

Chapter 9. Weld and Weld Related Discontinuities

A discontinuity is an interruption of the typical structure of a weldment, such as inhomogeneity in the mechanical, metallurgical, or physical characteristics of the material or weldment. A discontinuity is by nature not necessarily a defect.

General

A weld that does not meet any or all of the specific requirements of a particular specification or code is considered a defective weld. A defective weld is by nature impossible to assess without reference to some particular standard or requirement related to the intended use of the weld. Not all weld discontinuities are defects. Hence, the former title of this chapter was somewhat misleading ("Weld Defects"). For practical reasons, the terminology used in this chapter will be addressed without regard to any particular code or standard for determination of acceptability or rejectability. This chapter will address itself to four general classifications or base metal discontinuities:

- (1) Those related to drawing or dimensional requirements
- (2) Those related to weldment and related discontinuities
- (3) Those related to undesired properties of weld metal or welded joint
- (4) Those related to properties of the base metal

These classes of discontinuities may be further subdivided as follows:

- (1) Dimensional
 - a. Distortion
 - b. Incorrect weld size
 - c. Incorrect weld profile
 - d. Incorrect final dimensions
 - e. Excessive weld reinforcement
- (2) Weldment and related discontinuities in weld
 - a. Porosity

- b. Slag inclusions
- c. Tungsten inclusions
- d. Incomplete fusion
- e. Inadequate joint penetration
- f. Undercut
- g. Cracks
- h. Surface irregularities
- i. Other irregularities

(3) Mechanical and chemical weld metal properties

(4) Base metal properties

The text describes some of the preceding welding discontinuities, limiting its scope to (1) defining the discontinuity, (2) explaining the possible cause of the discontinuity, and (3) outlining methods for possible corrective actions. The text is based on the most commonly used welding processes; however, the information will be useful for welds made by many other welding processes, covering (1) metals known to permit satisfactory production welds, (2) joint designs that can produce satisfactory weldments, and (3) filler metals that are capable of producing sound deposits.

Dimensional Discontinuities

Production of satisfactory weldments requires staying within specified sizes and shapes of welds and finished dimensions of an assembly. Dimensional data with tolerances may be found on drawings and in specifications and codes. Assemblies not meeting the requirements must be corrected before final acceptance. Discontinuities of this nature are shown in the paragraphs that follow.

Distortion: The welding operation involves the application of heat and the fusion of metal of the weldment. Stresses of high magnitude will result from thermal expansion and contraction and weld metal solidification, and will remain in the weldment after the structure has cooled. Such stresses tend to cause distortion (see Fig. 9.1). Rigid

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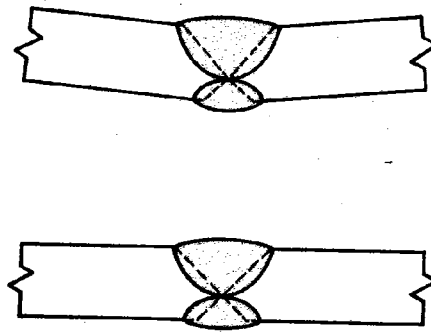


Fig. 9.1—Distortion: angular (top); correct alignment obtained by use of proper control methods (bottom)

fixtures and careful selection of welding sequence, welding processes, and joint design will minimize this condition. Peening, if permitted by specification and performed under controlled conditions, has also been used to some extent to help reduce distortion. Sequencing of welds may balance stresses and reduce or avoid distortion.

Correction of distortion in a completed weldment requires one or more of the following procedures:

- (1) A straightening operation, with or without the application of heat
- (2) The removal of the weld or welds causing the distortion and subsequent rewelding
- (3) The addition of weld metal in specific areas
- (4) A postweld heat treatment

The corrective measures selected usually depend upon the specification that must be met or the terms of an agreement between the fabricator and the customer.

Incorrect Joint Preparation: Established welding practice requires proper joint dimensions for each type of joint, consistent with the thickness of the material being welded. Failure to meet these criteria may result in a greatly increased tendency to produce discontinuities in the weld, in addition to the possibility of creating distortion. Therefore, it is important that joint

preparation is the same as shown in the applicable drawings and within specified limits of the specification.

Incorrect Weld Size: The size of a normal equal-leg fillet weld is expressed as the leg length of the largest isosceles right triangle that can be inscribed within the fillet weld cross section (shown in Fig. 9.2). The size of a groove weld is the joint penetration (depth of chamfering plus the root penetration when specified). Welds that are not of the correct size, either too big or too small, may be detected visually, by the use of a weld gage, or by comparison with approved workmanship samples.

Incorrect Weld Profile: The profile of a finished weld may have considerable effect on its performance under load. The profile of one pass of a multipass weld may have considerable effect on the tendency for discontinuities such as incomplete fusion or slag inclusions to be produced when subsequent layers are deposited. Requirements concerning the acceptability of discontinuities of this nature are usually included in the specifications. Failure to conform to these requirements constitutes a weld defect. Figure 9.2 illustrates various types of weld profiles.

Overlap is the condition in which weld metal protrudes beyond the bond line at the toe of a weld. Figure 9.3 illustrates this. The condition tends to produce notches that are dangerous, due to the resultant concentration of stress under load.

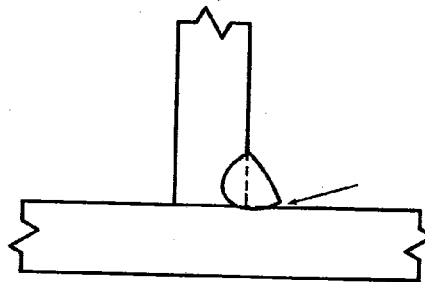
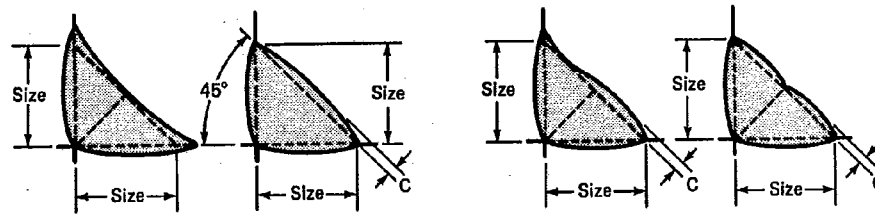


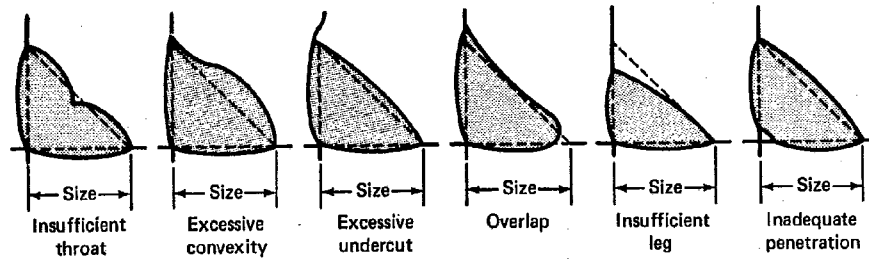
Fig. 9.3—Overlap



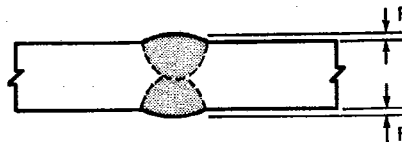
Note: Convexity C shall not exceed $0.1 \text{ actual size} + 0.03 \text{ in.}$

(A) Desirable fillet weld profiles

(B) Acceptable fillet weld profiles

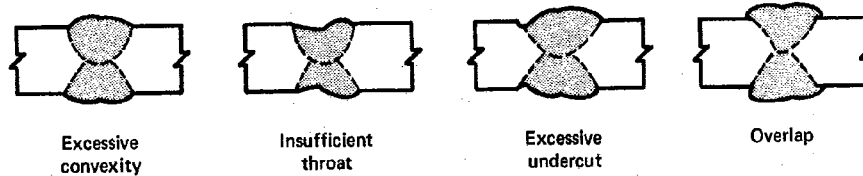


(C) Unacceptable fillet weld profiles



Note: Reinforcement R shall not exceed $1/8 \text{ in.}$

(D) Acceptable butt weld profile



(E) Unacceptable butt weld profiles

Fig. 9.2—Weld profiles

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Overlap is usually caused by the use of either incorrect welding technique or by improper electrical conditions. Overlap can also occur at the toe of the reinforcement of the completed weld groove. Excess convexity, although not so severe as overlap, tends to produce notch effects in welds. These notches are dangerous in the case of a fillet weld because they concentrate stresses under load. Excess convexity is also harmful in the case of an intermediate pass in a multi-layer groove weld, because incomplete fusion or slag inclusions may occur unless prevented by grinding or gouging prior to deposition of additional weld metal. This discontinuity is usually due to insufficient current or incorrect welding techniques.

Excess concavity may occur with all types of welds. The actual strength of such types of welds is considerably less than that of standard size welds and root pass welds in pipe. In the case of fillet welds, the throat is less than normal as measured by the length of leg. This condition tends to occur primarily in the flat position in fillet welding and in the 5G or 6G pipe welding position. It is usually caused by excessive welding currents or arc lengths. The only exception is that of downhill welding.

Excessive weld reinforcement is also undesirable. It tends to stiffen the section and establishes notches that create stress concentrations. This condition may result from improper welding technique or insufficient welding current (see Fig. 9.2).

Incorrect Final Dimensions: Weldments are fabricated to meet certain dimensions, whether specified on detailed drawings or hand-written sketches. The fabricator must be aware of the amount of shrinkage to be expected at each weld joint. This will affect the final overall dimensions of the product. The effect of welding sequence on distortion and the use of postweld heat treatment to provide dimensional stability of the weldment in service should also be recognized by the fabricator.

Weldments that require rigid control of final dimensions usually must be finished by machining or grinding after welding or after postweld heat treatment to stay within limits. Tolerances for as-welded components obviously will depend upon the thickness of the material, the

alloy being welded, and the overall size of the product. Thus, tolerances in final dimensions might be specified as from plus-or-minus a few thousandths of an inch to as much as plus-or-minus a quarter of an inch or more.

The inspector should discuss weldment dimensions and tolerances with the fabricator or the designer, or both, so that he can devote his major efforts towards those dimensions that are critical. Discussion prior to fabrication is most important. After completion of fabrication, it may be too late.

Weldment and Related Discontinuities

During welding, a certain amount of discontinuities may exist within the weld. These include porosity, cracks, inadequate joint penetration, slag inclusions, etc. This type of discontinuity is described as weldment and related discontinuities. The term is not used in the sense that there is a change of metallographic structure at these points, but rather that there is an interruption or a discontinuity in the soundness of the weld or its base material. Discontinuities of this nature are described in the paragraphs that follow.

Porosity: The primary causes for porosity are dirt, rust, and moisture on the surface of the base metal, in the welding consumables (such as electrodes and gases), and in the welding equipment (such as cooling systems and drive rolls). Porosities differ from slag inclusions in that they contain gases rather than solids, and are generally spherical in shape.

The formation of porosity is most readily prevented by using clean materials and well-maintained equipment. In addition, excessive current and excessive arc lengths should be avoided. High consumption of the deoxidizing elements of the covering of shielded metal arc electrodes may take place during deposition if excessive current and arc lengths are used, leaving insufficient quantities available to combine with the gases in the molten metal during cooling.

The distribution of porosity within a weld is of some importance. Its occurrence may be generally classified as follows:

Uniformly scattered porosity. This distribu-

tion is one in which the voids or pores are scattered more or less uniformly throughout the weld metal. The individual pores may vary in size from almost microscopic to one-eighth inch or more.

Cluster porosity. Frequently, pores occur in clusters separated by considerable lengths of porosity-free weld metal. Such clusters are often associated with changes in welding conditions (for example, changes in conditions when welding is stopped or started).

Linear porosity. Linear porosity occurs generally in the root pass and is often regarded as a special case of inadequate joint penetration. Linear porosity is usually defined by the number and size of the pores and their linear distribution with respect to the axis of the weld.

Note:

(1) Figures 9.4, 9.5, and 9.6 illustrate typical examples of various forms of porosities.

(2) Figure 9.6, in addition to illustrating porosity, also shows a welding fitup problem. This is known as mismatch (also called "hi-low"). Depending upon the specification or code being used in fabrication, the mismatch condition may or may not be accepted after the weld is completed.

(3) Figure 9.7 also illustrates porosity together with a slag inclusion.

Slag Inclusions: This term is used to describe the oxides and other non-metallic solids that are entrapped in weld metal or between weld metal

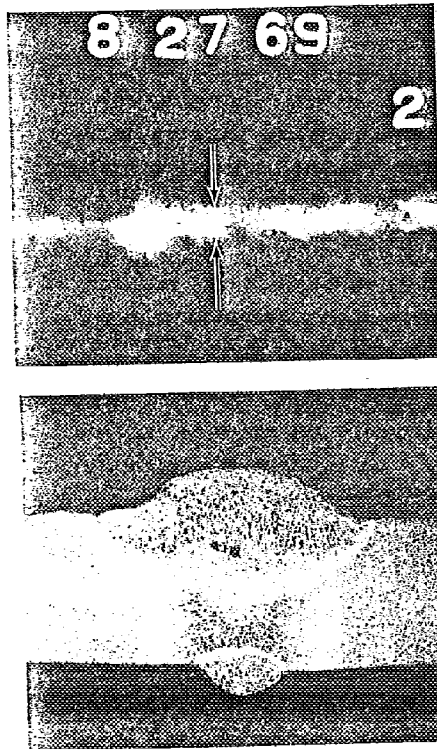


Fig. 9.4—Porosity

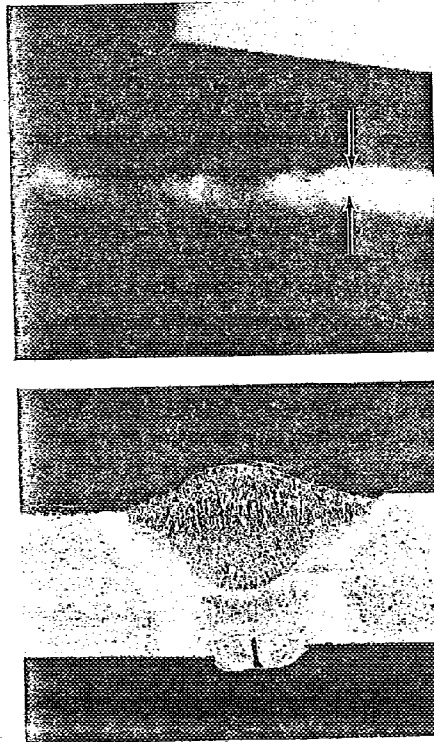


Fig. 9.5—Porosity, vertical

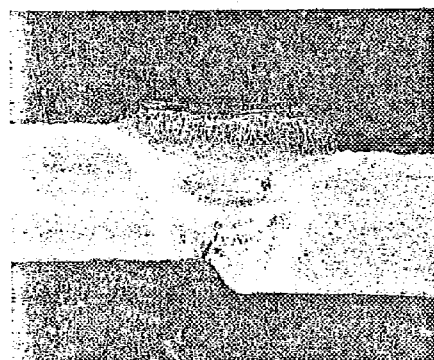


Fig. 9.6—Porosity, hi-low, and inadequate penetration

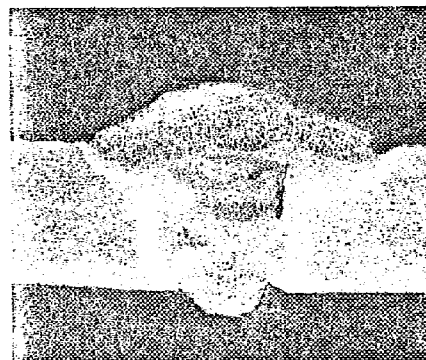
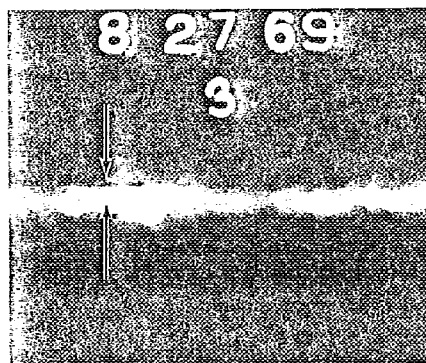


Fig. 9.7—Elongated slag and porosity

and base metal. During deposition of filler metal and subsequent solidification of weld metal, many chemical reactions occur between the weld metal and the electrode covering materials, forming slag compounds soluble only to a slight degree in the molten metal. Due to their lower specific gravity, slags rise to the surface of the molten metal unless they are restrained.

During welding by the shielded metal arc process, slag may be formed and forced below the surface of the molten metal by the stirring action of the arc. Slag may also flow ahead of the arc, causing the metal to be deposited over it. Also, with some electrode types, slag in crevices of previously deposited weld metal will not remelt and will be trapped in the same location. When slag is present in the molten metal

from any cause, factors such as high viscosity of the weld metal, rapid solidification, or too low a temperature may prevent its release. Gas dents or pock marks may occur on the weld surface when gas pressure is developed between the slag and molten weld metal interface.

Most slag inclusions can be prevented by proper preparation of the groove before each bead is deposited, using care to correct contours that are difficult to penetrate fully with the arc. The release of slag from the molten weld metal will be expedited by any factor that tends to make the metal less viscous or retard its solidification (such as high heat input).

Note: (1) Figures 9.7, 9.8, and 9.9 illustrate typical examples of slag inclusions.

(2) Figure 9.9, in addition to illustrat-

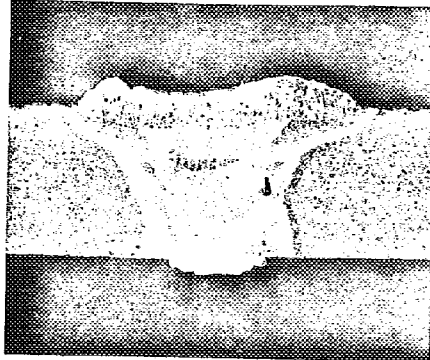
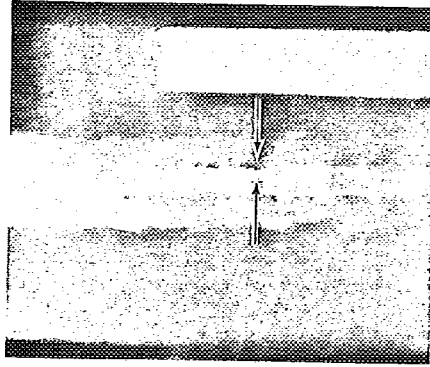


Fig. 9.8—Elongated slag

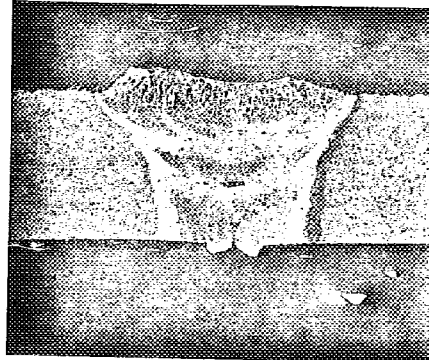
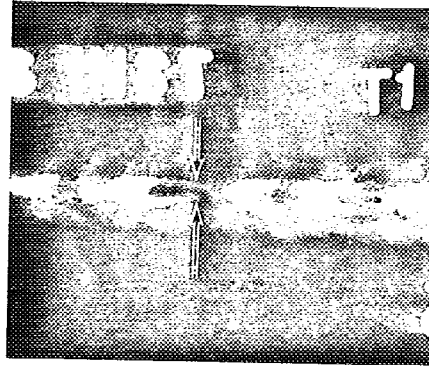


Fig. 9.9—Slag inclusion in filler and shrinkage crack

ing a slag inclusion, also shows another welding defect known as a shrinkage crack.

Tungsten Inclusions: The gas tungsten arc welding process uses a non-consumable tungsten electrode to create an arc between the tungsten electrode and the workpiece. Filler metal may or may not be added. The occasional touching of the electrode to the work or to the molten weld metal may transfer particles of the tungsten into the weld deposit.

Under certain circumstances the tungsten inclusions may be visible to the unaided eye. Generally, however, they are detected during radiographic inspection. In most cases, a limited number of tungsten inclusions are accepted; often they are evaluated on the same basis as porosity or slag. Where filler metal additions

are used, either intermittently or not at all, as in the welding of thin materials, the frequency of tungsten inclusions is reduced. The use of superimposed high-frequency current for arc starting also tends to minimize or eliminate tungsten inclusions at weld starts. Tungsten inclusions may be minimized by using thoriated tungsten or zirconium-tungsten electrodes with direct current, reverse polarity. Pure tungsten is used for most ac GTAW applications.

Incomplete Fusion: This term is sometimes inaccurately applied to the condition later referred to as inadequate joint penetration. It is used here to describe the failure to fuse together adjacent layers of weld metal or weld metal and base metal. This failure to obtain fusion may occur at any point in the welding groove.

Incomplete fusion may be caused by failure to

raise the temperature of the base metal (or previously deposited weld metal) to the melting point. It may also be caused by failure to dissolve, by such techniques as heating or fluxing, the oxides or other foreign material present on the surface to which the deposited metal must fuse.

It should not be inferred from this brief discussion that it is necessary to melt an appreciable portion of the sidewalls of the groove in order to be certain of securing proper fusion. It is only necessary to bring the surface of the base metal to the fusion temperature to obtain metallurgical continuity of the base and weld metal:

Note: Figure 9.10 illustrates a typical example of incomplete fusion.

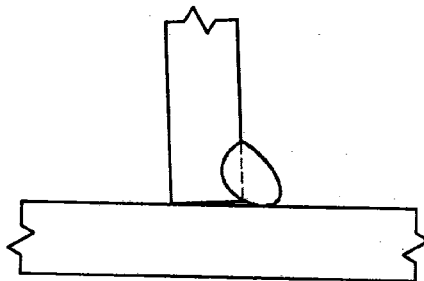


Fig. 9.10—Incomplete fusion

Inadequate Joint Penetration: This term describes the failure of the filler metal and base metal, or the base metal alone if no filler metal is used, to completely fill the root of the weld. It may be caused by the failure of the root face of a groove weld to reach fusion temperature for its entire depth, or the failure of the weld metal to reach the root of a fillet weld. This would leave a void that was caused by bridging of the weld metal from one member to the other.

Although inadequate joint penetration may, in a few cases, be due to failure to dissolve surface oxides and impurities, heat transfer conditions at the joint are a more frequent source of this discontinuity. If the areas of base metal

that first reach fusion temperatures are above the root, molten metal may bridge these areas and screen off the arc before the base metal at the root melts. In arc welding, the arc will establish itself between the electrode and the closest part of the base metal. All other areas of the base metal will receive heat principally by conduction. If the portion of the base metal closest to the electrode is a considerable distance from the root, conduction of heat may be insufficient to attain fusion temperature at the root.

Inadequate joint penetration is undesirable, particularly if the root of the weld is subject to either tension or bending stresses. The unfused area permits stress concentrations that could cause failure without appreciable deformation. Even though the service stresses in the structure may not involve tension or bending at this point, the shrinkage stresses and consequent distortion of the parts during welding will frequently cause a crack to initiate at the unfused area. Such cracks may progress, as successive beads are deposited, until they extend through or nearly through the entire thickness of the weld.

The most frequent cause of this type of discontinuity is the use of a groove design not suitable for the welding process or the conditions of actual construction. When a groove is welded from one side only, complete penetration is not likely to be obtained consistently if the root opening is too great (even though the root opening is adequate), the root opening is too small, or the included angle of a V-groove is too small. Any of these conditions will make it difficult to reproduce qualification test results under conditions of actual production. If, however, the design is known to be satisfactory, inadequate joint penetration may be caused by using electrodes that are too large or electrode types that have a tendency to bridge, an abnormally high rate of travel, or insufficient welding current.

The above applies where full penetration is required by the designer. When joints have been designed for partial penetration, the above is not a consideration.

Note: (1) Figures 9.6, 9.11, and 9.12 illustrate typical inadequate penetration.

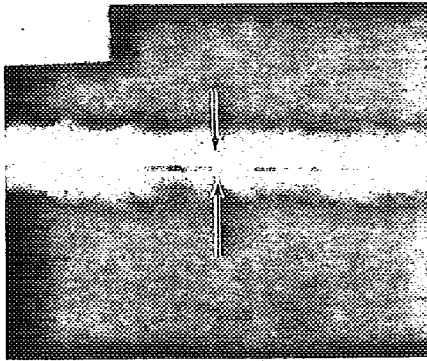


Fig. 9.11—Inadequate penetration

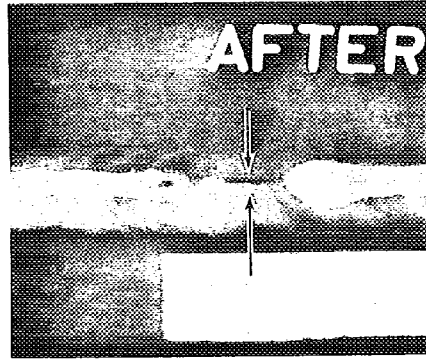
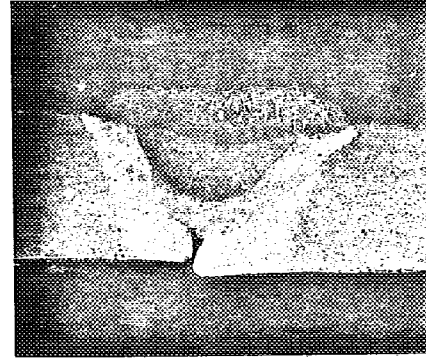
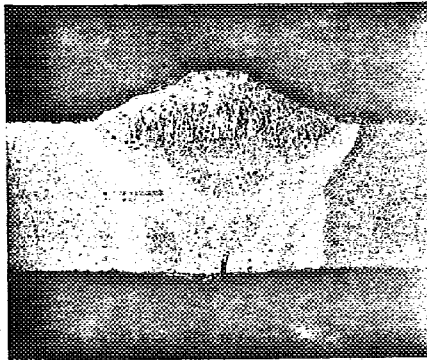


Fig. 9.12—Hi-low and inadequate penetration



(2) Figure 9.12, in addition to illustrating inadequate penetration, also shows a mismatch condition previously mentioned in this chapter.

Undercut: This term is used to describe either (1) the melting away of the sidewall of a welding groove at the edge of a layer or bead, thus forming a sharp recess in the sidewall in the area to which the next layer or bead must fuse; or (2) the reduction in base metal thickness at the line where the last bead is fused to the surface (e.g., at the toe of the weld).

Undercut of both types is usually due to the technique employed by the welder. With a specific electrode, excessive current or too long an arc may increase the tendency to undercut. However, different types of electrodes show widely varying characteristics in this respect.

With some, even the most skilled welder may be unable to avoid undercutting under certain conditions. These conditions primarily involve position and accessibility of the joint, although magnetic arc blow may also be a factor. Undercut of the sidewalls of a welding groove will in no way affect the completed weld if the condition is corrected before the next bead is deposited. Correction can be accomplished by grinding. Excessive undercut at the surface should not be permitted since it may materially reduce the strength of the joint, particularly with regard to fatigue stress.

The above applies to excessive undercut. All welds have some form of undercut, such as arc wash. The codes also recognize this and allow permissible undercut depth.

Note: (1) Figures 9.13, 9.14, and 9.27

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illustrate typical examples of undercut.

(2) Figure 9.14, in addition to illustrating undercut, also shows a mismatch condition.

Cracks: Cracking of welded joints results from localized stress that at some point exceeds the ultimate strength of the material. When cracks occur during or as a result of welding, little deformation is usually apparent.

It is known that weld metal or base materials that have considerable ductility under uniaxial stress may, when subjected to biaxial or triaxial stresses, fail without appreciable deformation. Shrinkage caused by welding operations frequently sets up multi-directional stress systems. If, because of such stresses, a joint (or any portion of it such as the heat affected zone) is unable to take appreciable deformation without failure,

additional stresses set up in deposition of subsequent layers (or in the welding of other joints) may force that part to deform and fail.

An unfused area at the root of a weld may result in cracks without appreciable deformation if this area is subjected to tensile or bending stresses. When welding two plates together, the root of the weld is subjected to tensile stress as successive layers are deposited, and, as already stated, a partially fused root will frequently permit a crack to start and progress through practically the entire thickness of the weld.

After a welded joint has cooled, cracking is more likely to occur if the metal is either hard or brittle. A ductile material, by localized yielding, may withstand stress concentrations that might cause a hard or brittle material to fail.

Weld metal cracking. The ability of the weld

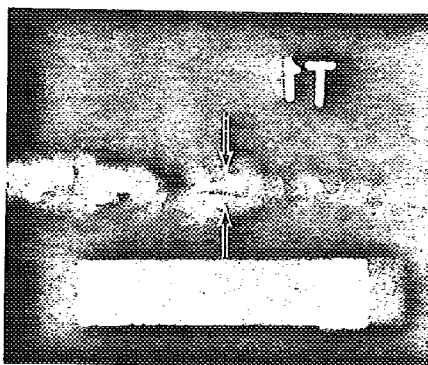


Fig. 9.13—Internal undercut



Fig. 9.14—Hi-low and internal undercut

metal to remain intact under the stress system imposed during the welding operation is a function of the composition and structure of the weld metal. In multi-layer welds, cracking is most likely to occur in the first layer of the weld and, unless repaired, will often continue through other layers as they are deposited. When cracking of the weld metal is encountered, improvement may be obtained by one or more of the following modifications:

- (1) Change the electrode manipulation or electrical conditions, to improve the contour or composition of the deposit.
 - (2) Decrease the travel speed. This increases the thickness of the deposit and provides more weld metal to resist the stresses.
 - (3) Use preheat to reduce thermal stresses.
 - (4) Use low hydrogen electrodes.
 - (5) Sequence welds to balance shrinkage stresses.
 - (6) Avoid quenching and cooling conditions.
- Three different types of cracks that can occur in weld metal are as follows:

(1) **Transverse weld cracks.** These cracks are perpendicular to the axis of the weld and, in some cases, extend beyond the weld into the base metal. This type of crack is more common in joints that have a high degree of restraint.

(2) **Longitudinal weld cracks.** These cracks are found mostly within the weld metal, and are usually confined to the center of the weld. Such cracks may occur as the extension of crater cracks formed at the end of the weld. They may also be the extension, through successive layers, of a crack that started in the first layer. A crack formed in the first layer and not removed or completely remelted before the next layer is deposited tends to progress into the layer above, and thence each succeeding layer until, finally, it appears at the surface. The final extension to the surface may occur during cooling after welding has been completed.

(3) **Crater cracks.** Whenever the welding operation is interrupted, there is a tendency for a crack to form in the crater. These cracks are usually star-shaped and progress only to the edge of the crater. However, these may be starting points for longitudinal weld cracks, particularly when they occur in the crater formed at the end of the weld. When the crater is formed elsewhere (for instance, when an electrode is

changed), the crack is usually welded when operation resumes. This, however, is not always the case, and sometimes fine, star-shaped cracks are seen at various locations. Crater cracks are found most frequently in materials with high coefficients of expansion such as austenitic stainless steels. However, the occurrence of any such cracks can be minimized or even prevented by filling craters to a slightly convex shape prior to breaking the arc.

The above discussion on cracking is an attempt to give a rudimentary knowledge of what can cause cracking but cannot always be applied, since many designs give no other alternatives because of the thicknesses involved, design criteria, accessibility, etc.

Note: Figures 9.15, 9.16, and 9.17 illustrate typical cracking in welds.

Base metal cracking. This type of cracking, usually longitudinal in nature, occurs within the heat-affected zone of the metal being welded and is almost always associated with hardenable materials. Hardness and low ductility in the heat affected zone in welded joints are metallurgical effects that result from the thermal cycle of welding and are among the principal factors that tend to cause cracking. While a complete metallurgical discussion is beyond the scope of this section, a rudimentary knowledge of the tendency of various groups of metals to harden or become brittle will be of value to the inspector.

In the case of low carbon, medium carbon, and low alloy steels, hardness and the ability to deform without rupture depend upon the alloy group to which the steel belongs and also upon the rate of cooling from the elevated temperatures produced by the welding operation. The rate of cooling will obviously depend upon a number of physical factors such as:

- (1) The temperatures produced by the welding
- (2) The temperatures of the base metal
- (3) The thickness and thermal conductivity of the base metal
- (4) The heat input per unit time at a given section of the weld
- (5) The ambient temperature

With a given cooling rate, the low carbon steels will harden considerably less than the medium carbon steels. Low alloy steels exhibit

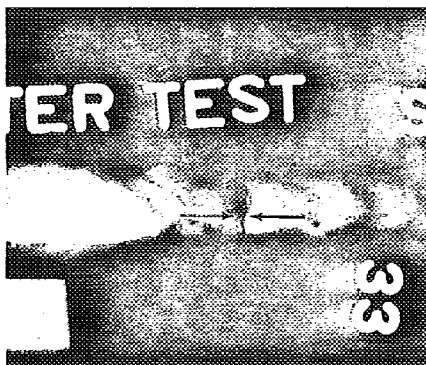


Fig. 9.15—Crack, transverse

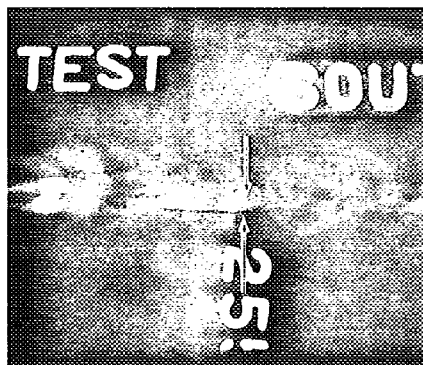


Fig. 9.16—Crack, adjacent to root

a wider variation in their hardening characteristics: some of them may be similar to low carbon steel, while others will react like medium carbon steel.

High alloy steels must be considered separately since this group includes the austenitic and ferritic stainless steels, as well as the martensitic steels. The latter behave similarly to the medium carbon and low alloy groups, except that they harden to a greater degree with a given cooling rate. Neither the austenitic steels (of which the common 18 percent chromium-8 percent nickel stainless steel is an example) nor the ferritic stainless steels (of which the low carbon straight chromium steels containing 12 percent or more chromium are an example) harden upon quenching from elevated temperatures. However, in general, the ferritic stainless

steels are rendered brittle (but not hard) by welding operations.

The metallurgical characteristics of the metals are of prime importance. Base metal cracking is associated with lack of ductility in the heat affected zone. Since ductility usually decreases with increasing hardness, cracking often occurs. This is not the whole answer, however, for it has been established that different heats of the same steel of equal hardenability vary appreciably in cracking tendency. Furthermore, recent information establishes beyond a doubt that in shielded metal arc welding the characteristics of the electrode as determined by its covering have considerable effect upon the tendency toward heat-affected zone cracking.

Hardenable steels are usually more difficult to weld for two reasons:

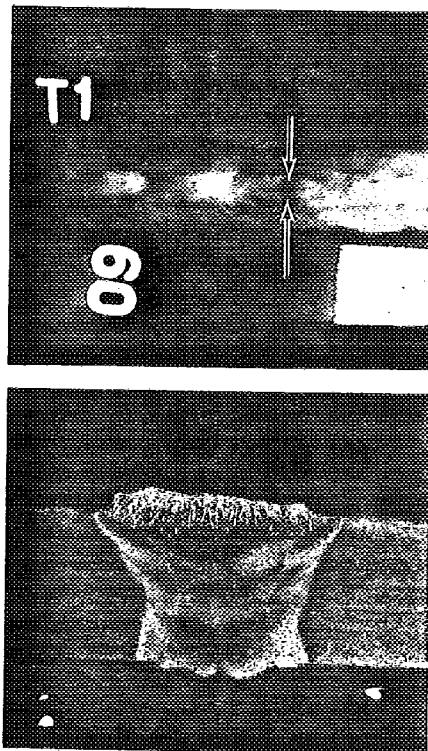


Fig. 9.17—Shrinkage crack

- (1) Variations in microstructure of the heat-affected zone, which can occur with variations in the cooling rate, cause differences in mechanical properties.
- (2) Such steels are usually used because of their higher tensile properties, and welding them can be likened to welding lower strength steels of greater thickness.

When base metal cracking is encountered with hardenable steels, the condition can be improved in the following ways:

- (1) Use of preheat to control cooling rate
- (2) Controlled heat input
- (3) Use of the correct electrode
- (4) Proper control of welding materials

While this subject has been treated in a general manner, each case usually involves requirements peculiar to the particular weldment in question.

However, the two types of base metal cracking that can occur as a result of the welding operation are as follows:

(1) Transverse base metal cracks. This type of cracking is across the direction of welding and usually associated with welds on steels of high hardenability. Such cracks usually cannot be detected until the weldment has cooled to room temperature.

(2) Longitudinal base metal cracks. These cracks are parallel to the weld and are in the base metal. They may be extensions of bond-line cracks. For fillet welds, longitudinal base metal cracks may be divided into two types: (a) toe cracks, which proceed from the toe of the fillet weld into the base metal, (b) root cracks, which proceed from the root of the fillet weld and progress into the base metal, and are evident occasionally on the opposite side (see Fig. 9.18).

In the case of groove welds, cracks are more likely to occur in the heat-affected zone adjacent to the weld. Cracks may also occur at the edge of the weld in the zone of fusion between the weld metal and base metal. Usually this type of crack is associated with steels of high hardenability when filler metal and base metal are entirely different in composition. This tends to form alloys with unpredictable properties in this zone.

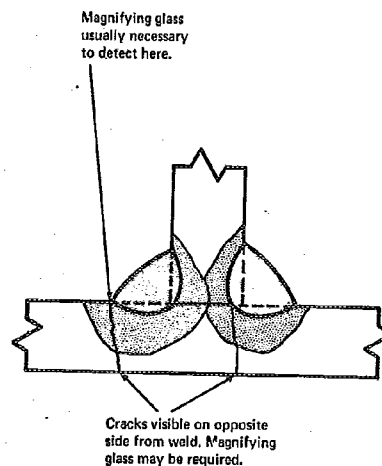


Fig. 9.18—Base metal cracking shown as it may occur at the root or toe of a fillet weld

Surface Irregularities: Occasionally, welding conditions cause pores to form in the surface of the deposit. The pattern can vary from a single pore every few feet to many pores per inch. Since the atmosphere produced by a welding process is an important factor in the weld metal produced, any change that varies the atmosphere will affect the end result.

One such change could be the difference between the air or gas available at the arc when a pass is being deposited at the bottom of a narrow groove, as compared to that available during deposition of the top layer of the same weld. Eliminating from consideration the base metal (which can be a factor), improvement is usually obtained through changing the electrical conditions, such as polarity and arc length.

It is important to eliminate this type of discontinuity or it could result in slag entrapment or other discontinuities. When high-quality welding is the goal, it is not safe to assume that these defects will fuse out. Good welding practice dictates their removal by chipping or grinding before deposition of succeeding layers.

Other Irregularities: Such irregularities as varying width of surface layer, depressions, variations in height of reinforcement, and non-uniformity of weld ripple cannot properly be classified as weld discontinuities; however, they are a part of the weld. While they may not affect the integrity of the completed weld, they frequently are covered by specification requirements and are thus subject to inspection.

Magnetic disturbance, poor technique, and improper electrical conditions can account for these irregularities. Such unusual conditions might be caused by lack of experience; location (that is, the welder is welding under a severe handicap such as restricted position during welding or poor visibility); or other factors peculiar to a specific job. Generally speaking, however, surface appearance reflects the ability and experience of the welder. As such, presence or absence of these discontinuities is important. The more uniform the surface of a weld, the better the eye appeal.

Figure 9.19 illustrates the surface appearance of welds produced under various electrical conditions with different techniques. Figure 9.20 illustrates excessive spatter; Fig. 9.21, poor surface

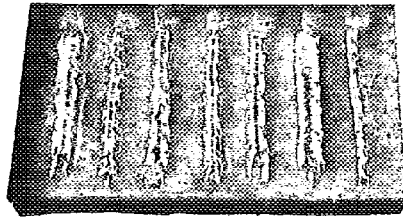


Fig. 9.19—A specimen showing welds made with various procedures

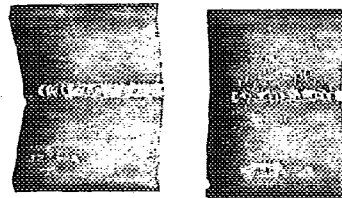


Fig. 9.20—Surface appearance

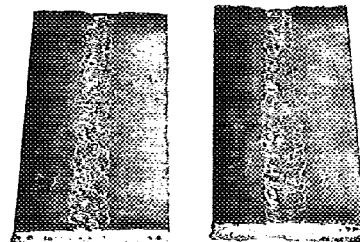


Fig. 9.21—Surface appearance: vertical groove weld

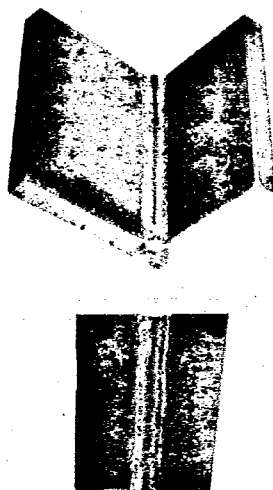


Fig. 9.22—Satisfactory weld contours and surface appearance

appearance; Fig. 9.22, satisfactory weld contours. Figures 9.21 and 9.22 are examples of satisfactory welds used as workmanship standards.

Mechanical and Chemical Weld Metal Properties

Filler Metal Properties: Specific mechanical and, in some cases, chemical properties are required of all welds made in any given weldment. The requirements depend upon the codes or specifications involved, and departure from these specified requirements could produce a defective weld. These properties in general are determined with specially prepared test plates (although in some cases such tests may be made on sample weldments taken from production). Where test plates are used, the inspector must determine that specified procedures are followed so that results will be indicative of actual weldment properties.

Mechanical properties that must be checked against prescribed requirements include tensile strength, yield strength, ductility, hardness, and impact strength. Also, chemical properties may

be deficient because of incorrect weld metal composition or unsatisfactory corrosion resistance; where required, these can be checked against the welding procedure specification.

Base Metal Properties: It should be pointed out that not all discontinuities are due to improper welding conditions. Many such difficulties may be attributed to the base metal. Base metal requirements are defined by applicable specifications or codes. Departure from these requirements should be considered cause for rejection.

Base metal properties that may not meet prescribed requirements include chemical composition, cleanliness, lamination, stringers, surface conditions (scale, paint, oil, etc.), mechanical properties, and dimensions. The inspector should keep factors such as these in mind when he is trying to determine the causes of welding difficulties that have no apparent cause.

Edge Laminations. Edge laminations (inclusions) may exist on all plates or pipe to some degree; laminations normally occur near the center of plate or pipe materials and tend to be parallel to the surface. They are usually caused by inclusions or blow holes in the original ingot. During rolling, these inclusions become elongated and appear as fibrous longitudinal stringers of nonmetallics. Criteria for acceptance are given in the ASTM and ASME material specifications. Consideration must be given to these acceptable inclusions.

Lamellar Tearing. Some rolled structural materials are susceptible to a cracking defect known as lamellar tearing. This crack has a characteristic morphology which is step-like in nature. The most commonly accepted theory is that when restraint stresses and thermal strains imposed by welding exceed the strength of the material in the through-thickness direction, the stress concentration at nonmetallic inclusions common to most structural materials precipitates cracks. The cracks initiate by decohesion of the inclusion-metal interface and propagate by ductile rupture to the next inclusion in that plane or by localized shear fracture to an inclusion which is in a slightly different plane. Refer to Chapter 7 on Metallurgy for information on laminations and lamellar tearing.

Note: Some additional radiographs showing welding discontinuities are to be found

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in the following figures: 9.23, 9.24, 9.25, 9.26, 9.27, 9.28, and 9.29.

Arc Strikes. Arc strikes outside of the area of permanent welds should be avoided on any base

metal. The AWS Structural Welding Code requires that any cracks or blemishes caused by arc strikes be ground to a smooth contour and checked to ensure soundness.

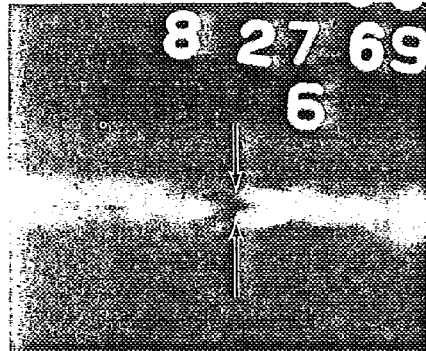


Fig. 9.23—Horseshoe crater

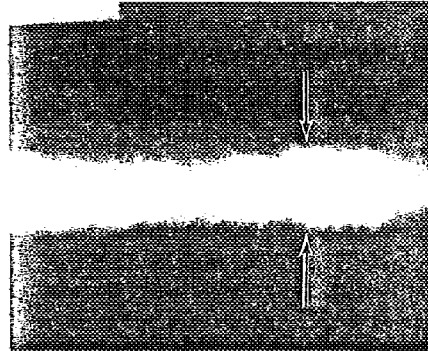


Fig. 9.24—Excessive external weld buildup

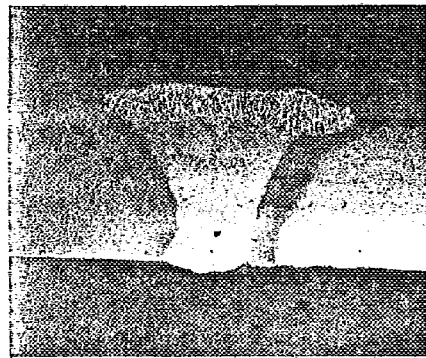
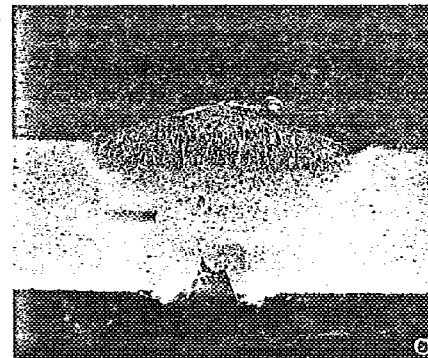


Fig. 9.25—Hollow bead



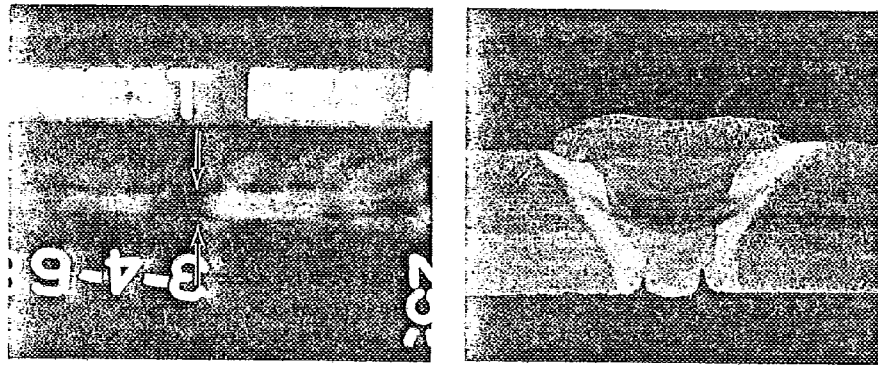


Fig. 9.26—Stop-start with shrinkage

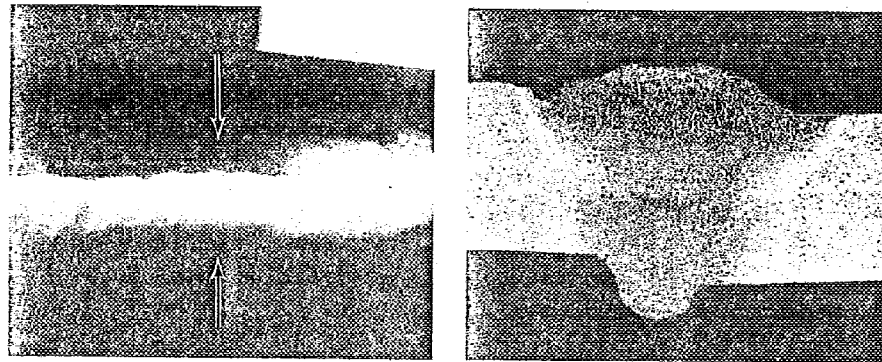


Fig. 9.27—External undercut, excessive penetration and hi-low

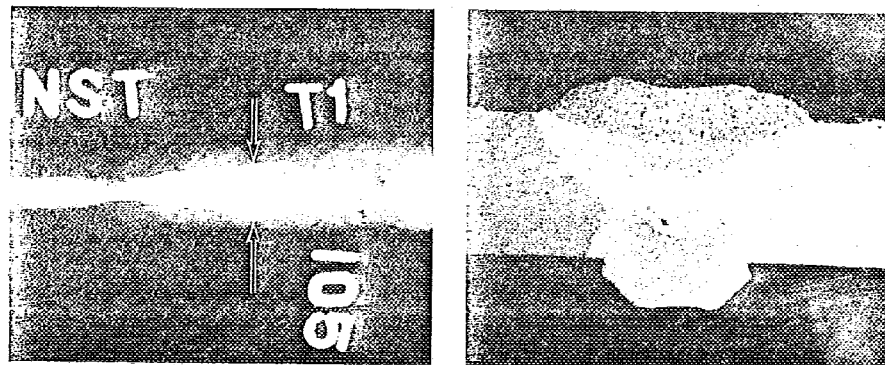


Fig. 9.28—Excess penetration

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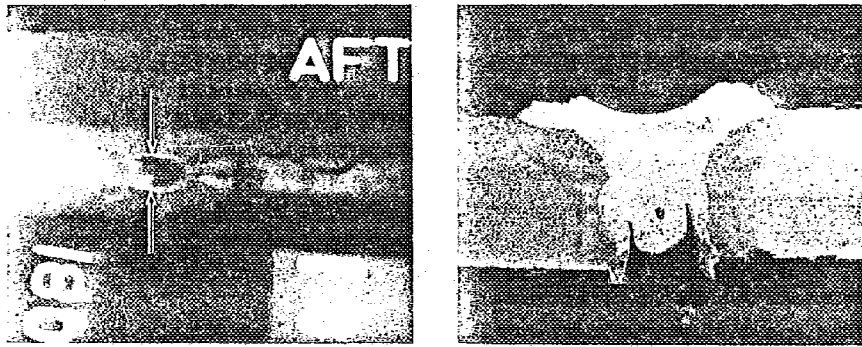


Fig. 9.29---Melt-thru area

Glossary of Weld Discontinuities

melt-thru. Melt-thru refers to a coalescence of weld metal beyond the root of the weld. Melt-thru may also involve a melting of metal away from the root of the weld, thus forming a cavity or hole in the root of the weld (see Fig. 9.29).

cracks. A fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement (see Figs. 9.15, 9.16, 9.17, and 9.18).

slag inclusion. Nonmetallic solid material entrapped in weld metal or between weld metal and base metal (see Figs. 9.7, 9.8, and 9.9).

excess penetration. Excess penetration results in an excess of the weld metal on the back side of a joint and is usually associated with the root pass (see Figs. 9.27 and 9.28).

reinforcement of weld. Weld metal in excess of the quantity required to fill a joint (see Fig. 9.24).

undercut. A groove melted into the base metal adjacent to the toe or root of a weld and left unfilled by weld metal (see Figs. 9.13, 9.14, and 9.27).

hi-low. Hi-low represents mismatch or misalignment of the plate or pipe ends across the weld root (see Figs. 9.6, 9.12, 9.14, and 9.27).

hollow-bead. Hollow-bead refers to an elongated gas pocket in any weld bead but is normally found in the root pass (see Fig. 9.25).

horseshoe crater. A horseshoe crater refers to an approximately circular surface condition extending into the weld metal in an irregular manner usually caused by a volumetric contraction of molten metal during solidification. These defects are normally associated with the root pass (see Fig. 9.23).

inadequate joint penetration. Joint penetration which is less than specified (see Figs. 9.6, 9.11, and 9.12).

porosity. Cavity type discontinuities formed by gas entrapment during solidification (see Figs. 9.4, 9.5, 9.6, and 9.7).

shrinkage crack. A shrinkage crack is usually formed by shrinkage or upsetting on the underside of a root bead and appears as a linear indication (see Fig. 9.9).

stop-start. A stop-start represents an approximately circular surface condition extending into the weld metal in an irregular manner that is the result of an abrupt interruption of the welding arc (see Fig. 9.26).

incomplete fusion. Fusion which is less than complete (see Fig. 9.10).