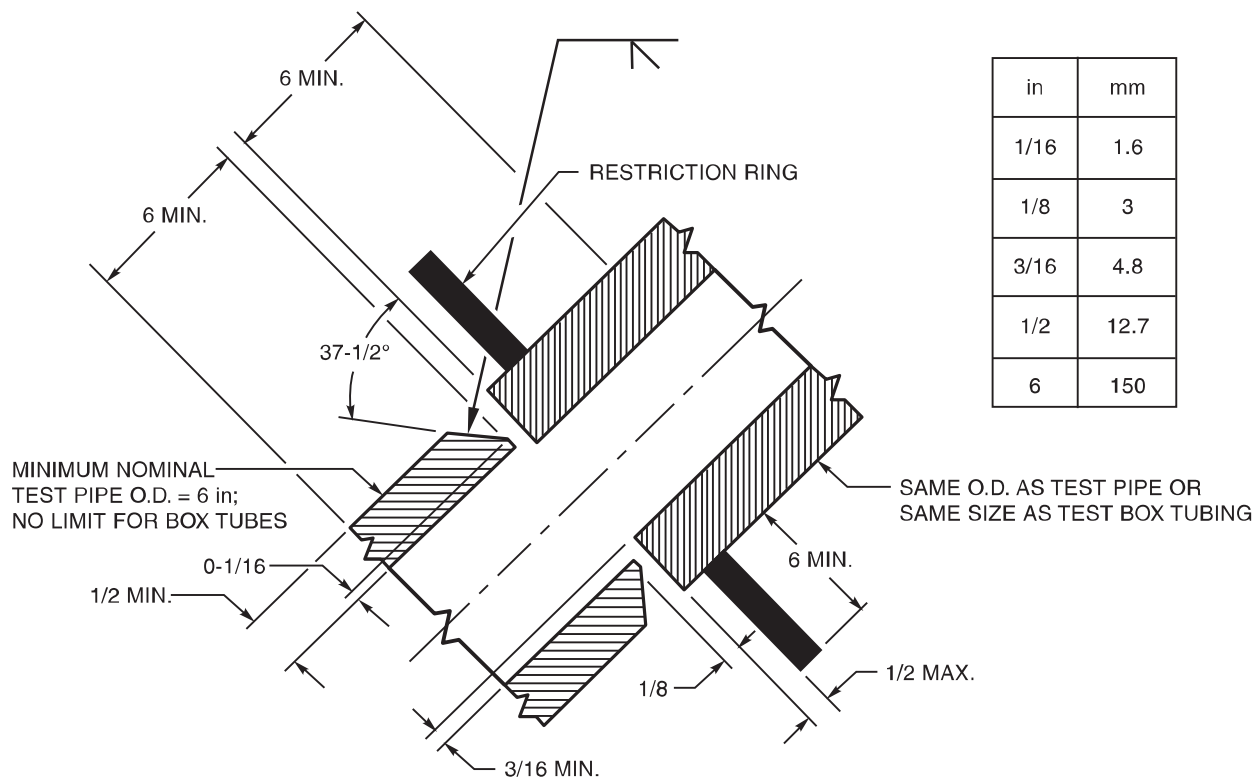


Figure 1.1—Restricted Access Joint for Welder Qualification Test

fabrication problems and evaluate workmanship. Visual examination only identifies surface discontinuities. Consequently, any valuable 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 valuable program of visual inspection before and during welding may reduce costs by revealing surface defects early in the fabrication process.

1.6.1 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.

1.6.2 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.

1.6.3 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.

1.6.4 Establish Hold Points

Consideration should be given to the establishment of hold points or check points where an inspection and acceptance is required 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.

1.6.5 Establish Documentation Plan

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

1.6.6 Review Material Documentation

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

1.6.7 Examine Base Materials

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

1.6.8 Examine Joint Fitup and Alignment

Joint fitup and alignment are critical to the production of a sound weld. Items that may be considered prior to welding include (see Figure 1.2):

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 fitup. The drawing or weld joint should be marked accordingly, so that the correct weld size can be verified during final inspection.

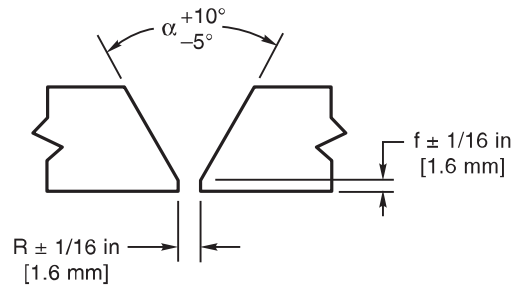
1.6.9 Review Storage of Welding Consumables

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

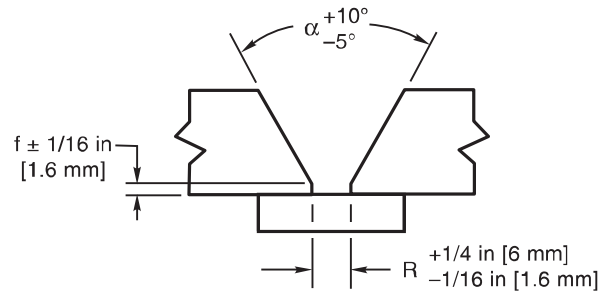
1.6.10 During Welding

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

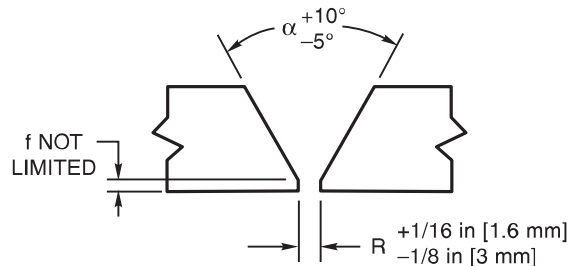
1. Check preheat and interpass temperatures
2. Check conformance to the Welding Procedure Specification (WPS)



(A) GROOVE WELD WITHOUT BACKING—
ROOT NOT BACKGOUGED



(B) GROOVE WELD WITH BACKING—
ROOT NOT BACKGOUGED



(C) GROOVE WELD WITHOUT BACKING—
ROOT BACKGOUGED

Figure 1.2—Joint Tolerances: With and Without Backing

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.

1.6.11 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. Preheat and all subsequent minimum interpass temperatures shall be maintained during the welding operation for a distance at least equal to the thickness of the thickest part welded, but no less than 3 inches in all directions from the point of welding along the entire length of the joint. On thick joints it is important that the preheat soak entirely through the joint. Maximum interpass temperature should be measured 1 in from the end of the joint just prior to initiating the arc for each pass. See Figure 1.3 for a typical method of measuring preheat and interpass temperatures.



Figure 1.3—Using a Temperature Indicating Crayon

1.6.12 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, AC, DC, Polarity, Amps, Arc Volts, and technique among others should be verified.

1.6.13 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.

1.6.14 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.

1.6.15 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.

1.6.16 After Welding

Following welding, some typical action items requiring attention by an inspector include:

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

1.6.17 Examine Weld Surface Quality

Visually examine the weld surface and verify that the weld contour meets the applicable acceptance criteria. 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
5. Underfill
6. Overlap
7. Cracks

8. Metallic and nonmetallic inclusions
9. Excessive reinforcement

1.6.18 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.

1.6.19 Verify Dimensional Accuracy

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

1.6.20 Review Subsequent Requirements

Review the specification to determine if additional operations are required. Such operations 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.

CHAPTER #2—WELD AND BASE METAL DISCONTINUITIES

2.0 Aims of Chapter #2

The aims of Chapter #2 are to familiarize the inspector with typical weld and base metal discontinuities encountered during metal fabrication. This chapter 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.

2.1 Weld Surface Conditions

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 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, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, should be used to eliminate confusion. An example of additional terminology occurs in AWS D1.1/D1.1M, *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.

2.2 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 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.

2.2.1 Scattered Porosity

Figure 2.1 illustrates scattered porosity which is uniformly distributed throughout the weld metal.



Figure 2.1—Scattered Porosity

2.2.2 Cluster Porosity

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

2.2.3 Piping Porosity

Figure 2.2 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*.

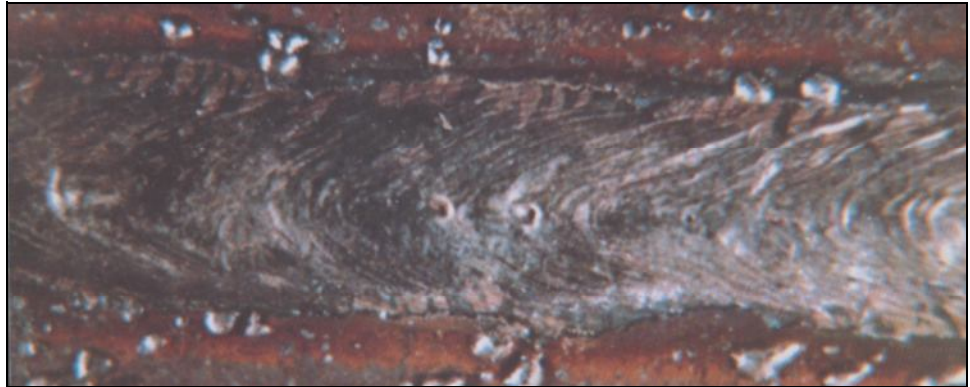


Figure 2.2—Surface Appearance of Piping Porosity

2.2.4 Aligned Porosity

Figure 2.3 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.



Figure 2.3—Aligned Porosity with Crack

2.2.5 Elongated Porosity

Figure 2.4 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.



Figure 2.4—Elongated Porosity

2.3 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 2.5–2.9. 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 heat is used.

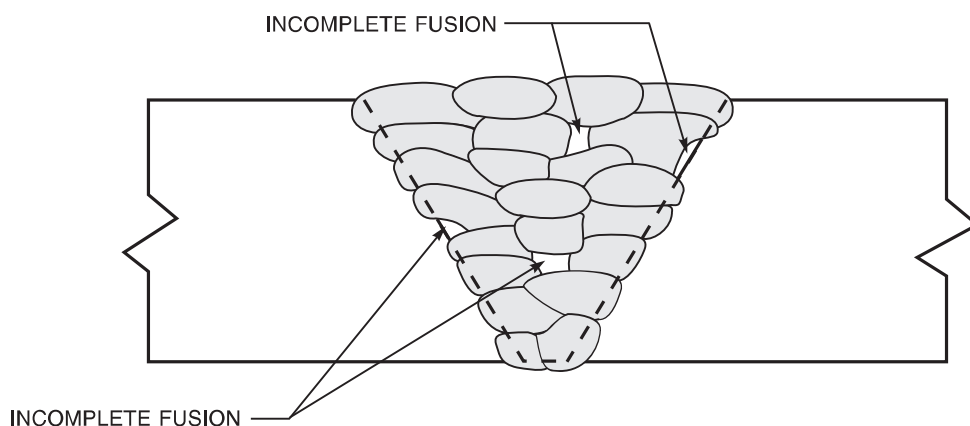


Figure 2.5—Various Locations of Incomplete Fusion

2.4 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 2.10–2.12. 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.



Figure 2.6—Incomplete Fusion



Figure 2.7—Incomplete Fusion at the Groove Face

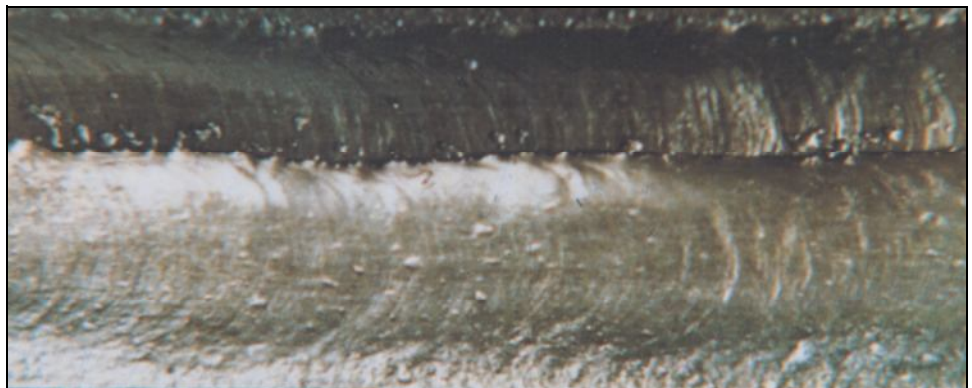


Figure 2.8—Incomplete Fusion Between Weld Beads

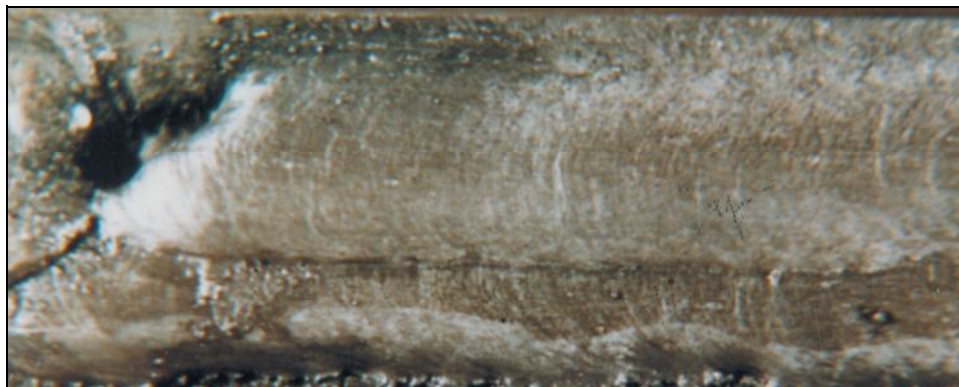


Figure 2.9—Incomplete Fusion Between the Weld and Base Metal

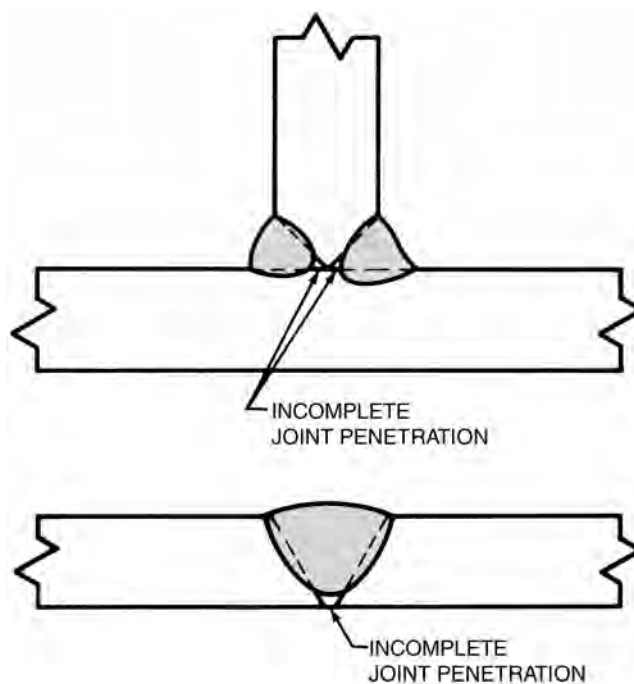


Figure 2.10—Incomplete Joint Penetration

Some welding processes have much greater penetrating ability than others. For joints welded from both sides, backgouging may be specified before welding the second 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.



**Figure 2.11—Incomplete Joint Penetration
with Consumable Insert**



Figure 2.12—Incomplete Joint Penetration

2.5 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 2.13 and 2.14. 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.

2.6 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 2.15 and 2.16.

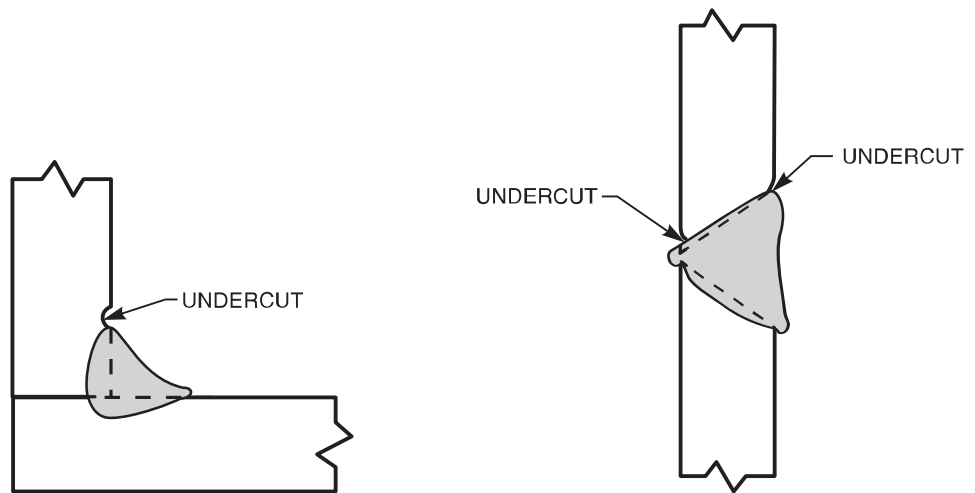


Figure 2.13—Examples of Undercut

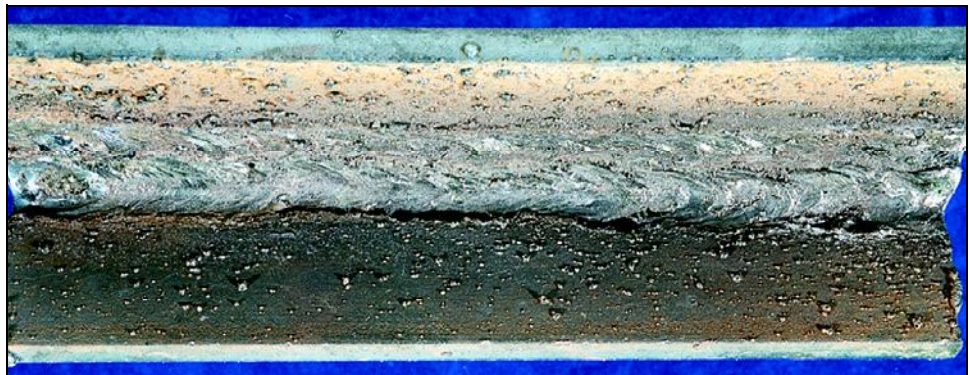


Figure 2.14—Undercut at Fillet Weld Toe

2.7 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 2.17 and 2.18.

2.8 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.

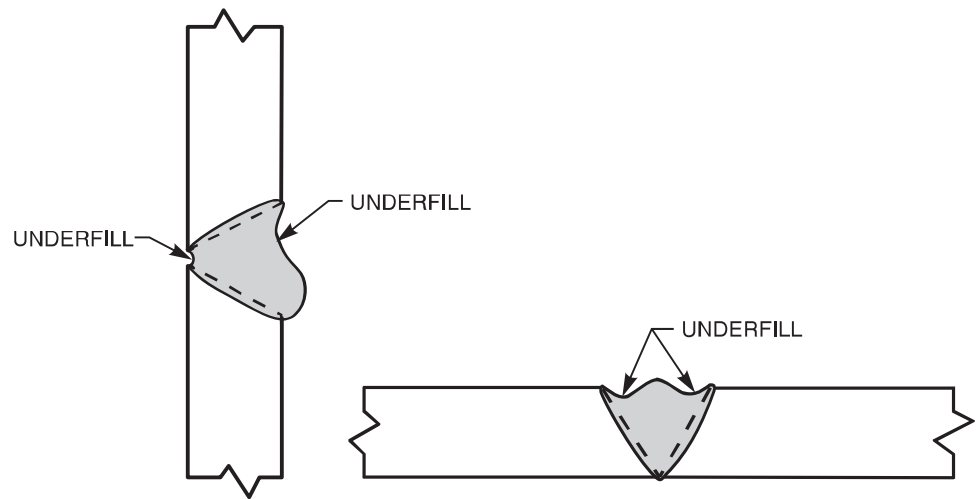


Figure 2.15—Underfill



Figure 2.16—Underfill Using Flux Cored Arc Welding in Steel

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 2.19. A delamination is the separation of a lamination under stress.

2.9 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.

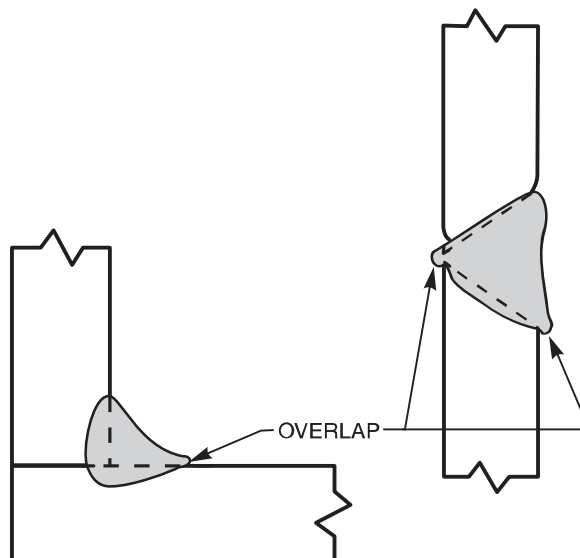


Figure 2.17—Overlap



Figure 2.18—Overlap

2.10 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 (HAZ), 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 2.20. If a crack is found during welding, it should be completely removed prior to additional welding. Welding over a crack rarely eliminates the crack.

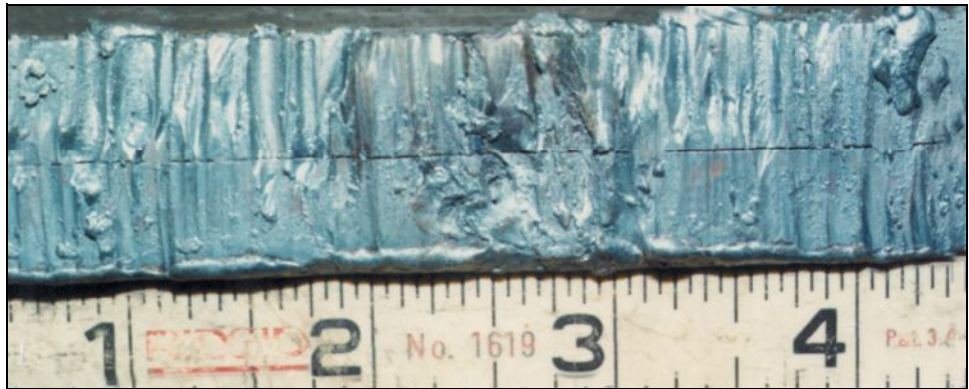


Figure 2.19—Laminations

2.10.1 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-affected zone. Longitudinal cracks are illustrated in Figure 2.21 and shown in Figure 2.22. 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 illustrated in Figure 2.21 and shown in Figure 2.23.

2.10.2 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

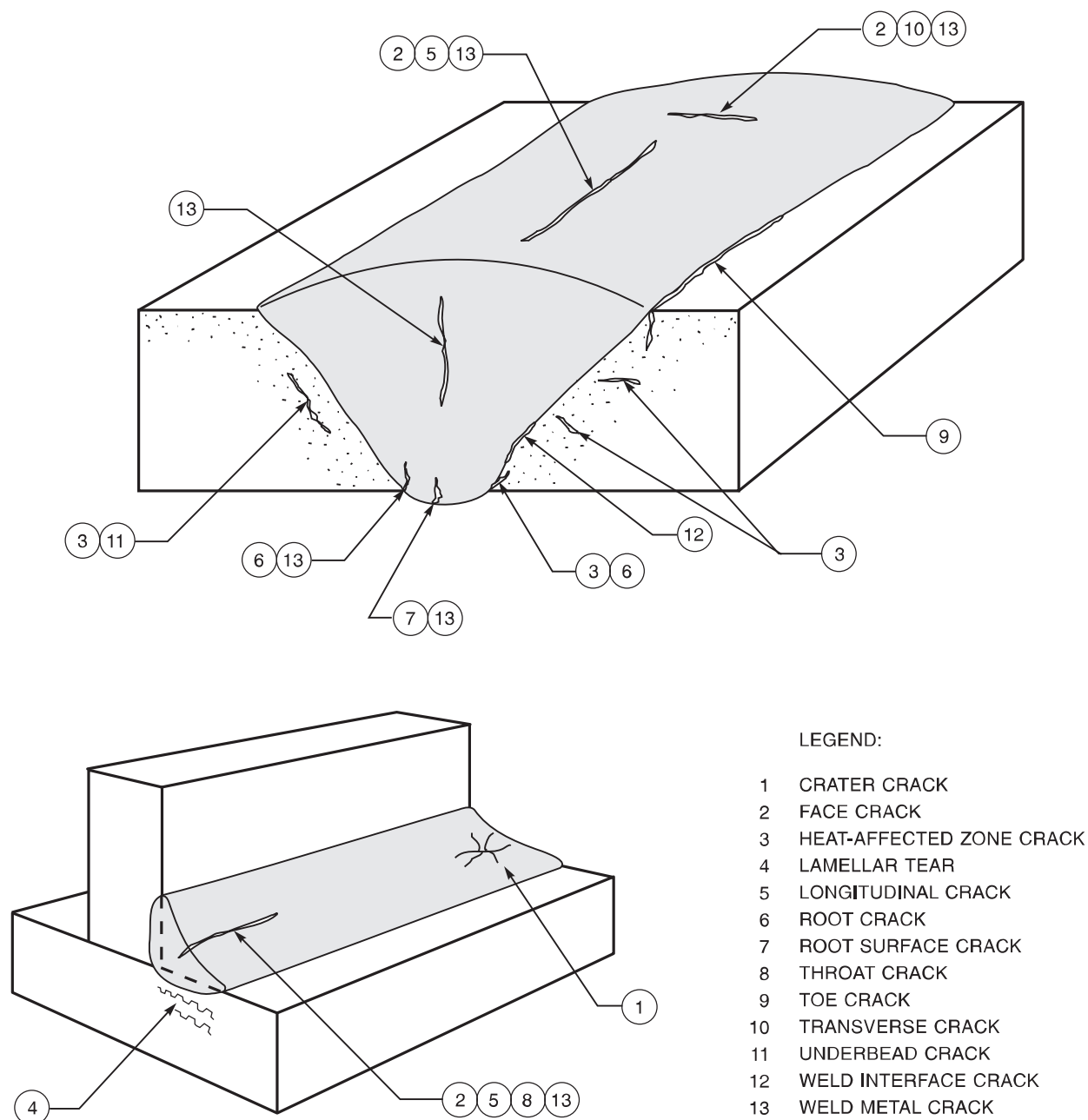


Figure 2.20—Types of Cracks

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.

2.10.2.1 Throat Cracks

Throat cracks are longitudinal cracks oriented along the throat of fillet welds. A throat crack is shown in Figure 2.24. They are generally, but not always, hot cracks.

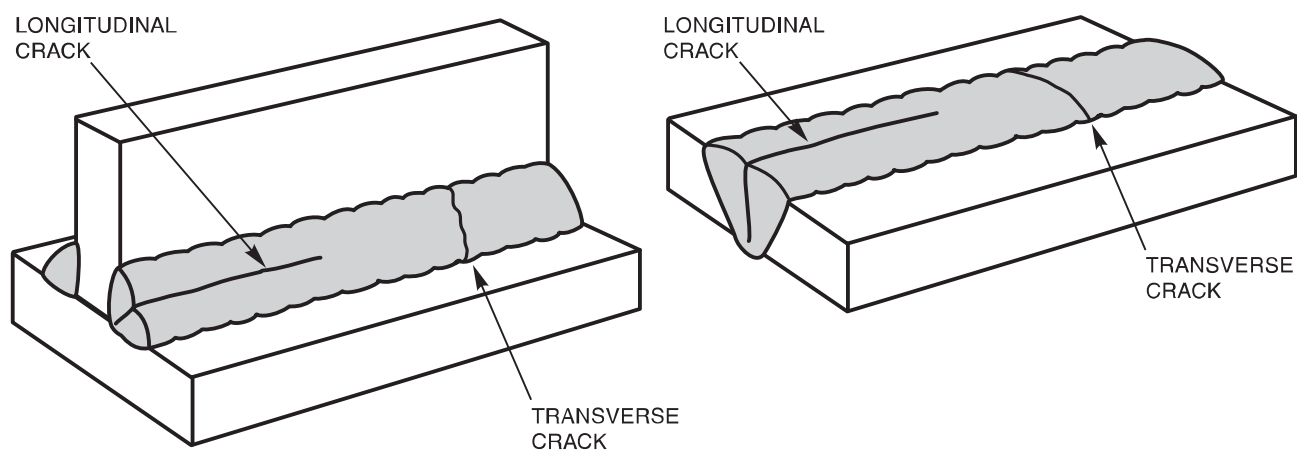


Figure 2.21—Longitudinal vs. Transverse Cracks



Figure 2.22—Longitudinal Crack and Linear Porosity



Figure 2.23—Transverse Cracks



Figure 2.24—Throat Crack

2.10.2.2 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 2.20.

2.10.2.3 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 2.25. 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 2.26.



Figure 2.25—Crater Crack

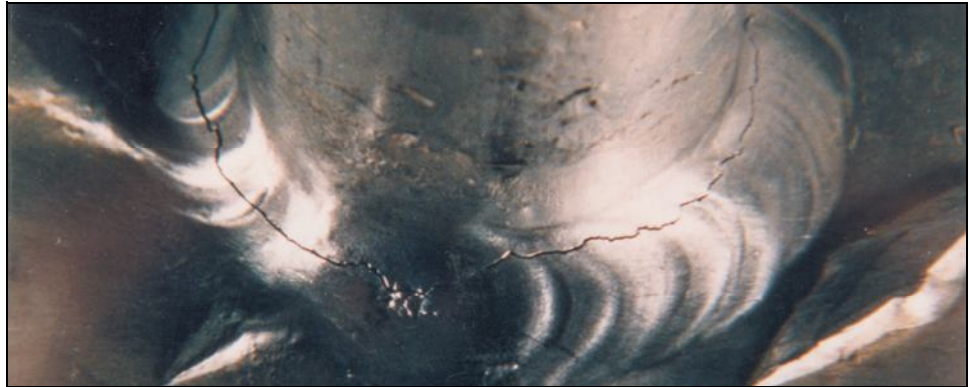


Figure 2.26—Longitudinal Cracks Propagating from Crater Crack

2.10.2.4 Toe Cracks

Toe cracks, Figures 2.27 and 2.28, 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.

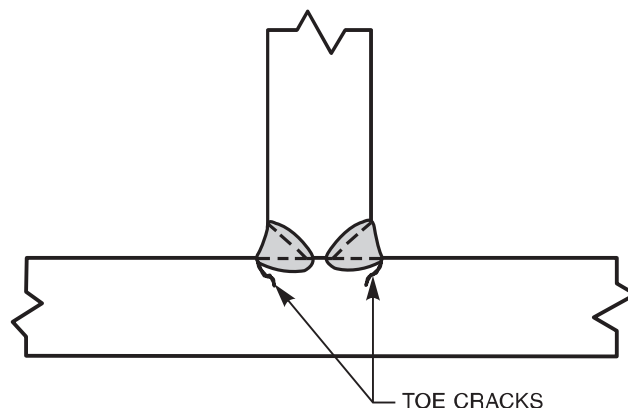


Figure 2.27—Toe Cracks

2.10.2.5 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 2.29. Underbead cracks can occur when three elements are present simultaneously:

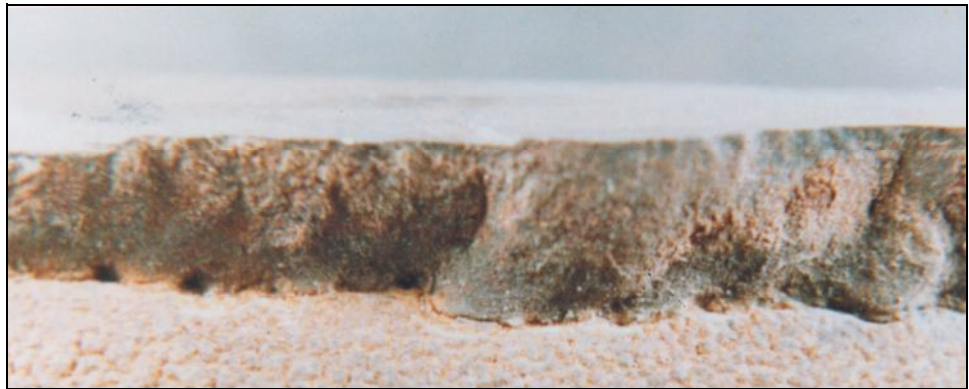


Figure 2.28—Toe Cracks

1. Hydrogen
2. A microstructure of relatively low ductility
3. High residual stress

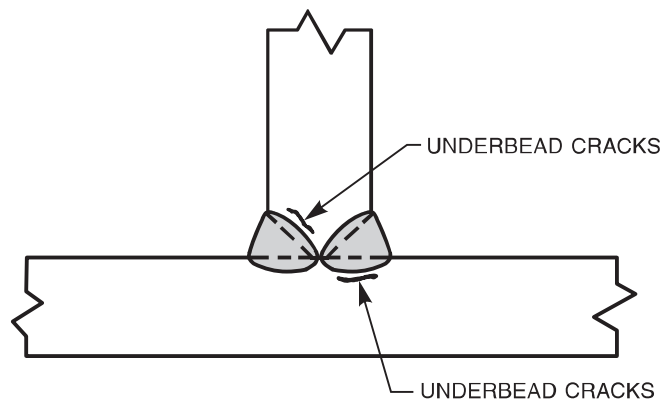


Figure 2.29—Underbead Cracks

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.

2.11 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 2.30.