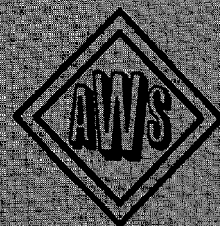


CHAPTER 10:**WELD AND BASE METAL
DISCONTINUITIES****Introduction**

Discontinuities are imperfections in welds or base metals. Ideally, a sound weld should have no discontinuities at all, but welds are not perfect; imperfections do exist in varying degrees.

There is a temptation to call discontinuities defects, but as a matter of terminology the terms discontinuity and defect should be carefully distinguished by all inspectors. A defect is rejectable. Some discontinuities are acceptable. A discontinuity becomes a defect when it exceeds acceptable limits imposed by acceptance standards. An imperfection of lesser magnitude than that is still a discontinuity, but it is not a defect.

The welding inspector's primary job is to inspect the fabricator's work to see that it meets the requirements of the contract. To be able to do this, he must be familiar with acceptance standards, which spell out the acceptable limits for discontinuities. If a particular type of discontinuity is permissible in the welds to be inspected, the acceptance standards, code or specification must specify the criteria used to discriminate between acceptable imperfections and defects.

The criteria used to discriminate between acceptable imperfections and defects are described in the following terms:

- Type of discontinuity
- Size of discontinuity
- Location of discontinuity

All three criteria must be considered to judge whether a discontinuity is severe enough to be considered a defect.

Types of Discontinuities

Discontinuities have been categorized under the following twelve types:

- Porosity
- Inclusions, both metallic and nonmetallic
- Underfill
- Incomplete fusion
- Incomplete joint penetration
- Overlap
- Undercut
- Lamination and delamination
- Seams and laps
- Lamellar tearing
- Crack
- Arc strike

TABLE 1
COMMON TYPES OF DISCONTINUITIES

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

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

SOURCE: ANSI/AWS B1.10-86

TABLE 2
DISCONTINUITIES COMMONLY ENCOUNTERED WITH WELDING PROCESSES

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

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

SOURCE: ANSI/AWS B1.10-86

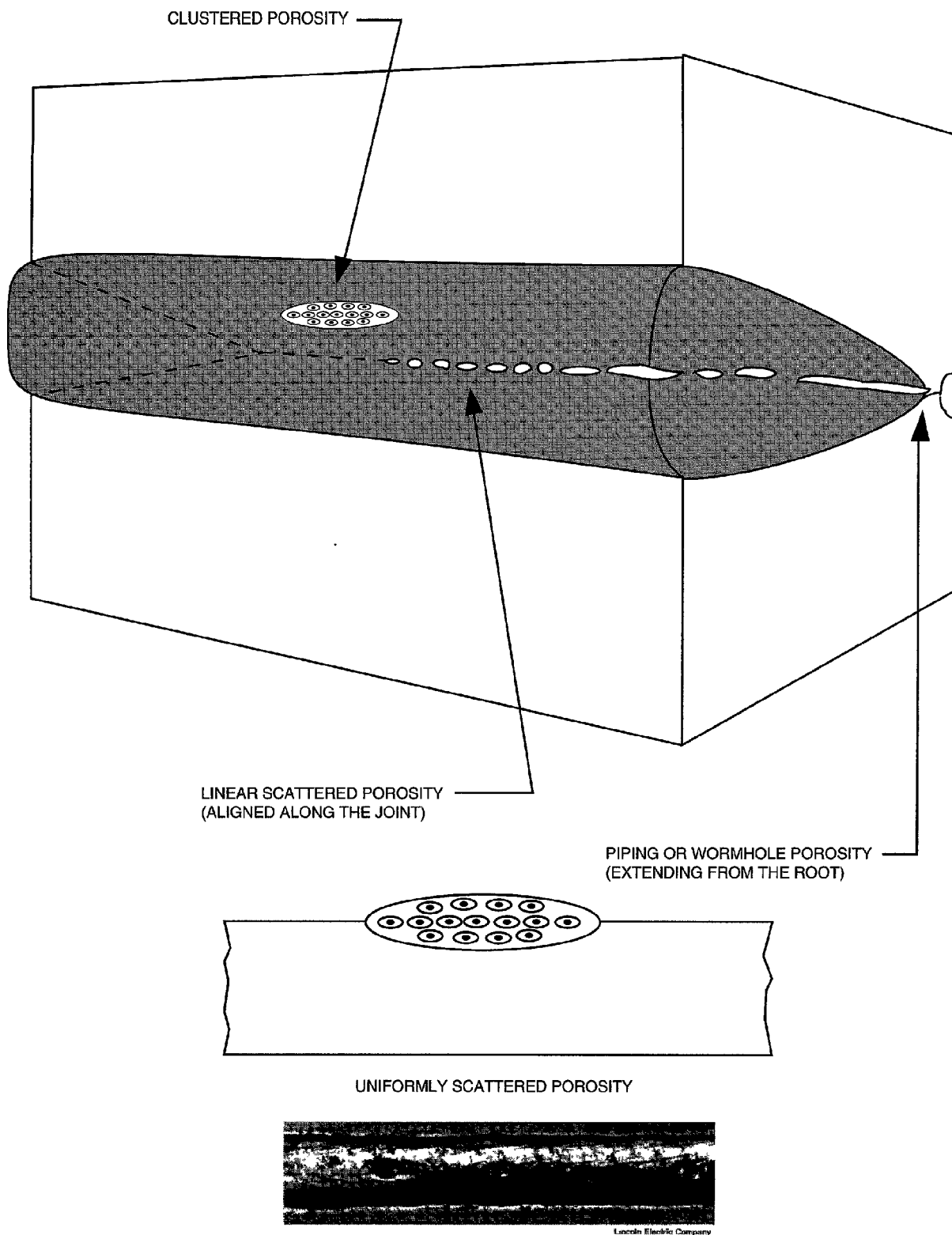
Porosity

Porosity results when gas is entrapped in solidifying metal. This will be discussed only with respect to welds (although porosity is also commonly seen in castings). The entrapped gas comes from either the gas used in the welding process or the gas released from chemical reactions occurring during the welding process. Proper welding technique avoids gas formation

and entrapment. Faulty or dirty materials may produce gas. The gas becomes trapped in the form of porous discontinuities in the weld.

Porosity usually occurs in the form of rounded discontinuities, but in a severe case the porosity is cylindrical. These large cylindrical pores are called piping porosity (or "wormholes"). The presence of porosity is a sign that the welding process is not being properly controlled or that the base metal and welding fluxes are contaminated

10-4



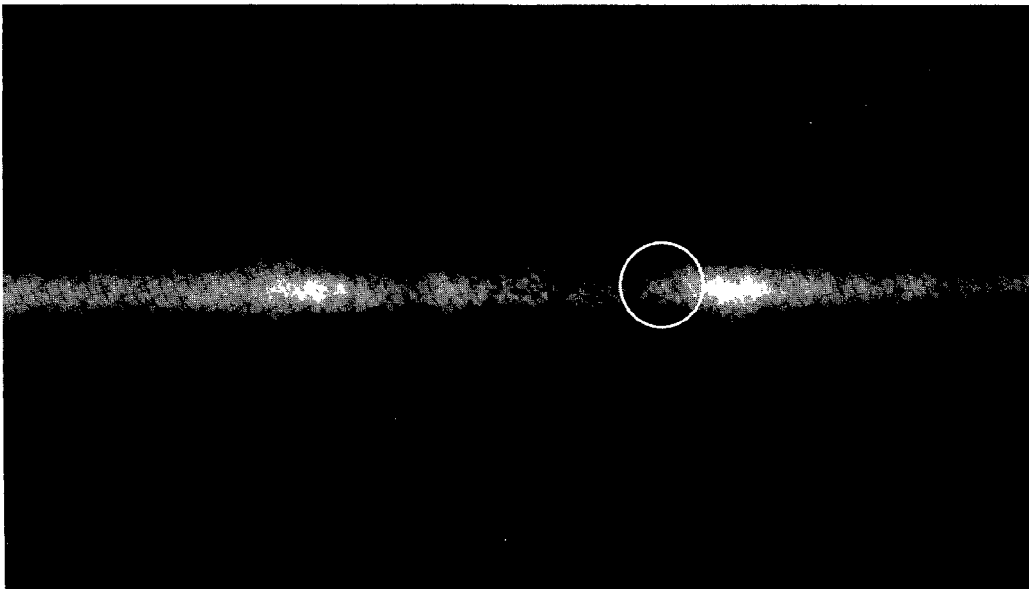
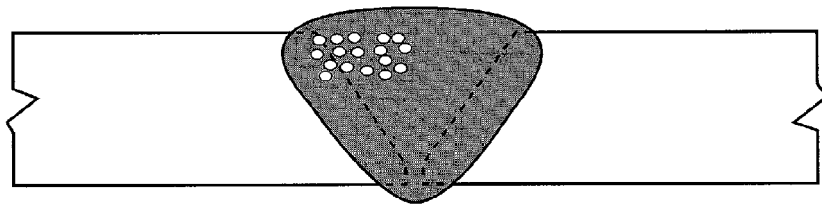
with gas producing elements. Generally speaking, porosity in small amounts does not significantly intensify stress, making it a less critical discontinuity compared to those with sharp ends.

The distribution of porosity can be helpful in determining what type of fault caused the porosity. If the porosity is uniformly scattered, the cause could either be faulty materials or poor technique used throughout the weld.

A cluster of porosity is likely to result from improper initiation or termination of the weld.

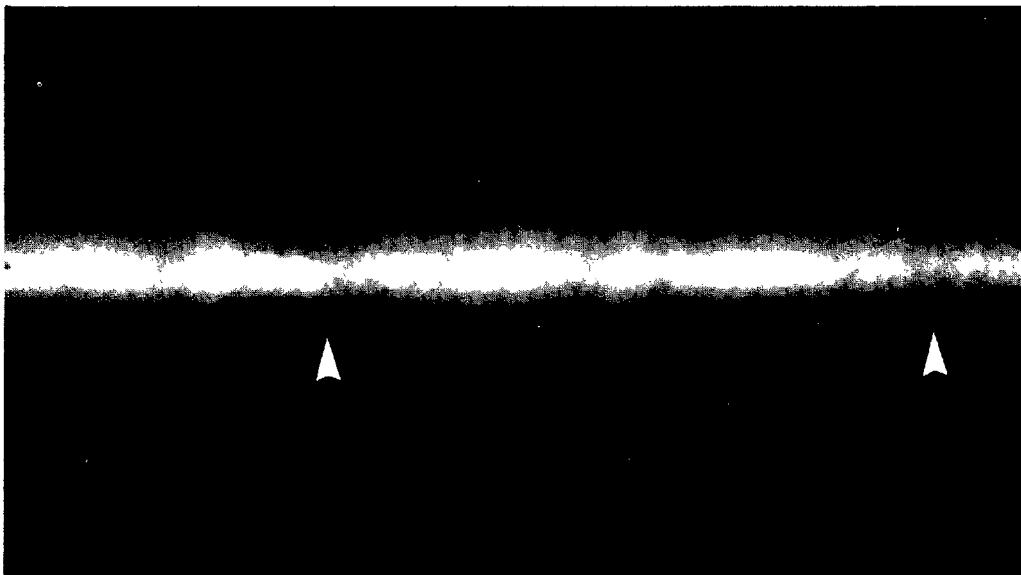
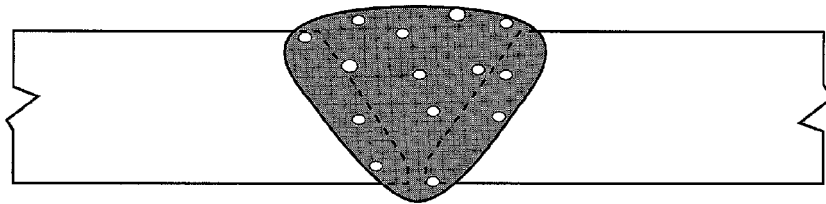
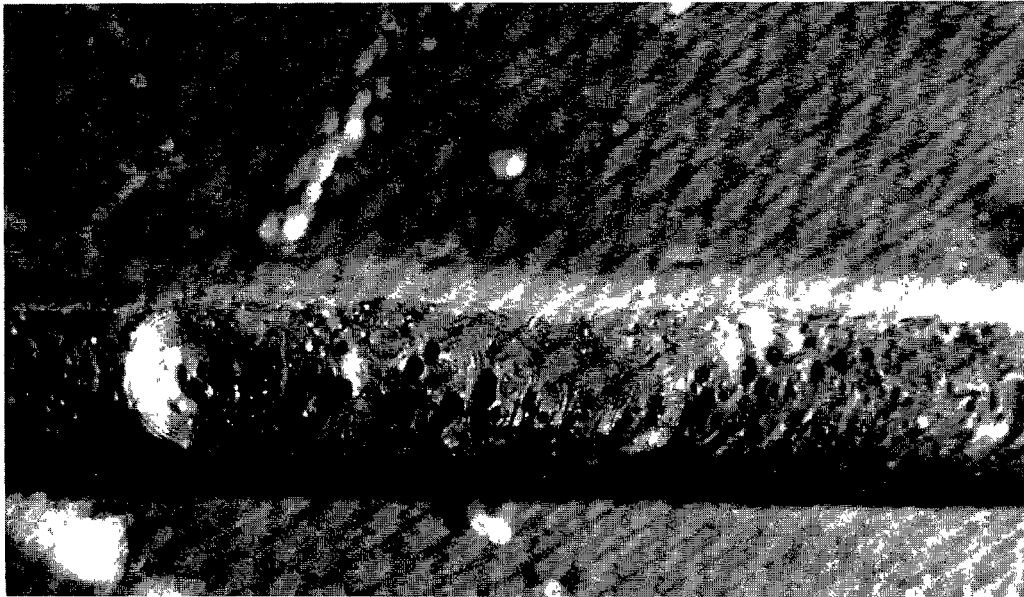
Linear porosity aligned along a joint boundary would suggest that contamination triggered a chemical reaction, which produced unwanted gas. Such contamination could have been eliminated by preparing the joint properly.

Piping porosity is an elongated gas discontinuity extending from the weld root toward the surface and is also evidence of the presence of surface contamination.

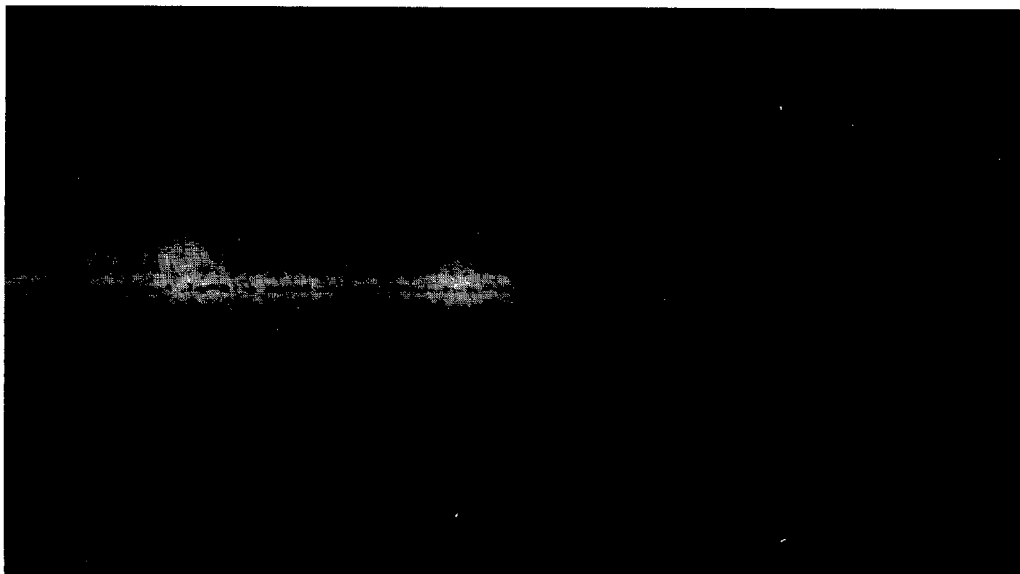
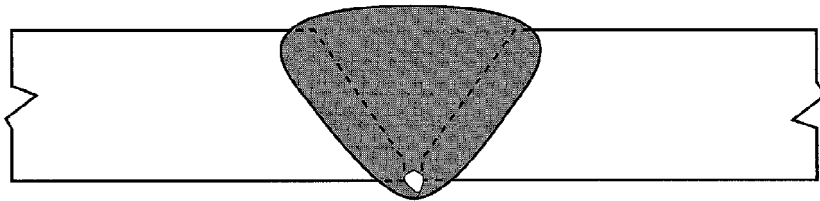
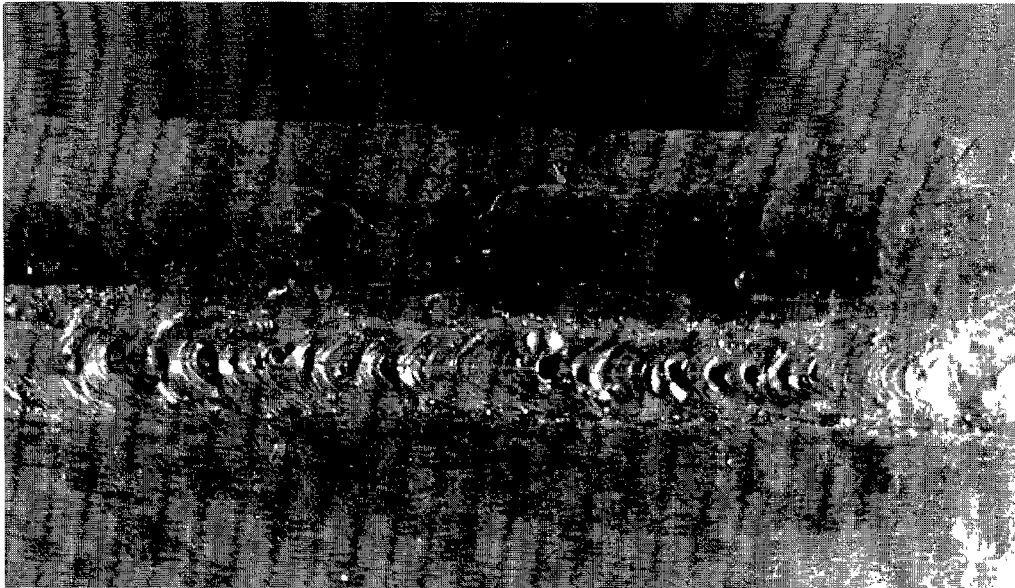


RADIOGRAPH OF CLUSTER POROSITY

10-6

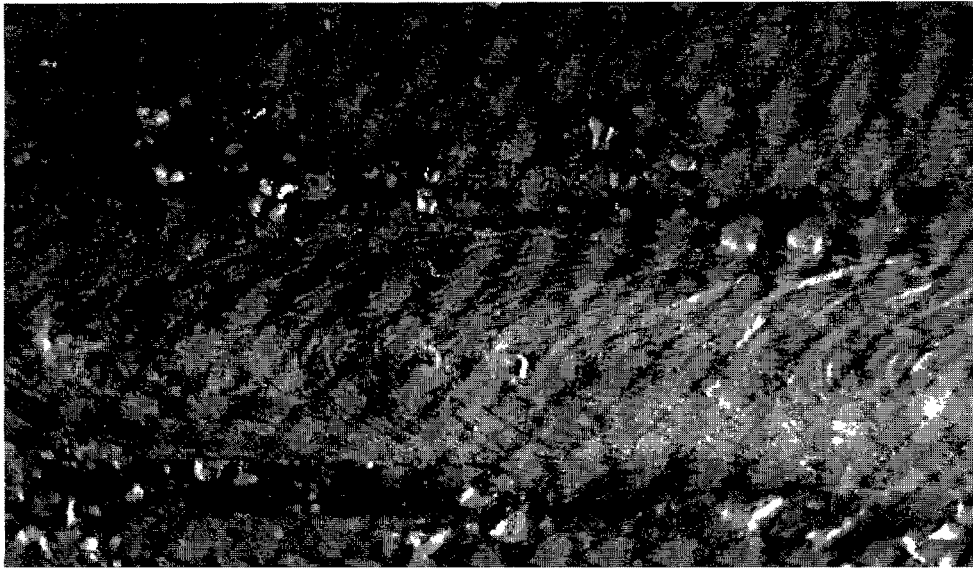


RADIOGRAPH OF SCATTERED POROSITY



RADIOGRAPH OF LINEAR (ALIGNED) POROSITY

10-8



SURFACE APPEARANCE OF PIPING POROSITY

Inclusions

Inclusions result when solid materials are entrapped in solidifying metal. Inclusions interrupt the continuity of the weld, and some loss in structural integrity will result where they are present.

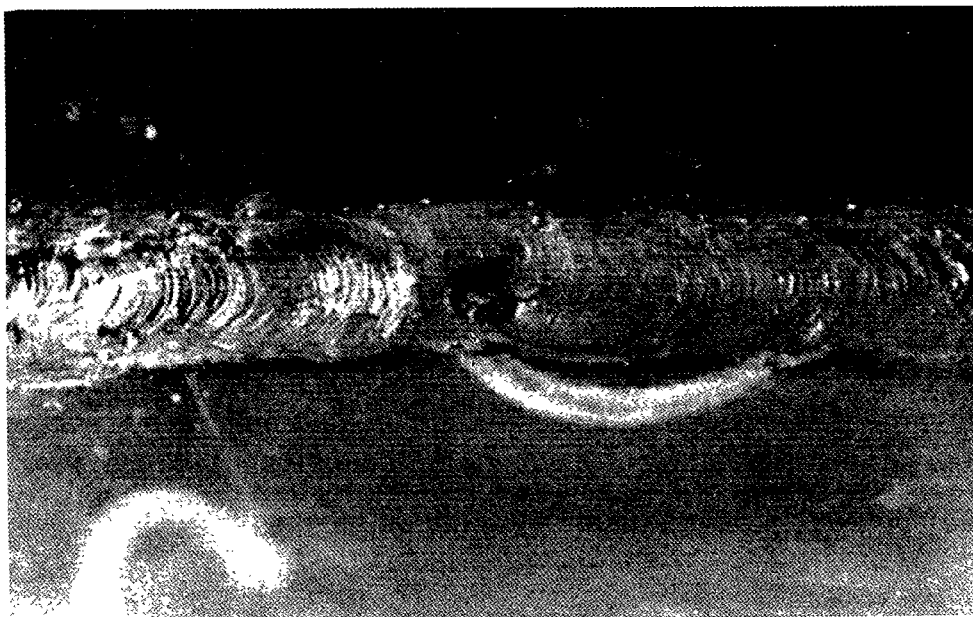
Nonmetallic (Slag and Oxides) Inclusions:

These types of inclusions result from faulty welding or cleaning techniques and/or the failure of the designer to provide proper access for welding within the joint. Molten slag and oxides will flow to the top of the weld if allowed. Sharp notches in joint boundaries or between passes often cause slag to become entrapped under the molten weld metal. Parallel lines of elongated slag inclusions, sometimes called "wagon tracks" because of their radiographic appearance, often result if the welder produces a convex root pass in

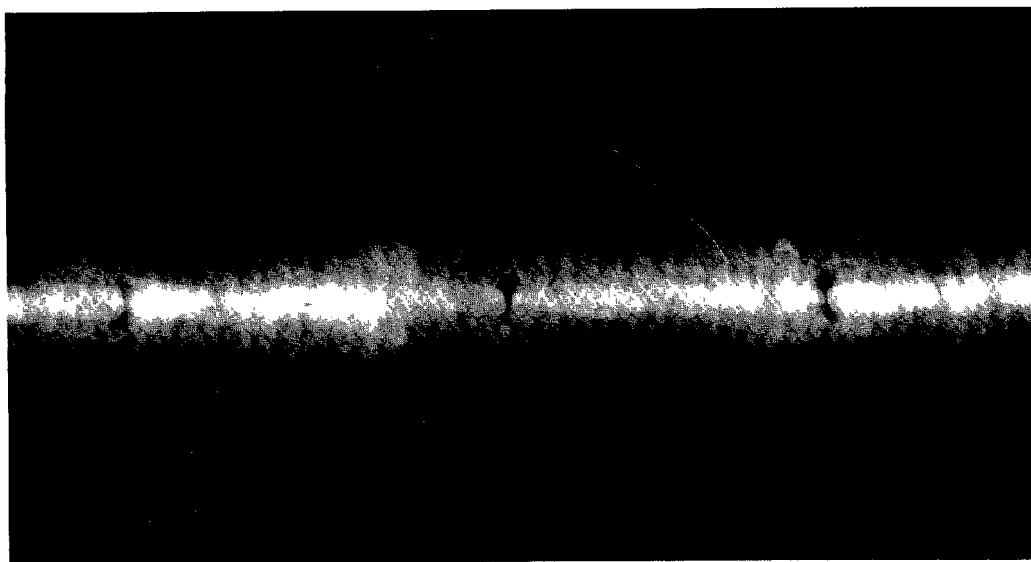
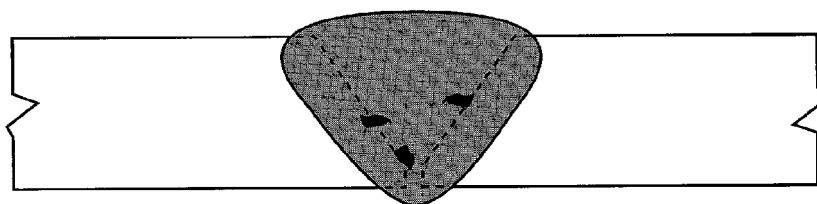
an open root pipe joint and fails to adequately clean the slag on either side of this weld pass.

Metallic Inclusions: These inclusions are usually tungsten particles trapped in weld metal. They most often occur in gas tungsten arc welding but may also result if the plasma arc welding process is improperly applied. These tungsten inclusions appear as light areas on radiographs because tungsten is highly opaque to radiation. This is just the opposite from most other discontinuities, which will show up as dark regions on the radiographic film.

Copper inclusions result if copper backing bars or backing shoes are used, such as in electroslag welding. Improper application of the plasma arc welding process could result in overheating of the copper constricting nozzle which could also cause copper inclusions in the weld.

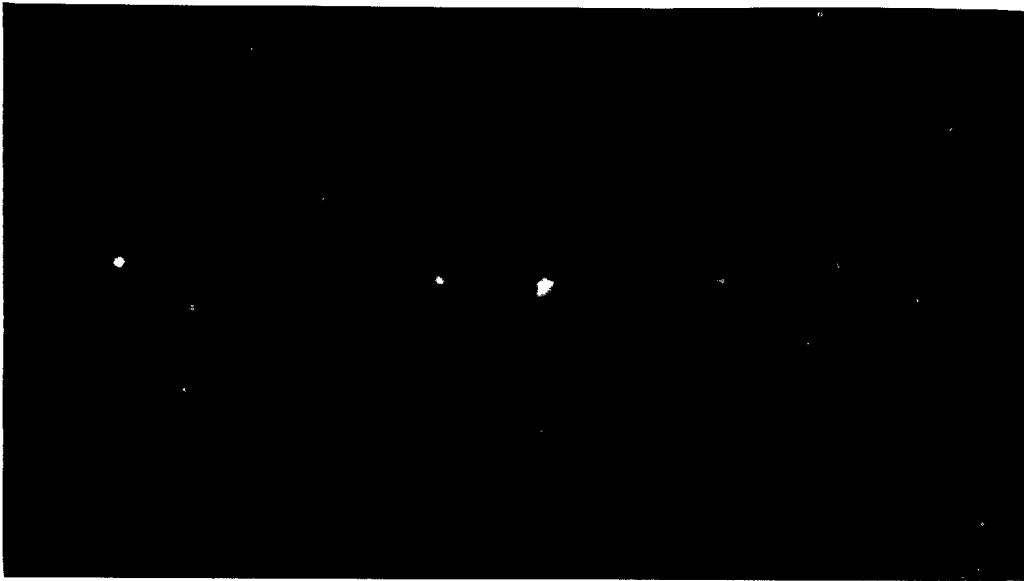
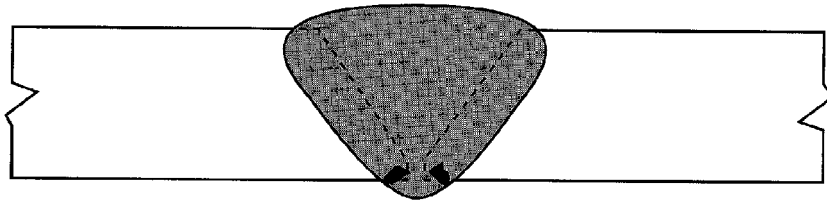


SURFACE SLAG INCLUSIONS

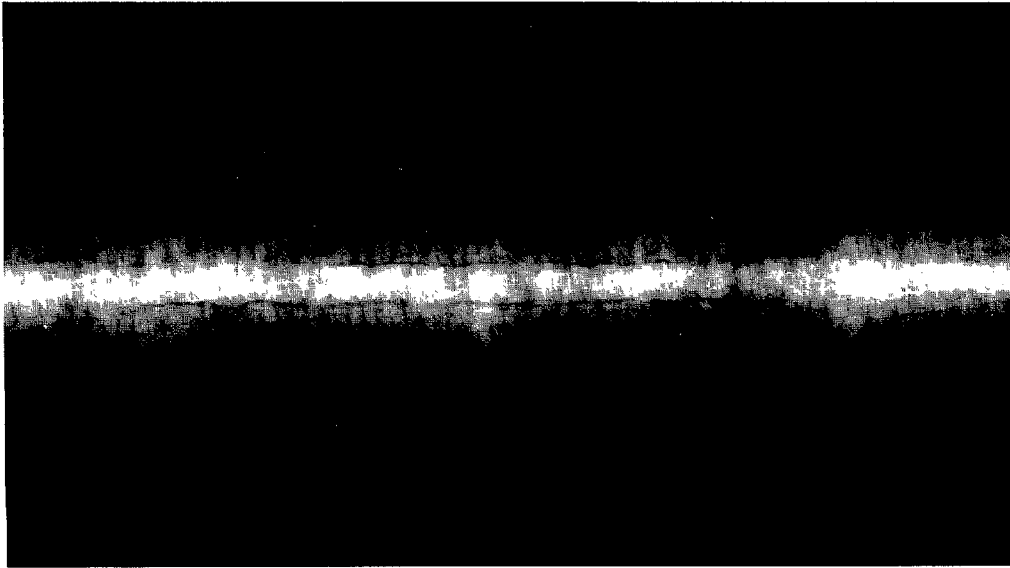
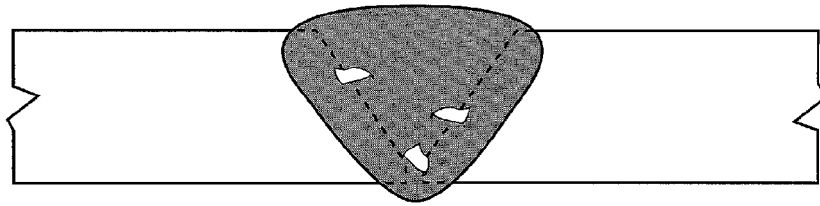


RADIOGRAPH OF INTERPASS SLAG INCLUSIONS

10-10



RADIOGRAPH OF ELONGATED SLAG LINES (WAGON TRACKS)



RADIOGRAPH OF TUNGSTEN INCLUSIONS

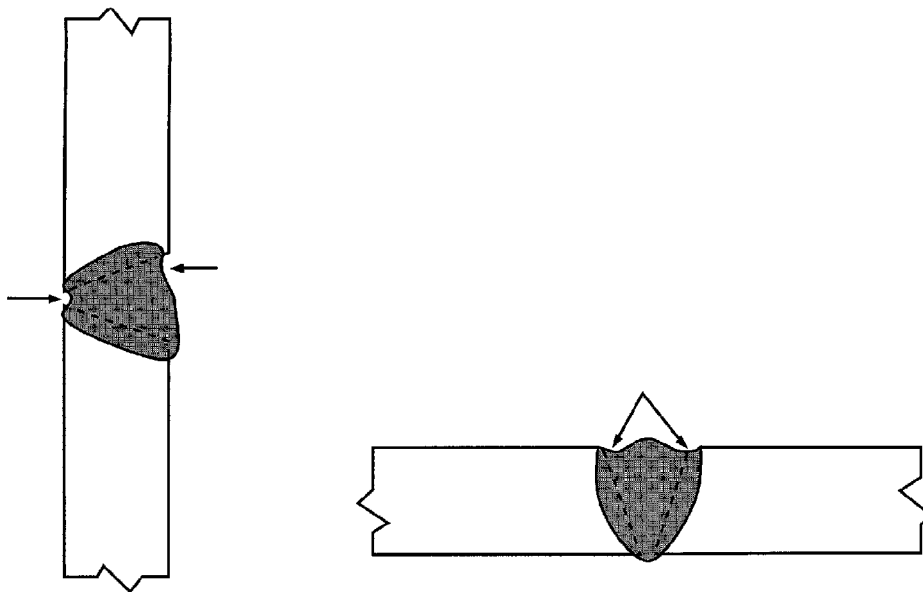
Underfill - is a depression on the face or root surface of a groove weld below the surface plane of the adjacent base metal. In other words, the welder or welding operator has failed to completely fill the groove, resulting in an undersize weld. On pipe welds, underfill at the weld root may also be referred to as “internal concavity” or “suck-back”.

Incomplete Fusion - is the failure of the liquid weld metal to fuse into the entire groove face of the joint or to adjacent weld beads. Incomplete fusion is usually caused by insufficient application of heat to all faces of the joint. However, incomplete fusion can also be caused by the presence of oxides which inhibit fusion by remaining tightly secured to the base metal.

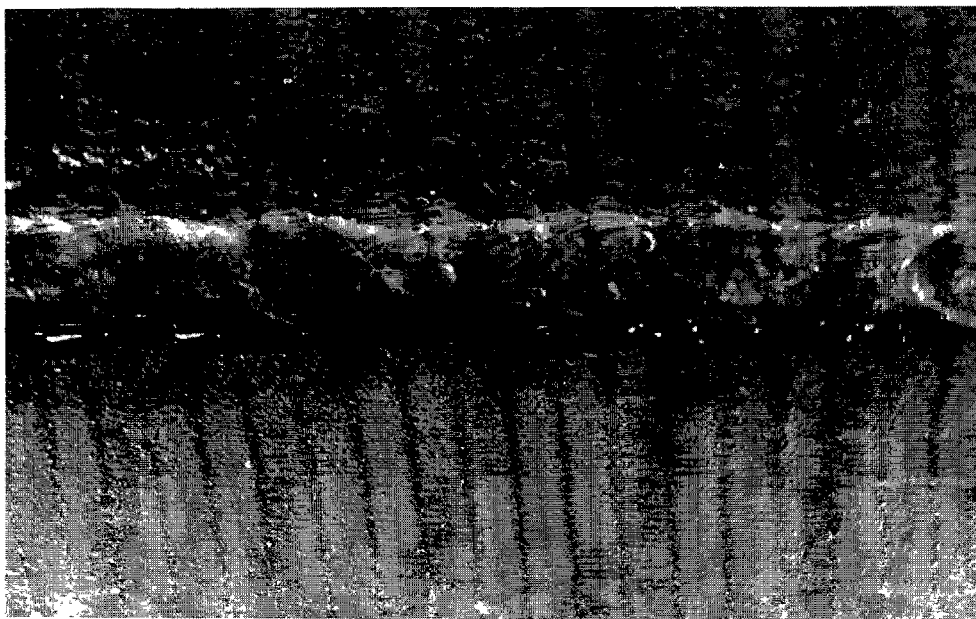
Incomplete Joint Penetration - results when the weld metal fails to extend completely through the joint thickness. The amount of joint penetration required in any joint should be specified on drawings. Whether that amount of joint penetration can be obtained depends upon the accessibility of the heat source and filler rod to the face area. This discontinuity can also result from improper joint designs.

The presence of incomplete joint penetration in a joint requiring complete joint penetration could also be referred to as inadequate joint penetration, or joint penetration which is less than that specified. Many codes require the use of joint backing for single-groove welds or backgouging of double-groove welds to assure that complete joint penetration can be attained.

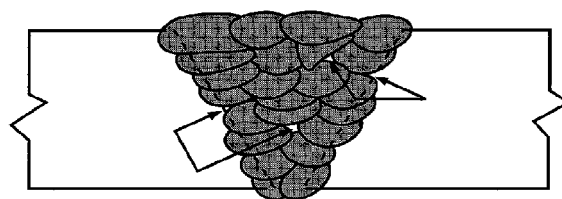
10-12



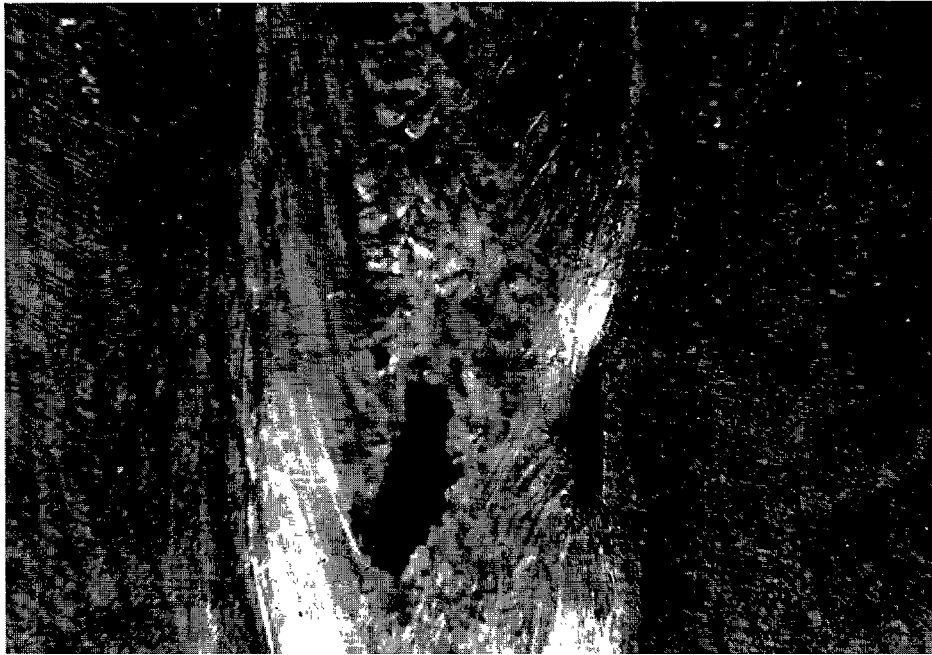
UNDERFILL



UNDERFILL USING FLUX CORED ARC WELDING IN STEEL



VARIOUS LOCATIONS OF INCOMPLETE FUSION

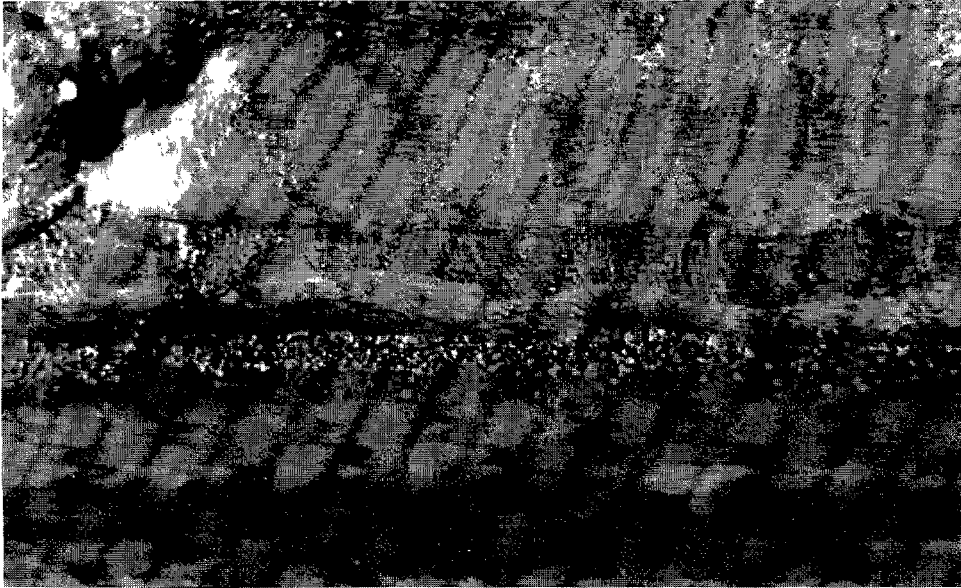


INCOMPLETE FUSION AT WELD FACE

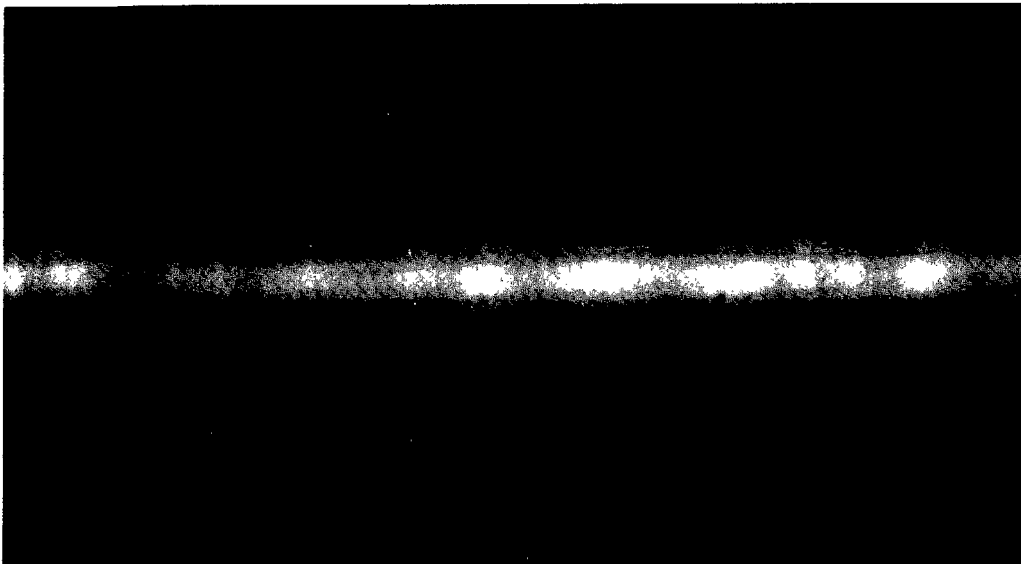
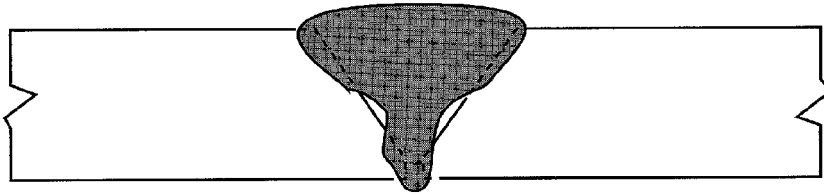


INCOMPLETE FUSION BETWEEN INDIVIDUAL WELD BEADS

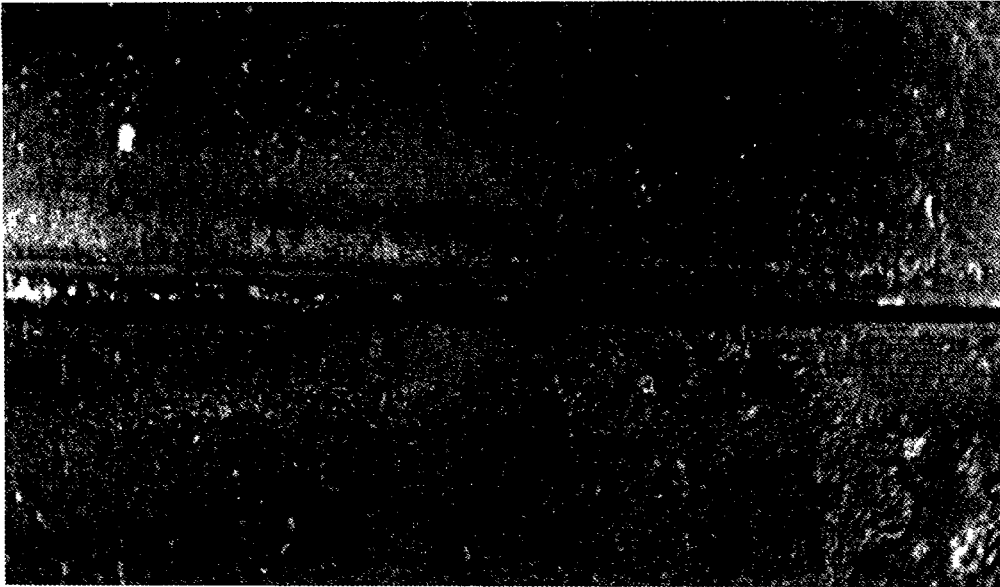
10-14



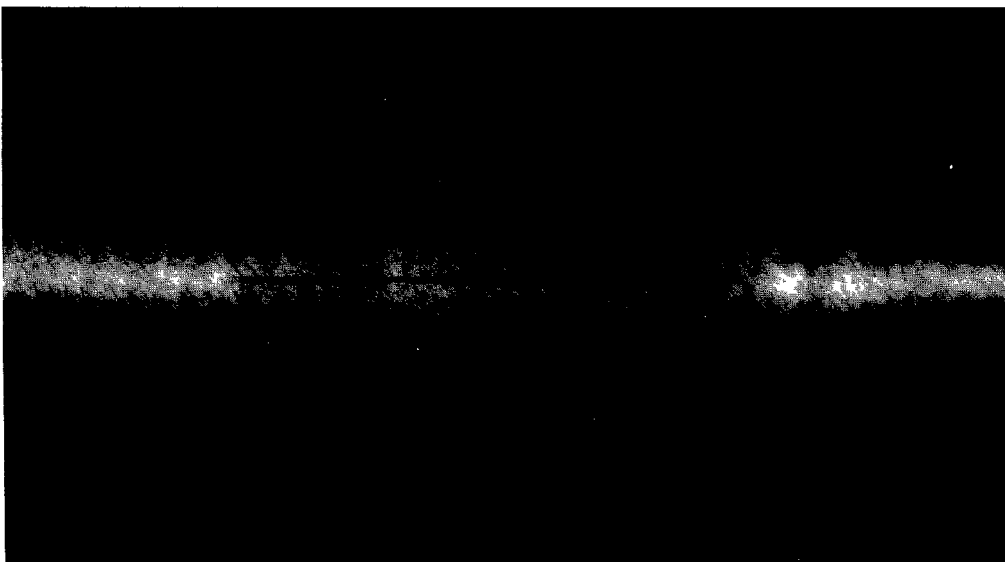
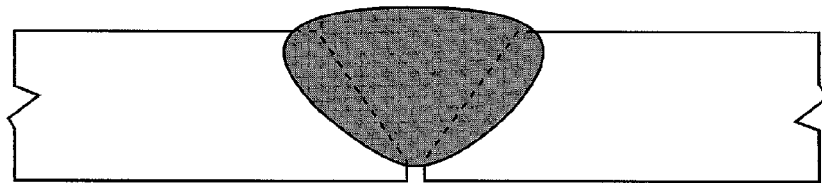
INCOMPLETE FUSION BETWEEN THE WELD AND BASE METAL



RADIOGRAPH OF LACK OF SIDE WALL FUSION (LOF)



INCOMPLETE JOINT PENETRATION



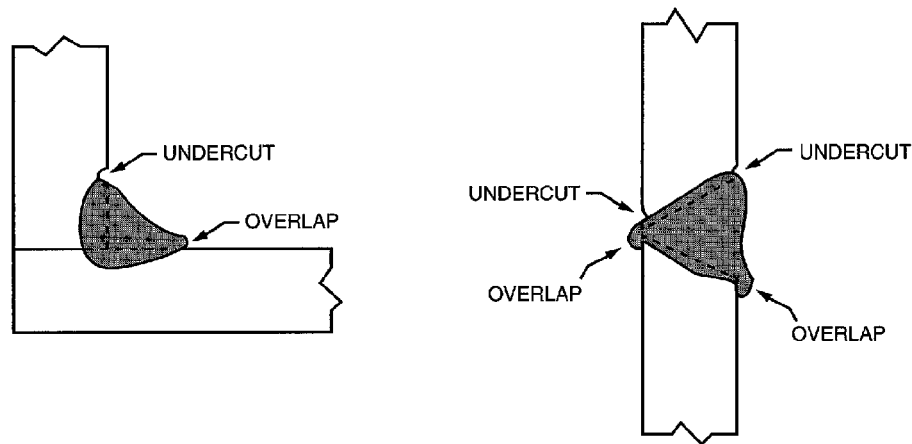
RADIOGRAPH OF INCOMPLETE JOINT PENETRATION

10-16

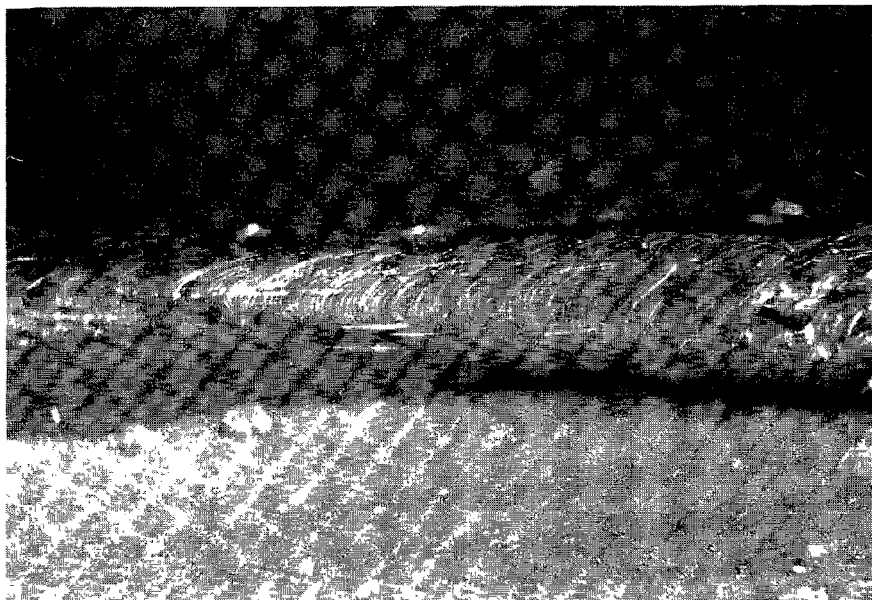
Overlap

Overlap is the protrusion of weld metal beyond the toe or weld root of the weld joint without fusion. The resulting discontinuity is a severe mechanical notch on the surface. This discontinuity is similar to incomplete fusion with the difference being the location where the fusion failed to take place.

Overlap is caused by the inability of the weld metal to fuse with the surface, especially when tightly adhering oxides cover the base metal. Overlap results from lack of control of the welding process in the form of insufficient heat (current too low), inadequate travel speed, improper selection of welding materials (lack of deoxidizers), or improper preparation of the joint (failure to remove mill scale or other surface coatings).



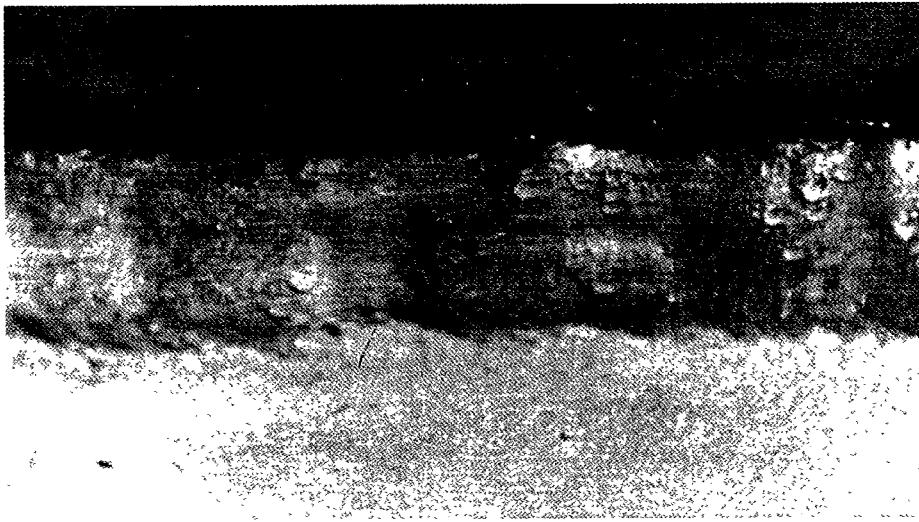
WELD FLAWS



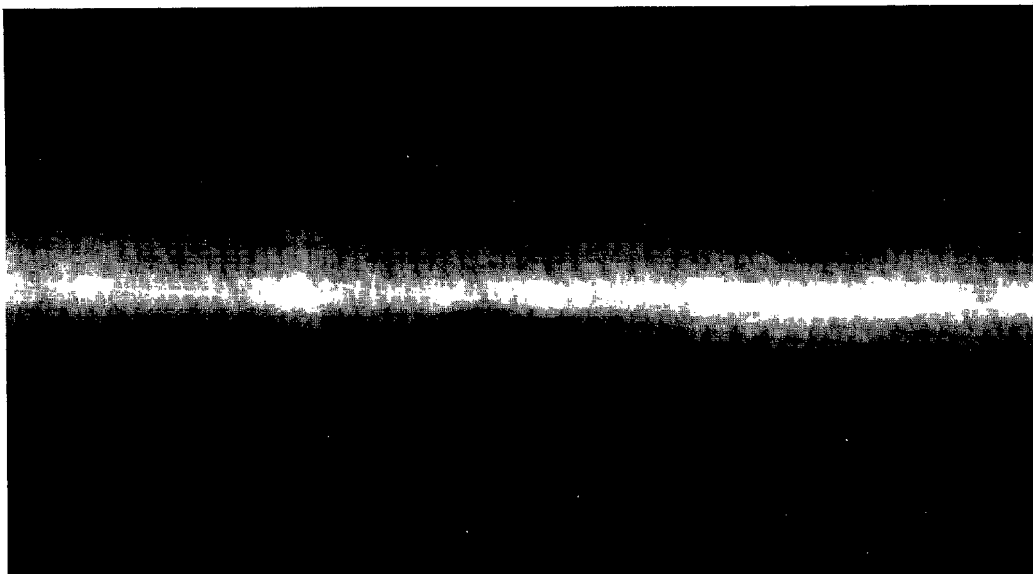
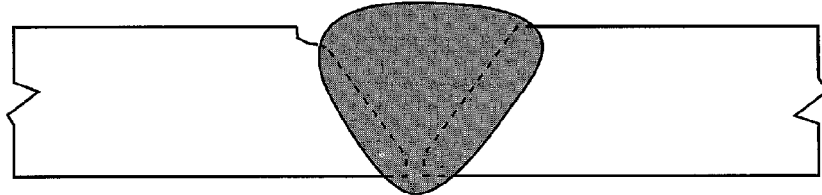
OVERLAP

Undercut - is a surface discontinuity resulting from melting of the base metal at the either the weld toe or weld root. It takes the form of a mechanical notch at the these locations. Undercut is caused by the application of excessive heat

(excessive weld current) or improper electrode manipulation, which melts away the base metal. Use of excessive travel speeds will also cause undercut.



UNDERCUT AT FILLET WELD TOE

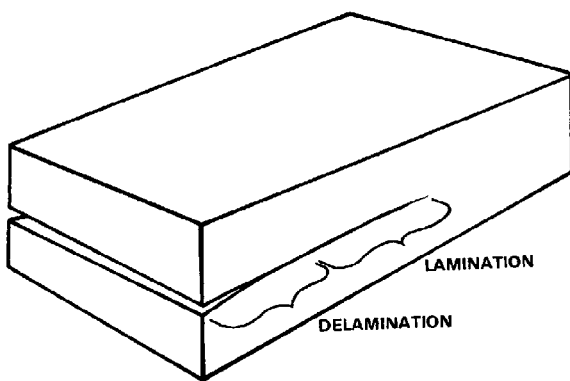


RADIOGRAPH OF EXTERNAL (SURFACE UNDERCUT)

10-18

Lamination and Delamination

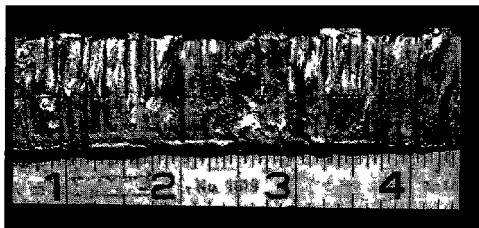
Laminations are flat, generally elongated, planar base metal discontinuities found near the center of rolled products. Laminations are formed when gas voids in the shrinkage cavity in the ingot are rolled flat but are not subsequently welded under the pressure of hot rolling. They generally run parallel to the surface of the rolled product and are most commonly found in structural shapes and plates.



Lamination and Delamination

They most often appear near the centerline of the material thickness. Since it would open as a sandwich, metal containing laminations cannot reliably carry stress in the through-thickness direction.

A delamination is the separation of a lamination under stress. The stress may be a result of distortion during flame cutting; it may be residual stress from welding, or it may be applied stress.



LAMINATIONS

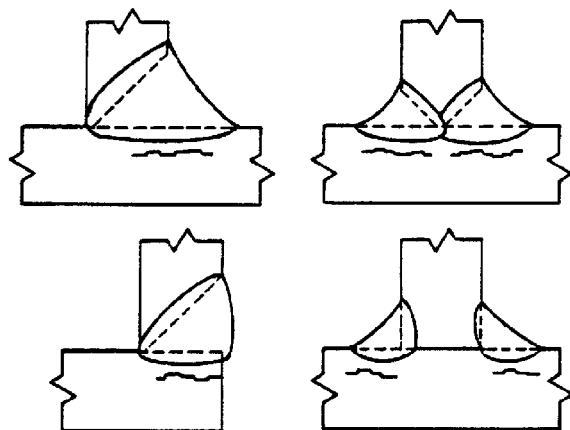
Ultrasonic testing is the only effective means of locating laminations unless they extend to an exposed edge of the material. They will not be revealed by radiographic testing.

Seams and Laps

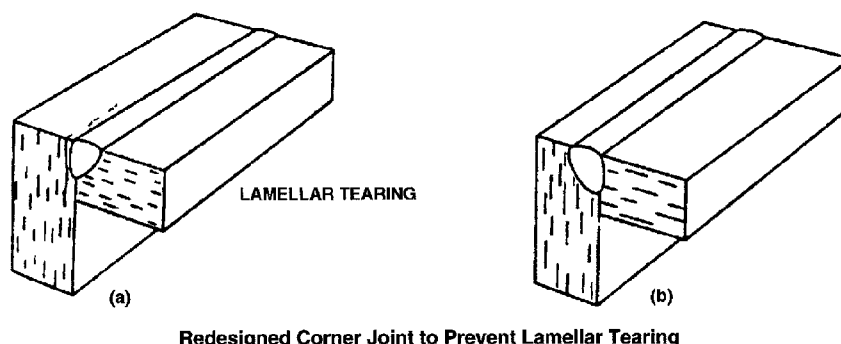
Seams and laps are linear base metal discontinuities found in rolled products which result from improper steelmaking practices. Seams and laps differ from laminations in that they always appear on the rolled surfaces. When they are parallel to the principal stress, they are generally not considered to be a critical defect. When perpendicular to the applied or residual stress, they will often propagate as a crack. Welding over seams and laps can cause cracking.

Lamellar Tearing

Lamellar Tearing is a fracture separation in heavy weldments, found within or just beneath the heat affected zone of thick plates which were not adequately refined by the steel mill. Heavy plates and structural shapes receive limited working from their ingot stage to the final thickness, which may not remove all traces of ingotism. Rolling and forging impart good properties in the direction of metal flow (the "X" direction) but the strength and ductility perpendicular to the rolled surface (the through-thickness or "Z" direction) remain poor.



Weld Configuration which may cause Lamellar Tearing



Massive welds poorly located adjacent to a thick plate will transmit weld shrinkage stresses into the plate in its weakest direction, creating tears parallel to the surface which then are linked together by shear fractures, forming steps connected by risers perpendicular to the surface. The phenomenon is called lamellar tearing, because the plate opens up as though it were made of stacked sheets or lamellae. The engineer should change the joint design to bring the shrinkage stresses more in line with the rolling direction.

A reduction in the amount of weld required will also reduce the tendency for this type of discontinuity.

Lamellar tears may extend over long distances and are located more deeply than underhead cracks, which differ in shape, cause and location.

Cracks

Cracks may occur in the weld or base metal, or both, when localized stresses exceed the strength of the material. Cracking is generally associated with discontinuities in welds and base metals, with notches, with high residual stresses, and often with hydrogen embrittlement. Welding-related cracks often look as though the metal were brittle. There is little evidence at the crack boundaries that the metal deformed before it cracked. Cracks can be classified as either *hot cracks* or *cold cracks*.

Hot cracks develop at high temperatures. They commonly form on preferential solidification of alloys of the metal near the melting point. Hot cracks propagate between the grains when the

preferential solidification occurs. Cold cracks develop after solidification is complete and are often service-related. Delayed cracks are commonly caused by the presence of hydrogen in a crack-susceptible microstructure subjected to some applied stress. Cold cracks may propagate either through or between grains.

Longitudinal cracks lie parallel to the weld axis. They are called longitudinal cracks, whether they are centerline cracks in the weld metal or toe cracks in the heat affected zone of the base metal.

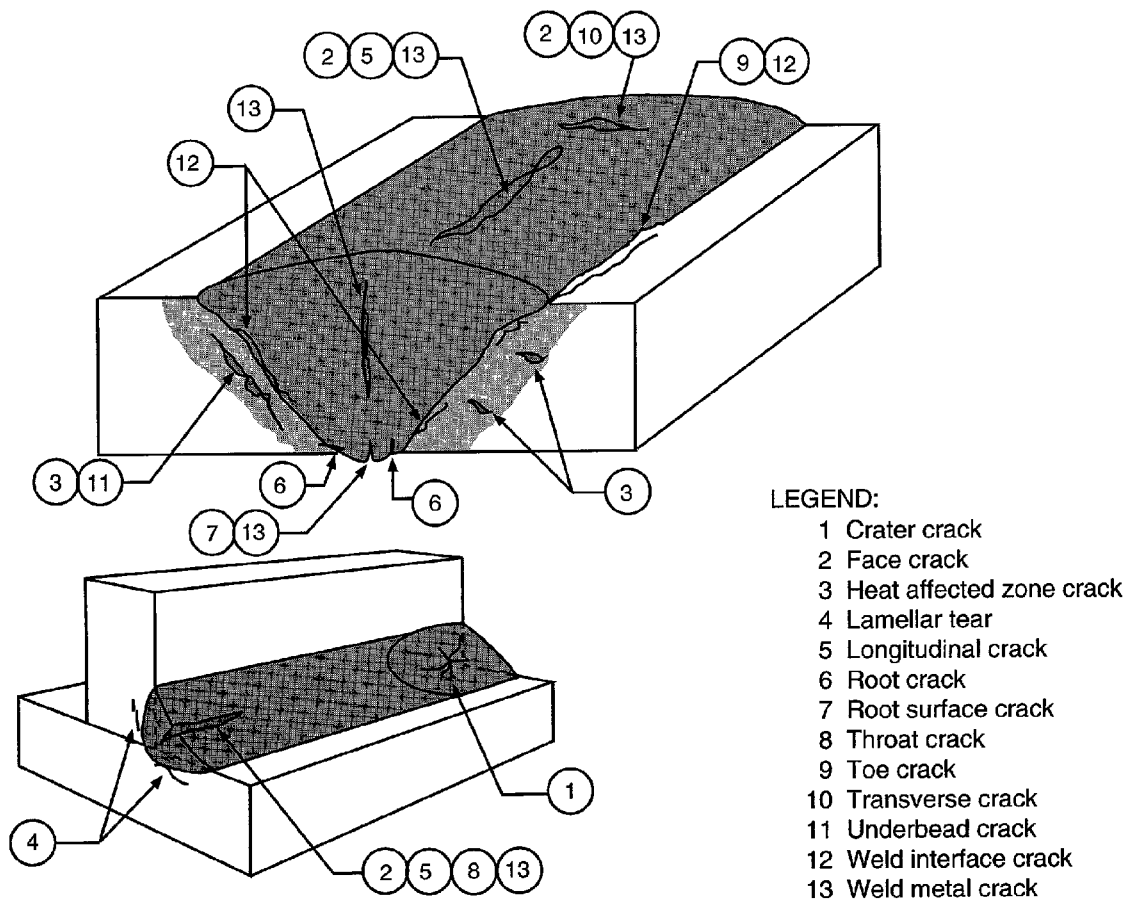
Transverse cracks are perpendicular to the weld axis. They may remain within the weld metal or extend from the weld metal into the adjacent heat affected zone and the remainder of the base metal. In some weldments, transverse cracks will form in the heat affected zone of the base metal and not in the weld.

Crater cracks occur in the crater formed by improper termination of a weld pass. They are considered hot cracks and are sometimes referred to as "star cracks" because they often radiate in several directions from the center of the crater. However, they also have other shapes. Crater cracks are usually shallow, allowing for their removal with minimal grinding.

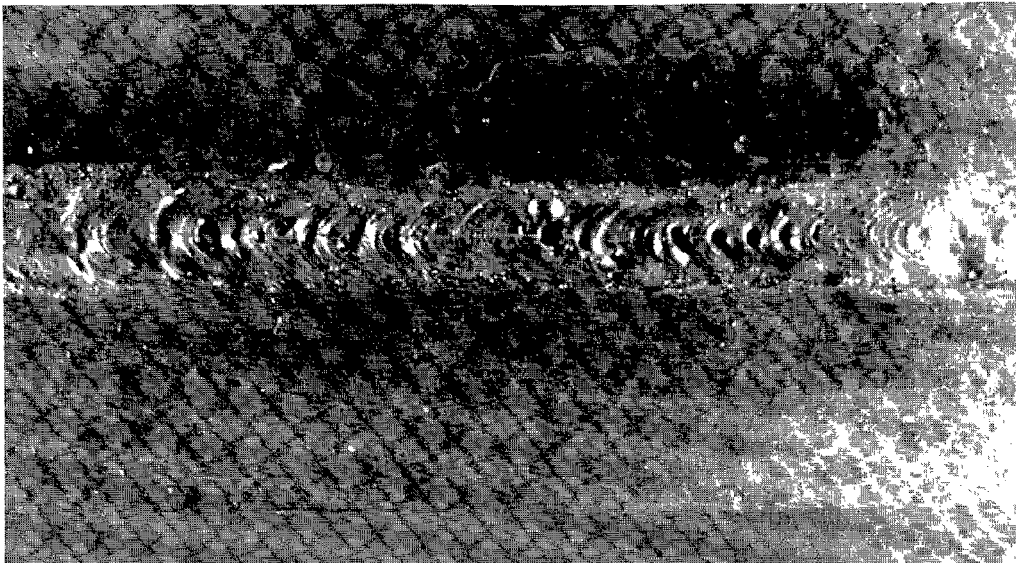
A **throat crack** is a longitudinal crack in the weld face of either a groove or fillet weld.

Toe cracks are generally cold cracks. They begin and grow from the weld toe where residual

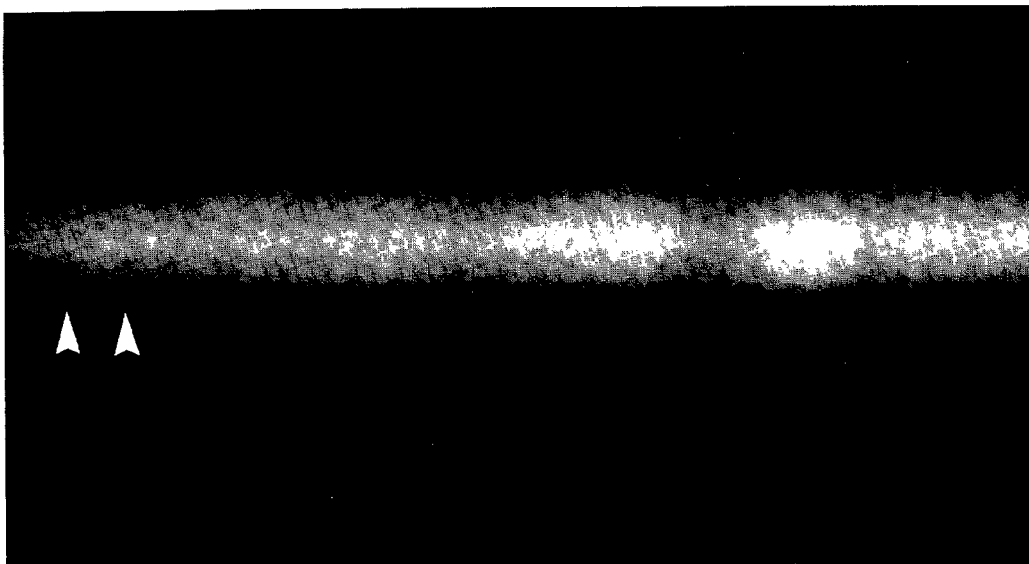
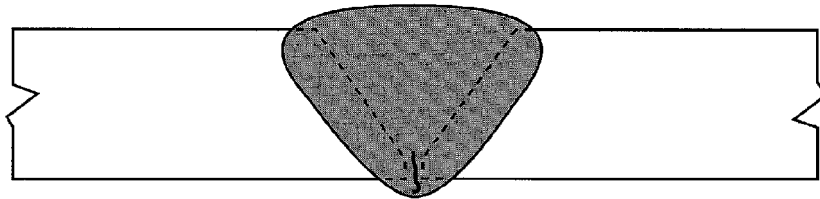
10-20



CRACK TYPES

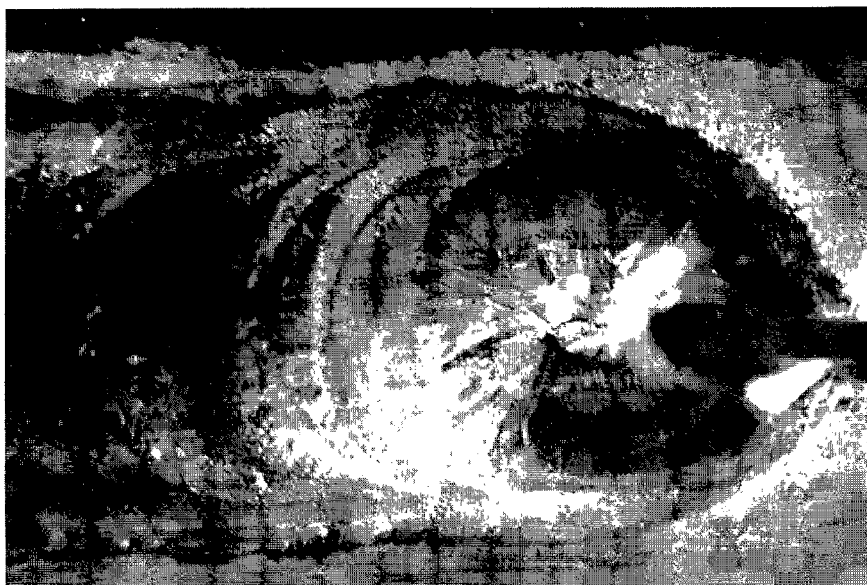


LONGITUDINAL CRACK AND LINEAR POROSITY



RADIOGRAPH OF LONGITUDINAL CRACK

10-22

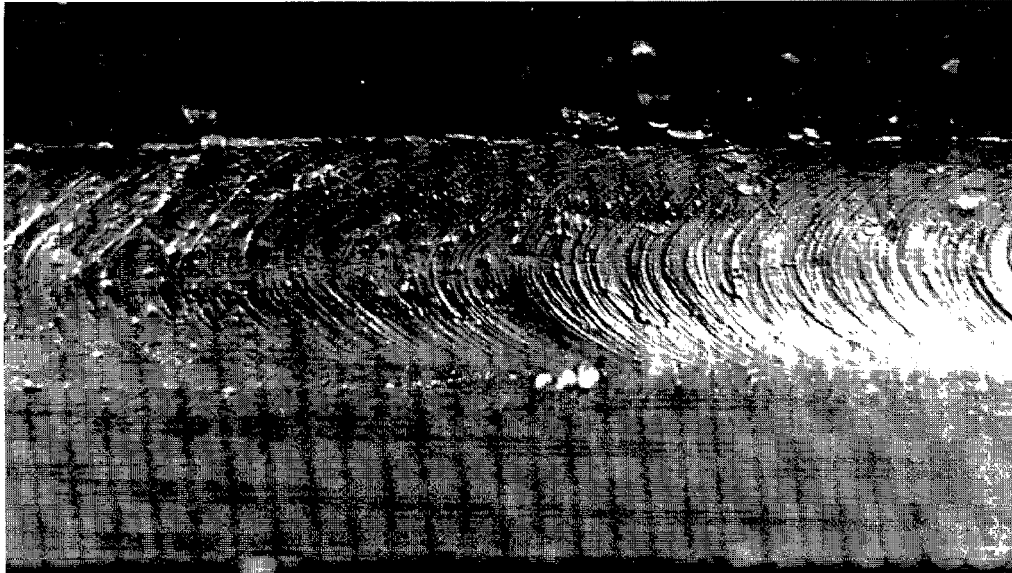


CRATER CRACK

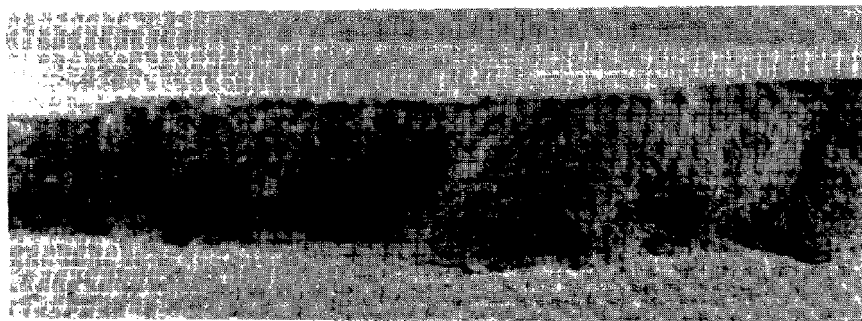
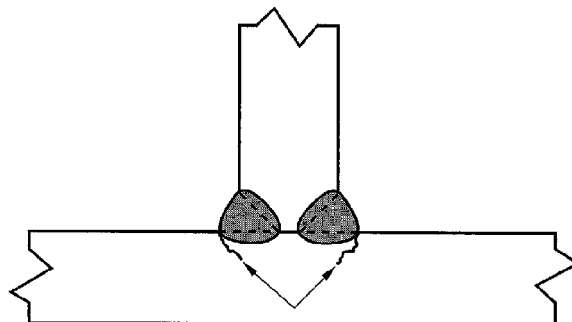


LONGITUDINAL CRACK PROPAGATING FROM CRATER CRACK

10-23



THROAT CRACK

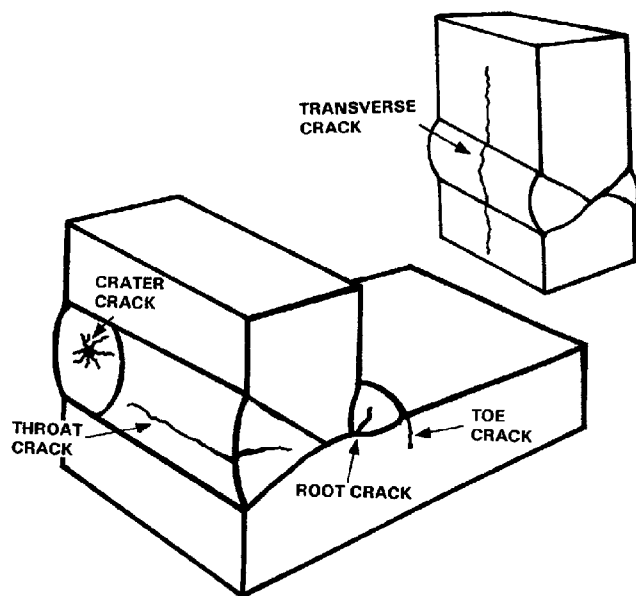


TOE CRACKS

10-24

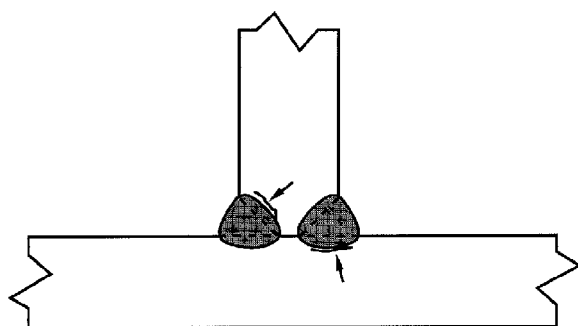
stresses are high, especially when the weld exhibits excessive reinforcement or convexity.

Toe cracks initiate approximately perpendicular to the metal surface, but may tend to curve and follow the weld heat affected zone.

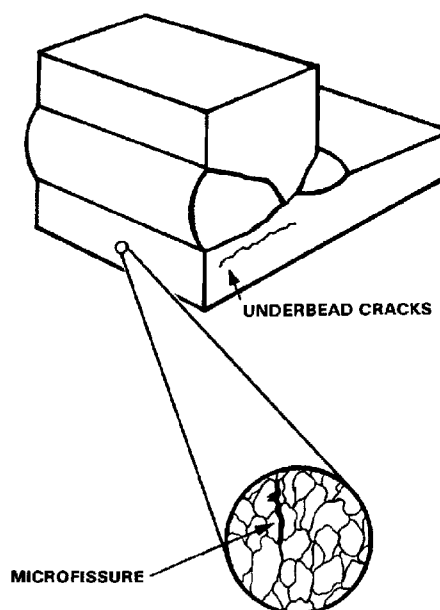


Root cracks are longitudinal cracks in the weld root. They are generally a form of hot cracking.

Underbead and heat-affected zone cracks are usually cold cracks that form in the heat affected zone of the base metal. They are most often short, but they may join to form a continuous



Underbead Cracks



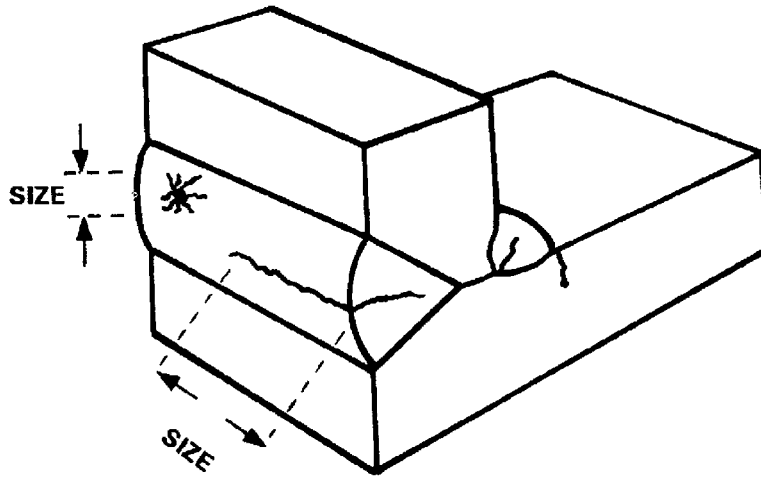
crack, especially when three simultaneous conditions are present: (1) hydrogen, (2) high-strength material (Rockwell "C" hardness of 30 or higher), and (3) high residual stress. Underbead and heat affected zone cracks can be either longitudinal or transverse.

Fissures are small or moderate size separations along grain boundaries. This discontinuity is easiest to see in electroslag welds because of the large grains commonly present. The separations may be either hot or cold cracks. The term *microfissure* is used if they are so small that magnification must be used to detect the separation. They are termed *macrofissure* if the separation is large enough to be seen with the unaided eye.

Arc Strike

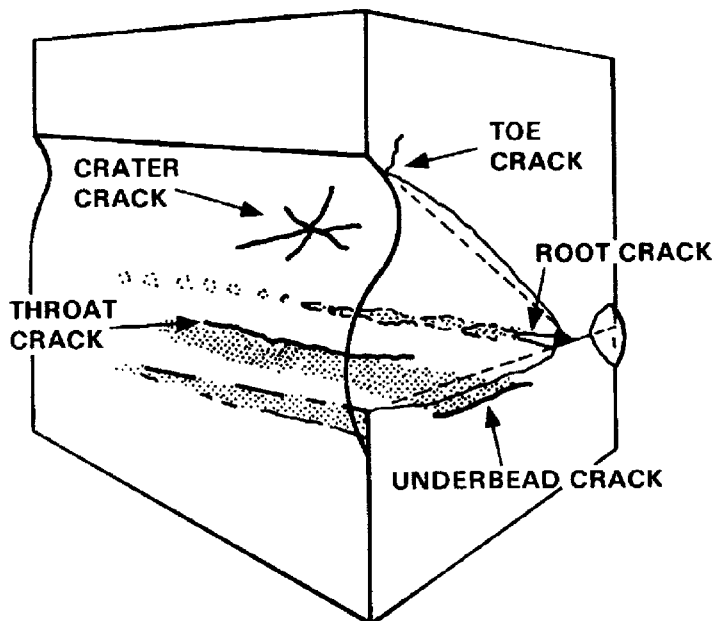
Arc strikes represent unintentional melting or heating outside the intended weld deposit area. They are usually caused by the welding arc but can be produced beneath an improperly secured work connection during welding. They can also result from improper contact of the prods used for magnetic particle testing.

The result is a small, remelted area that can be the source of undercutting, hardening or localized cracking, depending upon the metal composition. For that reason, they represent a dangerous condition which could result in catastrophic failure of the weldment.



Size of Discontinuity

The size of the discontinuity must be considered when evaluating the structural integrity of the entire weld. Acceptance standards specify the allowable size of discontinuity in terms of its linear dimensions.



Some discontinuities are acceptable as long as their size does not exceed specified limits. However, other types, such as cracks, are normally unacceptable regardless of length. In general, nonlinear discontinuities are permitted to be larger than linear types.

Location of Discontinuity

The location of a discontinuity may suggest the cause of the problem as well as its seriousness. The location of porosity can identify where contamination exists. The welding inspector must consider the location and orientation of some discontinuities to determine how much the load-carrying capacity of the structure will be degraded.

For structures which will be subjected to fatigue, or cyclic, types of loads, those discontinuities exposed to the surface are generally considered to be more severe. In fact, small surface discontinuities may be more damaging than subsurface ones, even though the size of those subsurface discontinuities is much greater.

Summary

The welding inspector will be asked to examine welds to determine their acceptability in accordance with various codes and specifications. One of the aspects of this activity will be the visual identification of weld discontinuities. The inspector must be capable of identifying the type of discontinuity, because different types of discontinuities have different levels of permissibility.

In addition to identifying the types of weld discontinuities present, it will also be helpful to know what conditions might have lead to the creation of those discontinuities. That way, corrective action can be taken to prevent further occurrence.

10-26

REVIEW -**CHAPTER 10
WELD AND BASE METAL
DISCONTINUITIES**

- Q10-1** A discontinuity is:
- a. always a defect.
 - b. always a reject.
 - c. always acceptable.
 - d. rejectable if it exceeds code limits.
 - e. none of the above
- Q10-2** The criticality of a particular weld discontinuity can be judged on the basis of:
- a. whether it is surface or subsurface.
 - b. whether it is linear or nonlinear.
 - c. whether it has a sharp end condition.
 - d. all of the above
 - e. none of the above
- Q10-3** What discontinuity is generally considered to be the most severe?
- a. porosity
 - b. incomplete fusion
 - c. slag inclusion
 - d. crack
 - e. arc strike
- Q10-4** Which of the following discontinuities is least likely to be seen visually?
- a. toe crack
 - b. undercut
 - c. lamellar tear
 - d. overlap
 - e. none of the above

- Q10-5** Underbead cracks can result from which of the following welding practices?
- a. use of wet electrodes
 - b. welding on contaminated steels
 - c. welding over paint
 - d. all of the above
 - e. none of the above
- Q10-6** The weld discontinuity which results from improper termination of the welding arc is referred to as:
- a. undercut
 - b. overlap
 - c. crater crack
 - d. incomplete fusion
 - e. all of the above
- Q10-7** All but which of the following processes may result in the presence of slag inclusions in the completed weld?
- a. SMAW
 - b. PAW
 - c. FCAW
 - d. SAW
 - e. none of the above
- Q10-8** That discontinuity which results from the entrapment of gas within the weld cross section is referred to as:
- a. crack
 - b. slag inclusion
 - c. incomplete fusion
 - d. porosity
 - e. none of the above

10-28

- Q10-9** What base metal discontinuity, located at the weld toe, is caused by the welder traveling too rapidly?
- a. underfill
 - b. undercut
 - c. incomplete fusion
 - d. overlap
 - e. none of the above
- Q10-10** What weld discontinuity results when the welder travels too slowly causing excess weld metal to pour out of the joint and lay on the base metal surface without fusing?
- a. undercut
 - b. underfill
 - c. overlap
 - d. incomplete fusion
 - e. none of the above
- Q10-11** What weld metal discontinuity results when the welder fails to completely fill the weld groove?
- a. underfill
 - b. undercut
 - c. overlap
 - d. incomplete fusion
 - e. none of the above
- Q10-12** Excessive weld metal buildup on a groove weld is referred to as:
- a. excess convexity
 - b. excess weld reinforcement
 - c. overfill
 - d. all of the above
 - e. none of the above

Q10-13 The weld discontinuity which results from the initiation of the welding arc outside the weld joint is referred to as:

- a. incomplete fusion
- b. undercut
- c. overlap
- d. scratch start
- e. arc strike

Q10-14 What weld discontinuity shows up as a light region on a radiograph?

- a. porosity
- b. tungsten inclusion
- c. excess weld reinforcement
- d. a and b above
- e. b and c above

Q10-15 What base metal discontinuity results from improper steelmaking practice and is associated with the rolled surface?

- a. lamination
- b. delamination
- c. seam
- d. crack
- e. none of the above

10-30

Questions **Q10-16 through Q10-20** refer to the figure on the facing page:

Q10-16 What discontinuity is shown by #12b?

- a. longitudinal crack
- b. transverse crack
- c. face crack
- d. toe crack
- e. root crack

Q10-17 What discontinuity is shown by #11?

- a. lamination
- b. base metal crack
- c. lamellar tear
- d. seam
- e. lap

Q10-18 What discontinuity is shown by #12g?

- a. toe crack
- b. incomplete fusion
- c. root crack
- d. lamellar tear
- e. underbead crack

Q10-19 What discontinuity is shown by #5?

- a. undercut
- b. underfill
- c. overlap
- d. incomplete fusion
- e. toe crack

Q10-20 What discontinuity is shown by #10?

- a. lamination
- b. seam
- c. delamination
- d. base metal crack
- e. incomplete fusion

