

Nondestructive Examination (NDE) Technology and Codes
Student Manual

Volume 1

Chapter 3.0

Classification and Interpretation of Indications

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3.0 CLASSIFICATION AND INTERPRETATION OF INDICATIONS

Learning Objectives:

To enable the student to:

1. Understand and recognize common false and nonrelevant indications found when NDE is being performed.
2. Understand the different classifications of discontinuities.
3. Understand the origin and nature of common discontinuities.
4. Recognize the appearance of common discontinuities and the variables involved with interpretation.

3.1 Indications

The definition of the term “indication” as it applies to NDE is: “A response or evidence of a response disclosed through NDE that requires further evaluation to determine its true significance.”

When a specific NDE is performed on a part, and a response results, that response is an indication. The term “response” is intended to mean:

- A “bleed out” when performing a Penetrant Examination (PT),
- A particle buildup when performing a Magnetic Particle Examination (MT),
- A change in density on the radiographic film - Radiographic Examination (RT),
- A signal when performing Ultrasonic Examination (UT), and
- A meter deflection, signal, or digital change when performing Eddy Current Examination (ET).

Once the response is observed, the examiner must interpret it, and then categorize it into one of the following groups of indications:

- False,
- Nonrelevant, or
- Relevant or true discontinuity.

This section provides information that will enable an examiner or observer to identify and categorize indications.

3.2 False Indications

False indications are usually caused by conditions created by improper compliance with the procedure or through the examiner’s carelessness.

3.2.1 Penetrant Examination

A false indication in PT is usually caused

by improper PT processing of the part. Most common causes are improper or inadequate precleaning of the test surface, inadequate removal of excess surface penetrant during the penetrant-removal step, contaminated developer or surface roughness or contaminants such as scale and slag. Most of the false indications encountered in PT can be eliminated by proper test surface preparation and careful precleaning. Also, exercising care during removal of the excess surface penetrant also affects the clarity and size of actual discontinuity indications.

3.2.2 Magnetic Particle Examination

In MT, a false indication consists of particle buildup produced by mechanical or gravitational forces, rather than by magnetic leakage field forces. Particles may become lodged on the surface as a result of a contaminant. These particles present an image that may appear to be an indication caused by magnetic leakage field attraction and therefore interpreted incorrectly as a discontinuity indication. A false indication can usually be removed by applying a small amount of air pressure or light blowing, since there is no magnetic leakage field to hold it in place. Another method of removing a false indication involves a “quick dip” or rinse in a clean solvent. Particles that are not held by the residual magnetic force that normally holds true indications will be readily washed away. Neither of these methods is always effective since indications from subsurface discontinuities usually are held by weak residual magnetic fields. The washing action

of the solvent or air pressure may be substantial enough to inadvertently remove these indications.

Magnetic Writing is the easiest false / nonrelevant indications to create purposely or accidentally. Usually all that is required is that two parts of differing magnetic fields come into contact with each other. Local poles are formed at the area of contact and upon the application of particles; an indication appears that follows the area or line of contact. Indications caused by magnetic writing will not reappear after demagnetization and re-examination.

3.2.3 Radiographic Examination

Many false indications are encountered in RT; these are sometimes referred to as artifacts. Radiographic film is very sensitive to pressure, chemicals, light, mechanical forces such as bending, creasing, scratches, and other forms of rough handling. These conditions should be avoided and when present, many codes require the associated radiograph to be rejected if these indications interfere with or cause confusion during interpretation.

3.2.4 Ultrasonic/Eddy Current Examination

False indications encountered in ET typically result from stray electrical interference. In UT, spurious signals may be caused by the couplant interaction. In general, false indications from UT and ET are easily identified and corrected.

3.2.5 Summary of False Indications

The best way to determine whether or not an indication is false is to repeat the examination while exercising the proper precautions and following the procedure. False indications are generally not predictable and not repeatable.

3.3 Nonrelevant Indications

Nonrelevant indications are caused by normal or known conditions in the part or material. A response is expected, and the examiner should be able to identify its cause. A common type of non-relevant indication results from a known change in the cross-section or geometry. This condition, which is present as a result of the design or configuration of the part, causes a response to the probing medium in a manner similar to a true discontinuity. Generally, this type of indication can be easily identified since it appears in the same areas in similar parts and can be readily identified by referring to the appropriate part drawing. An example of this indication would be found in parts containing pressed fit conditions or other areas where two mating surfaces fit tightly together without metallurgical fusion. Another common nonrelevant indication can usually be found at sharp fillets, abrupt changes in section thickness and thread roots. In these cases, the probing medium reacts to these configurations in a manner similar to that of an actual discontinuity. This response is usually interpreted easily by reviewing the configuration or design of the part being

examined.

3.3.1 Penetrant Examination

The most common nonrelevant indication encountered during PT is the result of surface configuration variations. Excess penetrant tends to remain in crevices such as thread roots, or sharp changes in thickness, machined steps, and radical dimensional changes. The bleedout intensity is not as great as that encountered with press fit, or force fit conditions. It has been proven that surface openings as small as 13 micro-inches (250 x 13 micro-inches is equivalent to the thickness of an average sheet of paper) can be consistently detected with standard penetrants. It is easy, therefore, to understand how it is possible to obtain such a definite response from a crevice between closely mated surfaces. The most logical approach to eliminating this type of bleedout is to carefully mask the crevice without covering the test surface. Nonrelevant indications associated with surface configuration can be minimized by employing special penetrant removal techniques for the areas in question. Small cotton swabs or other appropriate aids used in these areas during the penetrant removal step can be helpful.

3.3.2 Magnetic Particle Examination

During MT, high amperage can cause a nonrelevant condition known as flow lines. Flow lines are usually defined as the texture revealed by etching a metal surface or section showing the direction of metal flow. This metal flow pattern results when high amperage is

induced into the part, especially in forgings. The indication pattern is similar to the etched surface of a specimen. This pattern is not indicative of discontinuities in the part. In some instances the pattern may help in revealing the flow line structure when an etching operation is not desirable.

Another nonrelevant indication that should not be overlooked is the one that appears at the junction of dissimilar materials. This type of indication is the result of the difference of permeability in the two materials. This indication also appears when magnetic materials are joined to nonmagnetic materials. A magnetic pole is created at the end of the magnetic material which is defined by particle alignment. When two magnetic materials are brazed together, the brazing material responds like a discontinuity since it is generally nonferrous material, and a very prominent indication results. A similar pattern is present in parts that have very tight joints, such as those resulting from force fit assembly. No matter how small the space between the mating parts, there is still some magnetic flux leakage, which causes particle attraction.

Nonrelevant indications are common at the junction of abrupt section changes where some of the flux lines actually leave the part following the path of least resistance. If permitted, re-examination at lower amperages may eliminate this indication.

3.3.3 Radiographic Examination

Variations in part and section thickness

cause density differences in a radiograph, which may be confused with or cause confusion in the interpretation of actual discontinuities. A qualified examiner viewing the film can generally identify these nonrelevant conditions. Reference to the applicable drawing, re-examination using angulations, or changing part alignment can confirm the interpretation. Press fit conditions, unfused zones in partial penetration welds, and other such radical changes in the parts cross section will also appear as density variations on the radiograph. Their outlines closely resemble the actual conditions; hence, interpretation usually is quite simple based on knowledge of the part.

3.3.4 Ultrasonic Examination

The ultrasonic beam reflects from an interface between two mating parts just as readily as from a discontinuity. Therefore, it should be expected that surfaces or interfaces that do not have a metallurgical bond or are not fused in the path of the ultrasonic beam will cause reflections, resulting in indications. Part geometry is once again the major cause of nonrelevant indications because changes in geometry result in beam reflection. Knowledge of part dimension, ultrasonic beam geometry and direction, and material characteristics will aid in proper evaluation.

3.3.5 Eddy Current Examination

“Edge or end effect” is a good example of a nonrelevant indication disclosed by ET. The eddy current field sees the edge or end of a test

part as an interruption, causing field imbalance when the probe or coil is positioned closed to the edge. Other nonrelevant conditions in a part examined by ET can be caused by grain structure variations, hardness changes, alloy differences, mass changes, etc. For example, if the part is being examined to determine variations in alloy content, other variables (although within the acceptable material specification range) could cause interferences. Current ET equipment can compensate for this condition to some degree by proper use of phase control. Use of appropriate standards can also minimize such variables resulting from nonrelevant conditions.

3.3.6 Summary of Nonrelevant Indications

Nonrelevant indications are not difficult to identify when the examiner is aware of their existence, possible causes and characteristics. Knowledge of the part being examined and reference to configuration, fabrication processes, material type, and characteristics will enable accurate interpretation of these indications. Nonrelevant indications are usually predictable and repeatable.

3.4 True Discontinuities

Discontinuities originate in various ways and can be categorized by their origin or cause.

3.4.1 Inherent Discontinuities

Inherent discontinuities are formed during the initial metal making process. Several types

of inherent discontinuities exist: inclusions, pipe, cracks and porosity.

3.4.1.1 Inclusions

Inclusions are nonmetallic impurities such as slag, oxides, and sulphides that are present in the original ingot (Figure 3-1). During rolling of billets into bar stock, impurities are rolled in a lengthwise direction. These direction-oriented inclusions in the finished product are generally referred to as nonmetallic inclusions or “stringers”. These stringers may be surface or subsurface and are usually short in length and parallel to the grain flow. Figure 3-2 illustrates how stringers are formed.

3.4.1.2 Laminations

Laminations are thin, flat discontinuities found in plate or sheet stock that is a result of gas, inclusions, or pipe in the original ingot (Figure 3-3). Laminations are generally considered to be internal discontinuities, except where edges of the plate or sheet are cut to expose the lamination. Laminations are generally parallel to the outer plate surface and are intergranular in nature if examined microscopically. Figure 3-3 illustrates typical laminations in rolled parts.

3.4.1.3 Pipe

Pipe is typically found in the center of rolled bars. This condition is caused by a shrinkage condition at the center of the ingot formed during solidification in the ingot, which becomes elongated in the rolling operations.

This condition is also illustrated in Figure 3-4.

3.4.1.4 Seams

Seams are surface discontinuities found in rolled bars and plate that are caused by compressing and elongating cracks, tears, or other indications on the surface of the ingot during rolling. Seams are generally long, and run along the length of the longitudinal axis.

3.4.2 Primary Processing Discontinuities

Primary processing discontinuities are caused by the primary shaping and forming processes such as forging, casting, rolling and drawing. During initial forming, or primary shaping of metal into a desired configuration or size, discontinuities may occur.

3.4.2.1 Casting

3.4.2.1.1 Casting Processes

Casting molten metals into molds is one of the oldest methods of metal forming. Cast ornaments and tools over 4,000 years old have been found from ancient Egyptian, Assyrian, and Chinese cultures. Molten metals such as iron, steel, and aluminum are cast into ingot molds and allowed to solidify before they are further processed. Castings range from small intricate precision parts to massive machinery sections weighing many tons.

The casting process requires a pattern (having the shape of the desired casting) and a mold made from the pattern. The mold must

withstand the temperature of the molten metal (i.e., sand, plaster of paris, ceramic, or metal). Wood, metal, and wax are typically used for patterns.

Some of the different methods of casting are categorized as follows:

- Sand,
- Centrifugal,
- Investment,
- Permanent, and
- Die.

Sand Casting - This process uses either moist sand with clay or dry sand with a type of binder. The pattern is usually in two halves; the cope (top half) and the drag (bottom half). Each pattern half is placed in a half of the flask. Sand is packed or rammed around each half of the pattern. The patterns are removed when the sand is hard and the two halves of the flask are joined. Holes called down sprues and runners are provided through the flask and into the mold cavity to introduce the molten metal during pouring. Other holes, or risers, are provided to act as reservoirs to feed metal into the mold as the metal shrinks. Risers also allow gases to escape.

Centrifugal Casting - Centrifugal casting is a process in which molten metal is poured into a rapidly rotating mold. The liquid metal is forced outward by centrifugal forces to the mold cavity. Wheels, tubing, and pipe are made by the centrifugal casting process. The centrifugal process also permits two dissimilar metals to be cast. For example, an outer surface of hard alloy can be poured, followed by an

inner layer of softer metal. This gives the casting an outer wear surface while maintaining the machinability and weldability of the inner layer.

Investment Casting - The investment casting process is sometimes called the “lost wax” process. Wax patterns, including their sprues and risers, are usually cast in metal molds (dies) or formed by injection molding. A ceramic shell is formed around the wax pattern by dipping repeatedly into a ceramic slurry. After a sufficient shell thickness is achieved, it is heated to above the melting temperature of the wax pattern. The liquid wax is discharged through a leakage passage, leaving the mold cavity for the pouring of the metal. Molten metal is poured into the ceramic mold and after it solidifies, the ceramic shell is vibrated until it separates, leaving the finished casting.

Permanent Mold Casting - Permanent molds are usually made of gray cast iron or steel, with graphite and other refractory materials usually used for steel castings. The molds are machined to a rough shape and hand finished, after which a refractory wash is applied to the mold. Molten metal is poured into the mold from a ladle as in the sand casting process. The mold must be heated and maintained at a specified temperature in order to produce good quality castings. The permanent mold process is a step between sand-casting and die-casting in that fairly high precision can be achieved, thus eliminating considerable machining time usually required for sand castings.

Die Casting - The die casting process differs

from the permanent mold and sand casting processes in that the metal is not poured into the mold but is injected under high pressures (from 1,000 to 100,000 psi). The two basic methods of die casting are the hot-chamber and the cold-chamber. Cold-chamber machines are used for casting aluminum, magnesium, copper-base alloys, and other high melting point alloys. Hot-chamber machines are used for casting zinc, tin, lead, and other low melting point alloys. Die-casting machines are heavy, massive, generally hydraulically operated, and capable of exerting the hundreds of tons of force needed to hold the die halves together. High pressure is necessary to keep the injected molten metal from leaking at the parting line. Small thin sections can be produced and close tolerances maintained. Surface finishes are usually so smooth that subsequent finishing or machining processes are not needed. The metal mold or die cools the molten metal at a higher rate than sand casting, thus producing a superior grain structure in the metal. The die casting process is typically used for small parts where high production is desired.

3.4.2.1.2 Casting Discontinuities

Discontinuities typically found in castings include dross, porosity or gas, cold shuts inclusions, shrinkage, and cold cracking.

Dross - Dross is a condition particularly associated with aluminum castings. This discontinuity results from poor casting practices employed in the foundry. The molten aluminum reacts with the atmosphere or

moisture and forms an aluminum oxide or nitride with some entrapment of gas. This type of discontinuity is primarily internal.

Porosity - Porosity is caused by the presence of gas, which is dissolved in the melt and precipitated at the grain boundaries as the casting cools. The total amount of gas that forms visible bubbles or pores depends upon the amount of gas in solution and on the rate of cooling. Porosity size and shape depends upon the mechanism of solidification of the particular alloy, shrinkage stresses, and composition of the melt with respect to the solubility of hydrogen; each contributes to the final form and distribution of the pores. Porosity is usually internal to the part and occurs in two basic forms, round and elongated. Gas porosity can be classified as follows:

- Porosity - small rounded cavities,
- Gas Hole - larger cavities, or
- Wormhole - tube-like gas cavities with significant length, and as the name implies, resembles wormholes.

Cold Shuts - These casting discontinuities are caused by a momentary interruption of the metal flow, resulting in partial solidification. The associated cooling forms an oxide coating on the surface which prevents fusion as other incoming molten metal continues to fill the mold. Cold shuts are usually very tight and extend to the surface.

Inclusions - Inclusions are various forms of foreign matter, such as sand, slag, or oxides

that becomes entrapped during the casting process.

Cold (or Stress) Cracking - This is a discontinuity which occurs due to the fracture of the metal, after solidification. The crack is a result of large contraction stresses and generally occurs on large castings of complicated shape.

Shrinkage - Shrinkage is a condition that results from insufficient metal being available as the casting solidifies. Generally, shrinkage occurs during liquid-to-solid contraction and can be further classified as:

- **Macro-Shrinkage.** In a well-designed mold this discontinuity will generally be found in risers. In appearance, this shrinkage typically exhibits zones of irregular cavities accompanied by branch-like indications.
- **Centerline Shrinkage (Filamentary).** If directional solidification is not promoted, a coarse form of shrinkage, which can be quite extensive, interconnected, and branching, may occur. The solidification range of the material being cast will affect the type of shrinkage cavity. With steel, which has a narrow solidification range, the cavity should occur on the centerline of the cast section. However, with alloys, which have a broad solidification range, the shrinkage will be more dispersed than centerline.
- **Micro Shrinkage.** This type of shrinkage is generally associated with equiaxial crystal structures rather than columnar crystals. Micro shrinkage is a very fine form of filamentary shrinkage and occurs between the dendrite

arms, known as interdendritic, and also at grain boundaries, known as intercrystalline.

- **Sponge Shrinkage.** As the name implies, this shrinkage resembles a sponge. It consists of shrinkage cavities and branchlike shrinkage.

- **Shrink Cracks or Hot Tears.** These discontinuities are developed during solidification of the metal since it contracts as it cools. The tension stresses caused by this contraction can result in ruptures in the metal. Figure 3-5 illustrates how this may form during casting.

- **Miscellaneous Shrinkage Mechanisms--** Additional shrinkage mechanisms can produce casting irregularities that can be detected by NDE. For the casting process, these mechanisms include:

1. **Misrun**—Misrun results from the failure of the molten metal to completely fill the mold cavity resulting in an absence of metal or void.
2. **Core Shift**—if the core moves during the pouring of the molten metal, it will lead to variations in internal dimensions or result in eccentric casting walls.
3. **Segregation**—Most metals contain alloys with their various constituents evenly distributed throughout the metal. Segregation occurs generally because each of the alloy constituents has different cooling temperatures, and this may result in areas which have greater concentrations of a given alloy.

4. **Unfused Chaplet**--A chaplet is a thin metallic support for a core and is generally melted by, and absorbed within, the molten metal. If this material is not totally consumed, a circular pattern representing the shape of the chaplet results.

3.4.2.2 Forging

3.4.2.2.1 Forging Processes

Forging is plastically deforming or shaping metal into desired shapes with compressive force, with or without dies. Forging dies are usually made of steel or steel castings. General forging classifications are opened die and closed die. They are also classified in terms of “close-to-finish” or amount of stock to be removed by machining. The type of equipment used provides further classifications (e.g., hammer, upset, ring, rolled, and multiple ram press forgings). In general, the type of forging that requires the least machining to satisfy finished part requirements has the best properties. If size and shape are the same, forgings are stronger than castings because of their inherent continuity of material flow lines.

- **Cold Forging** - Sizing or flattening of parts through cold forging is usually the least severe forging operation. Swaging or cold forging involves squeezing the blank material to an appreciably different shape and requires dies backed up substantially with hardened steel plates.

- **Hot Forging** - Hot forging (similar to cold

forging) permits greater movement of metal. Hot forging may be done with drop hammers, percussion presses, power presses, or forging machines. Hydraulic presses operate at pressure of 100 to 4,000 tons. Drop hammers operate at ½ to 120 tons pressure. Most forgings are made by the hot forging process.

3.4.2.2.2 Forging Discontinuities

The following are considered forging discontinuities:

Forging Laps - Forging laps result from metal being folded over and forced into the surface but not fused together.

Bursts - Bursts originate in the forging process, generally from improper forging techniques and a rapid cooling from the forging temperatures. These may occur as large fissures (Figure 3-6) or thin hairline cracks such as those sometimes prevalent in the heads of bolts and screws (Figure 3-7).

Flakes - Flakes are caused by improper cooling. They appear as small numerous discontinuities that are internal to the material.

Inclusions - These are the result of impurities in the original ingot; the impurities generally run parallel to the grain flow after forging. Due to improper forging techniques and subsequent poor grain flow, oxides may be forced into the material.

Flash Line Tear - As the name indicates, this discontinuity results when the excess metal

squeezed out from between the drop forge dies is not removed cleanly. The discontinuity is on the surface and can usually be detected visually.

3.4.2.3 Rolling

3.4.2.3.1 Rolling Process

During rolling, the original cast ingot is further processed into a slab, bloom, or billet. In turn, further processing produces plate, pipe, bar, and rod.

3.4.2.3.2 Rolling Discontinuities

Inherent discontinuities from the cast ingot will be stretched and lengthened in the direction of rolling. Additionally, the rolling process may introduce discontinuities into the part. These are generally on the surface and take the form of tears, seams, and other mechanical deformities.

3.4.2.4 Extruding

Extrusion of metal is the most severe forming process. The metal is forced to flow rapidly through a defined orifice or die. Forward extrusion of long tubes, rods, and shapes is usually performed hot in hydraulic presses.

3.4.3 Secondary Processing Discontinuities

Secondary processing discontinuities are

associated with finishing operations of the part. These discontinuities develop in the finishing operations of bars, tubes, plates, forgings and castings, and include machining, heat treating, grinding, forming, and plating.

3.4.3.1 Tears (Machining)

Because of improperly set or dull tools, the surface of the metal may be torn instead of cut. These tears are generally short and jagged and, in general, are at right angles to the direction of machining (Figure 3-8).

3.4.3.2 Heat Treating Cracks

In this process the metal is heated and cooled under controlled conditions for the purpose of hardening or securing other metallurgical characteristics. Cracking during this process usually results from stresses set up by unequal heating or cooling of certain portions of the parts. These cracks may occur either on the heating or cooling (quenching) cycles and are usually deep, seldom follow a definite pattern, and may be in any direction on the part. In particular, quench cracks often start at thin cross sections or where a sharp notch or other stress riser affords a starting point for a crack. Nonmetallic inclusions can also form a starting point for a crack (Figure 3-9).

3.4.3.3 Grinding Cracks

Grinding of metal surfaces frequently introduces cracks, which are the result of

thermal stresses. Overheating occurs as a result of the friction created by the grinding wheel coming in contact with the surface, as illustrated in Figure 3-10. These cracks may be due to the wheel becoming glazed so that it rubs instead of cuts the surface, too little coolant, too heavy a cut, or too rapid a feed. The cracks are generally at right angles to the direction of grinding, although in severe cases a complete network of cracks may result.

3.4.3.4 Forming Cracks

Forming cracks, which may be found in almost any type of metal, are caused by excessive stretching of the material in the various forming processes. The excessive stretching causes rupture of the material. These cracks are normally on the tension side of the formed area and parallel to the bend.

3.4.4 Service Discontinuities

Service discontinuities result from actual service conditions such as fatigue, corrosion, and erosion. Service discontinuities occur when the part is subjected to severe conditions after it is placed into service.

3.4.4.1 Corrosion

Corrosion is attack and loss of metal due to an electrochemical process that involves an anodic reaction and at least one cathodic reaction. Iron ore is an oxide of iron in chemical balance with the environment. When this iron ore is converted to iron, the chemical balance is changed and the iron becomes active

(i.e. it corrodes on contact with the natural environment and tries to revert back to its natural state). The natural environment usually contains moisture, which provides an electrolyte for a corrosion cell to form.

The two major types of corrosion are pitting and intergranular. Pitting is a localized corrosion that extends into the metal surface. Pitting corrosion appears as pin holes on the surface in varying degrees.

The susceptibility to intergranular corrosion (particularly in aluminum and some types of corrosion resistant steels) is caused by improper heat treating, or in-service use. The part then corrodes intergranular from the surface under certain conditions. This condition may appear as fine cracks.

3.4.4.2 Stress Corrosion

Stress corrosion cracking is a spontaneous failure of metals under combined action of corrosion and stress, residual or applied. The presence of high tensile stresses on the surface of certain materials in conjunction with surface corrosion may result in large cracks along grain boundaries. The level of stress that can cause this cracking are typically below the yield point of the material. Stress corrosion cracks are surface breaking and are usually found at sharp changes in section, notches or crevices, especially in structures which have not been stress relieved. Both ferrous and nonferrous materials are susceptible to stress corrosion cracking.

3.4.4.3 Microbiological Corrosion

Micro-organisms can grow in moisture traps in a structure. Aluminum is particularly susceptible. This type corrosion appears as localized surface attack or fungi type deposits, depending on the micro-organism involved.

3.4.4.4 Intergranular Corrosion

This type corrosion is caused by an electrochemical reaction along the grain boundaries in the material. It appears as craze cracking on the surface that will propagate into the material. An important consideration in welding is that unstabilized stainless steels will exhibit intergranular corrosion along the heat affected zone.

3.4.4.5 Fatigue

Cracks initiated by fatigue cycling almost always start at a stress riser at the surface of the material, where operating loads are highest, and generally progress at right angles to the direction of the principal cyclic stresses. Many of the various discontinuities described in this section might, under certain circumstances, provide the starting point from which a fatigue crack may propagate. Fatigue cracks propagate at different rates depending upon material characteristics and loads applied.

3.4.4.6 Wear

Wear is the loss of material from the surface due to a mechanical action. Wear can normally be recognized by visual examination

of the surfaces involved. Specific terminologies used to describe various types of wear are:

Abrasive Wear - This occurs when two surfaces move or slide against each other producing an abrasive or mechanical cutting action. Heat is usually generated during this abrasive action.

Adhesive Wear - This occurs when two surfaces move against each other and generate sufficient heat to cause localized intermittent welding or bonding and continued sliding fractures one side of the bond. Scuffing, galling, scoring, and seizing are all the results of adhesive wear.

Fretting Wear - Fretting wear occurs when two surfaces constantly impact each other without significant sliding movement. It is often seen on fasteners such as cotter pins, bolts, rivets, and sometimes in bearings that are static but subject to vibration. Fretting wear may appear as numerous small indentations.

Gouging Wear - This occurs when large fragments are removed from the surface by high energy impact from large pieces of material. The crushing of hard abrasive products such as rock and ores produces rapid surface damage.

Erosive Wear - Erosion occurs when particles in a fluid rub against a surface at high velocities and remove material from that surface. Erosive wear occurs in nozzles, pumps, impellers tubes, pipes, and valves.

3.4.5 Weld Discontinuities

Weld discontinuities are formed as a result of welding or joining of two metals by fusion with or without the addition of filler metal. Welding is similar in some respect to the casting process in that the metal is melted and allowed to solidify in place. Welding may be defined as “the permanent union of metallic surfaces by establishing atom to atom bonds between the surfaces”. It is also used to repair defective areas of castings, pipe or structures and to build up an overlay, hardfacing, or surfacing to provide a particular protective surface.

Welding discontinuities occur as a result of operator error, lack of skill, or noncompliance with a qualified weld procedure.

3.4.5.1 Cracks

Cracks are defined as fracture-type discontinuities characterized by sharp tips and a high length to opening ratio. Cracks can be classified as hot cracks (which occur at high temperatures during solidification) or as cold cracks (which occur after solidification is complete). Both types can be further categorized by their physical location within the weldment.

3.4.5.2 Longitudinal Cracks

Longitudinal cracks are parallel to the axis of the weld and are usually confined to the center of the weld. A longitudinal crack may be

an extension of a crack that started in the first layer. A crack formed in the first layer, if not removed, tends to propagate into the layer above, and into each subsequent layer until it reaches the surface. This condition may also be termed a throat crack. Figure 3-11 illustrates a longitudinal crack.

3.4.5.3 Transverse Cracks

These cracks are perpendicular to the axis of the weld and in some cases extend into the base metal. They may often be found near or in weld starts or stops. Figure 3-12 shows a transverse crack.

3.4.5.4 Crater Cracks

These cracks occur in the concave area (crater) at the termination of the weld bead, where the arc is broken. Crater cracks may be star shaped, longitudinal, or transverse (Figure 3-13). Crater cracks often serve as the initiation point for other types of cracking; as a result, they are considered serious by most specifications.

3.4.5.5 Porosity

Porosity is entrapped gas pockets, or voids free of any solid material, in the weld metal. Porosity is generally characterized as a smooth edged, rounded or elongated discontinuity. A pore may also have a sharp tail that could be the initiation point of a crack. Five types of porosity may be present in a weld.

Isolated Porosity - As the name implies, this

individual pore, either rounded or elongated, may be entrapped any place in the weld. Figure 3-14 is an example of isolated porosity.

Uniformed Scattered Porosity - Generally rounded in appearance, and as the name implies, uniform porosity is scattered at regular intervals throughout the weld (Figure 3-15).

Clustered Porosity - A group of pores in a small area separated by zones of porosity free weld metal is called clustered porosity, as illustrated in Figure 3-16.

Linear Porosity - Also called aligned porosity, linear porosity is characterized by a number of rounded pores, which follow a line parallel with the axis of the weld (Figure 3-17).

Piping Porosity - Piping porosity (or wormhole porosity) occurs as nonspherical pockets along grain boundaries or as elongated tubular voids that extend within the weld width or thickness. Figure 3-18 illustrates this type of porosity.

3.4.5.6 Inclusions

Slag Inclusions - These inclusions are oxides and other nonmetallic materials that are trapped in the weld metal, usually between the weld metal and base metal, or between weld passes (generally irregular in shape). Slag inclusions, however, may occur anywhere in the weld (Figure 3-19). Slag is sometimes trapped along the edges of a weld bead and buried under the next weld pass. This condition is sometimes referred to as wagon tracks

because of its radiographic appearance.

Tungsten Inclusions - Tungsten inclusions, which are associated with the Gas Tungsten Arc Welding/Tungsten Inert Gas (GTAW/TIG) occur when the nonconsumable tungsten electrode touches the work or the molten weld metal and transfers particles of the tungsten into the weld metal. These inclusions may be scattered in very fine particles, sometimes referred to as a tungsten cloud, or as a distinct particle that may be of considerable size.

3.4.5.7 Undercut

Undercut is a depression at the fusion zone between the weld and the base metal. It may be categorized as a structural condition since the fatigue life of the weldment may be reduced as a result of the undercut. Figure 3-20 illustrates undercut.

3.4.5.8 Burn Through

Burn through is a void or opening extending through the bottom of the weld joint that is caused by localized overheating of the first or second weld pass. When this localized area becomes molten, the metal runs out of the joint, leaving a void area. This molten metal may merely sag and form icicles, or it may melt completely to form a convex profile known as convexity (Figure 3-21).

3.4.5.9 Concavity

When the root profile is less than even with

the inside dimension of the parts being joined, it is referred to as concavity. It results in a reduction in weld thickness at the concave area.

3.5 Summary of True Discontinuities

The severity of a discontinuity is dependent upon its size, location, and type. Each discontinuity should be analyzed with respect to objective data in relationship to the fracture mechanics considerations for the material and the potential for failure based on the discontinuity type location, size, and intended service. Finally, the results of any failure in terms of risk analysis should also be considered.

3.5.1 Defects

The term “defect” implies a defective condition that would render a part unsuitable for its intended use. In some cases, the term “defect” may be used to describe a true discontinuity that is unacceptable to code acceptance standards or specifications.

3.5.2 Repair Considerations

The proper interpretation and classification of discontinuities is an integral part of NDE. It requires extensive experience and skill to consistently evaluate and correctly identify the various discontinuities. A discontinuity that is incorrectly interpreted or completely missed can be critical to the function of the part. Being overly critical can also create problems as a result of requiring unnecessary repairs.

Once a rejectable discontinuity is detected, it is essential that every effort be taken to assure that it has been completely removed. This may require additional examinations using the method originally used to detect the condition or a different method. For example, if the discontinuity was rejected as a result of an RT examination, PT or MT may be used during the excavation process to assure the discontinuity was completely removed. Once the repair is complete, the area should be re-examined to assure acceptability using the original NDE method.

3.6 Interpretation Summary

Effective interpretation can be achieved by being familiar with the following:

- The type of material;
- The process(es) to which the material has been subjected;
- Any unusual incident occurring to the material or part;
- The configuration, size, and variables associated with the object being examined;
- Assurance that the examination was performed properly;
- Thorough understanding of the applicable specifications and codes.

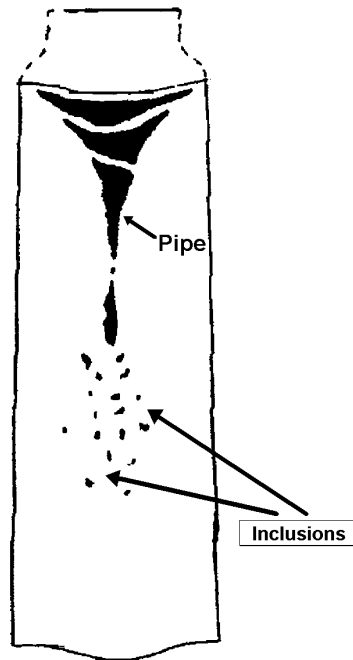


Figure 3-1 Inclusions in Ingot

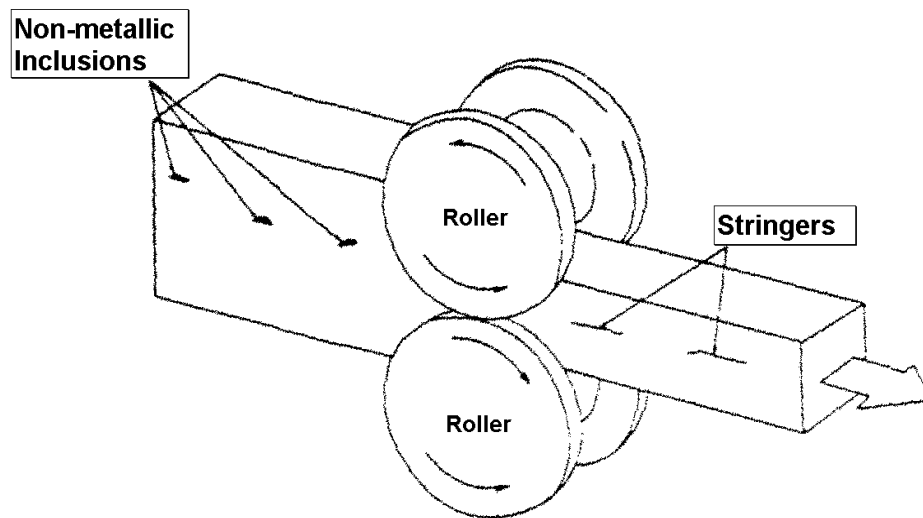


Figure 3-2 Stringers

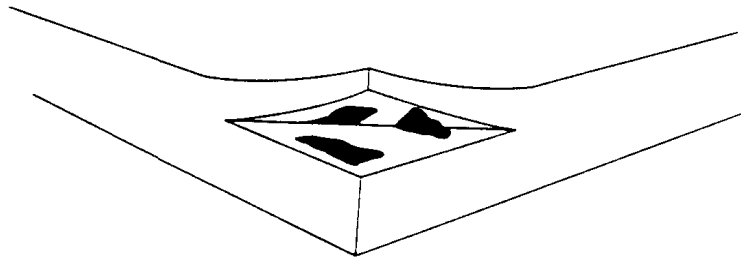


Figure 3-3 Laminations in Rolled Products

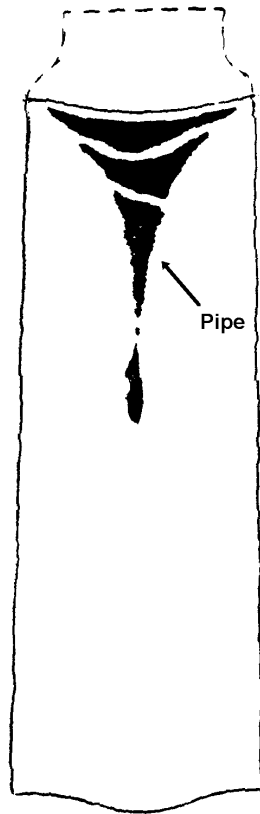


Figure 3-4 Piping in Ingot

How
SHRINK CRACKS and HOT TEARS
are made!

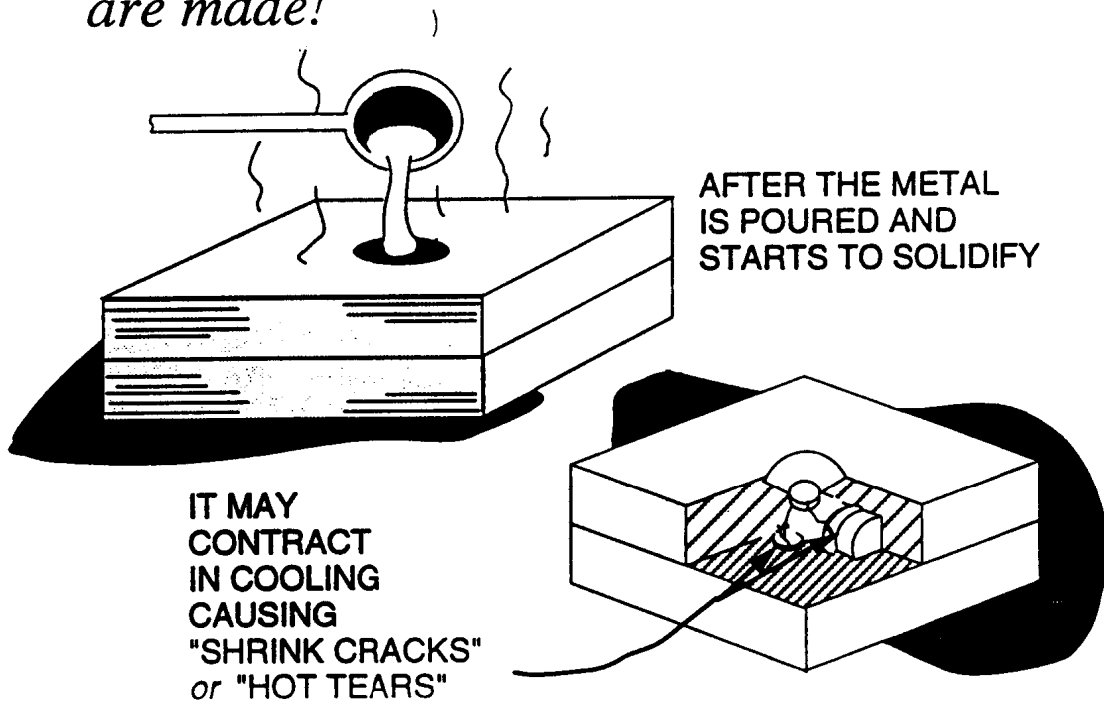
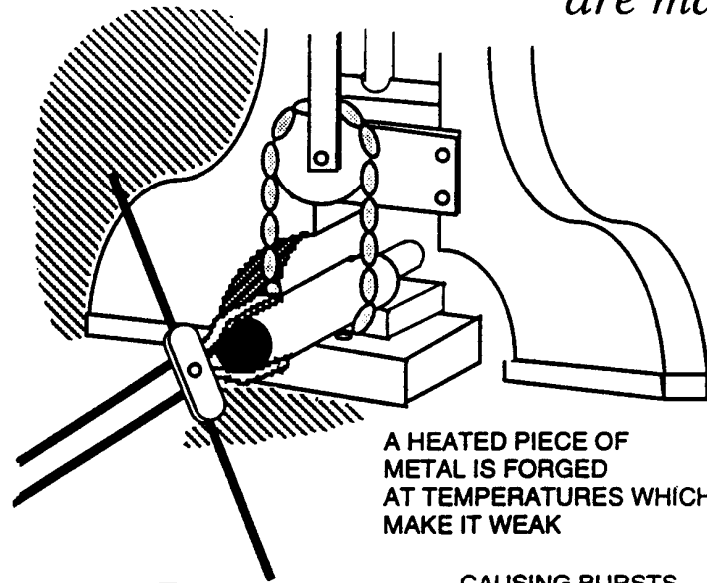


Figure 3-5 Shrink Cracks and Hot Tears

How
FORGING BURSTS
are made!



A HEATED PIECE OF
METAL IS FORGED
AT TEMPERATURES WHICH
MAKE IT WEAK

- CAUSING BURSTS
WHICH ARE USUALLY
INTERNAL

FLAKES ALSO
OCCUR BECAUSE
OF -

UNCONTROLLED
COOLING!

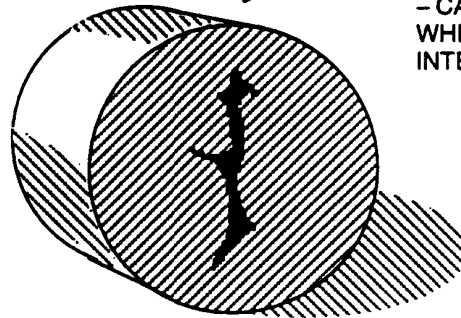


Figure 3-5
Shrink Cracks
and Hot Tears

Figure 3-6 Forging Bursts

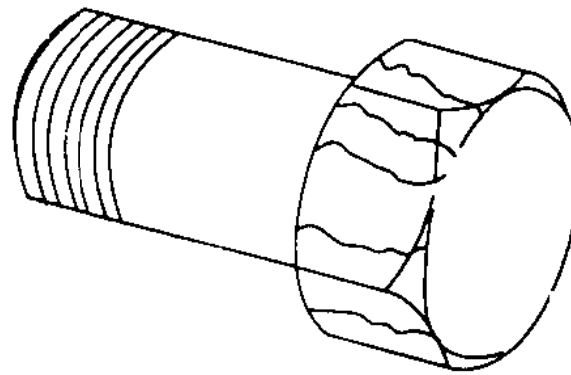


Figure 3-7 Forging Burst in the Head of a Bolt

How
MACHINE TEARS
are made!

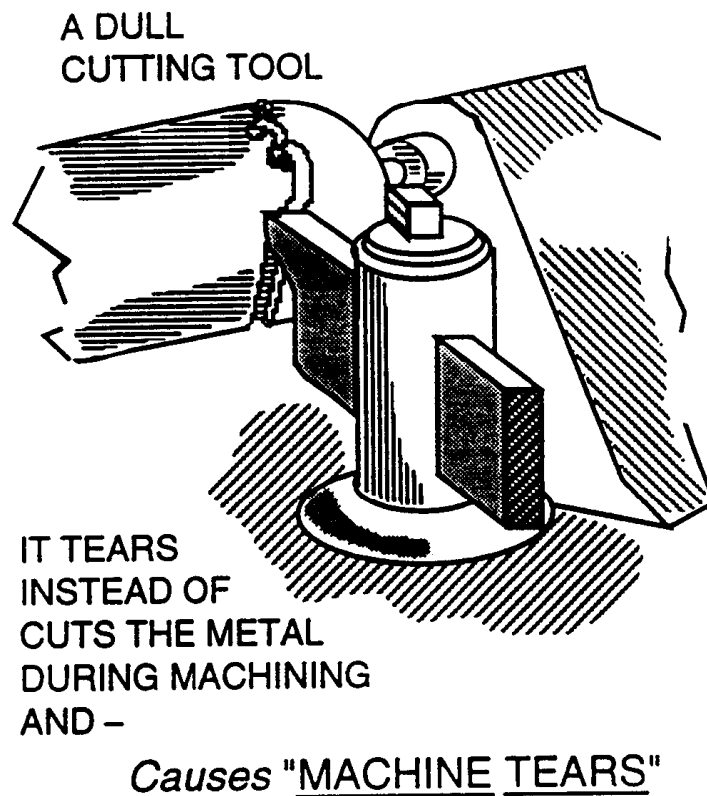


Figure 3-8 Machining Tears

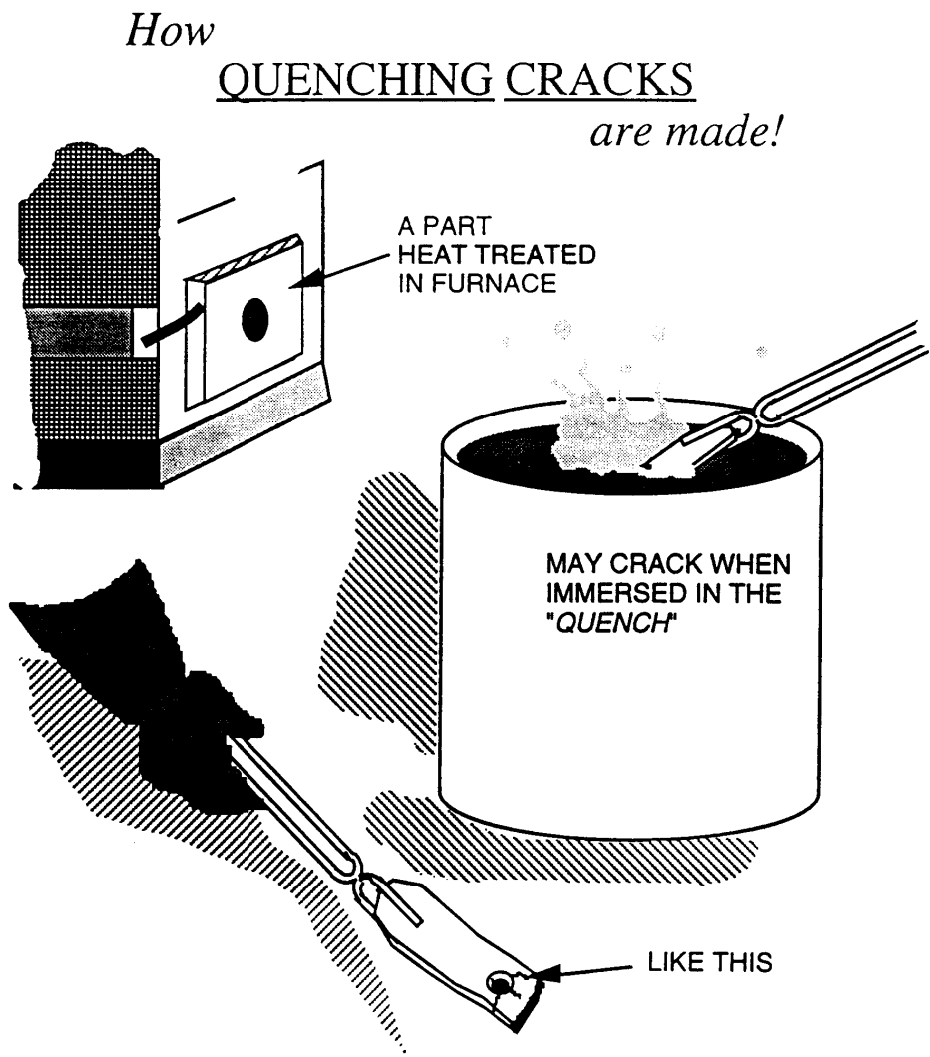


Figure 3-9 Quenching Cracks

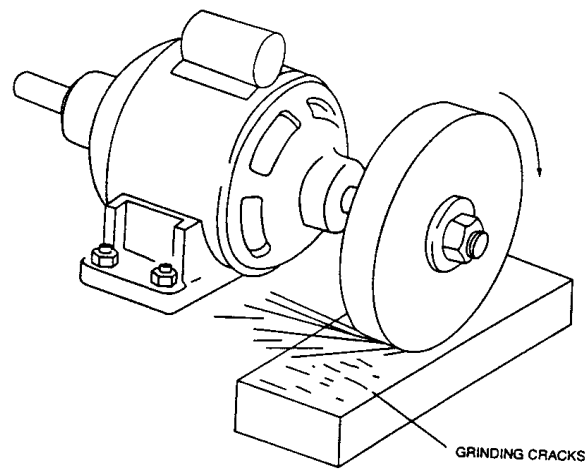


Figure 3-10 Grinding Cracks

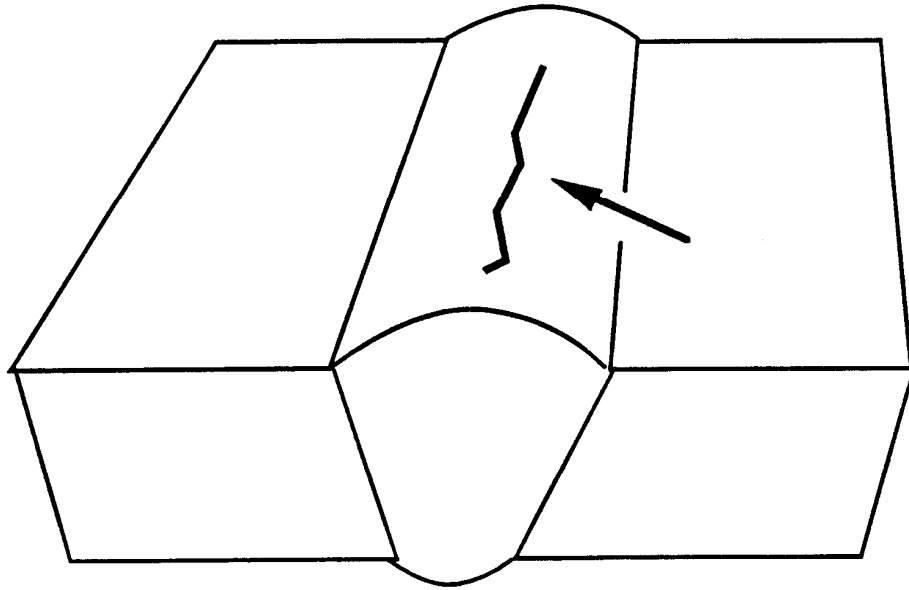


Figure 3-11 Longitudinal Cracks

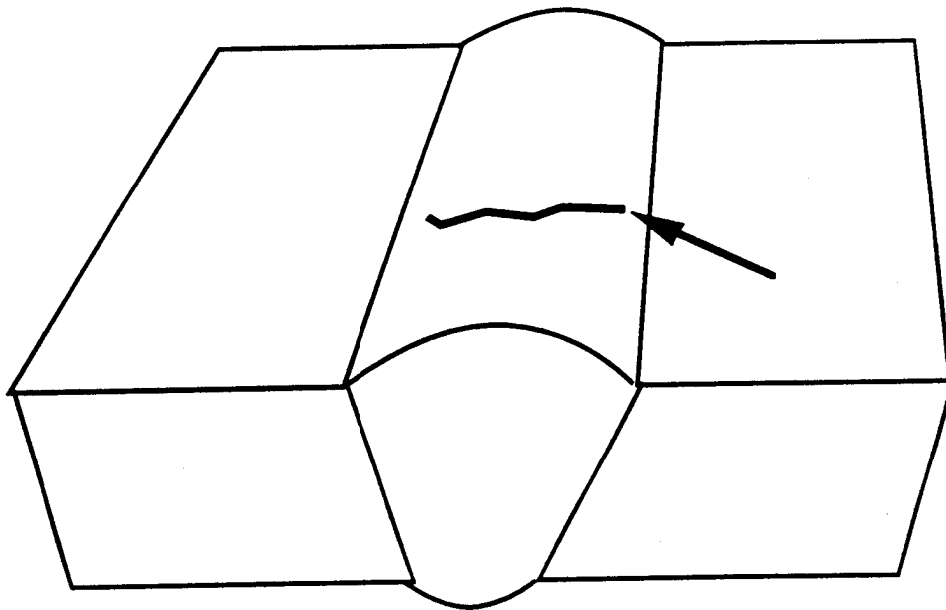


Figure 3-12 Transverse Cracks

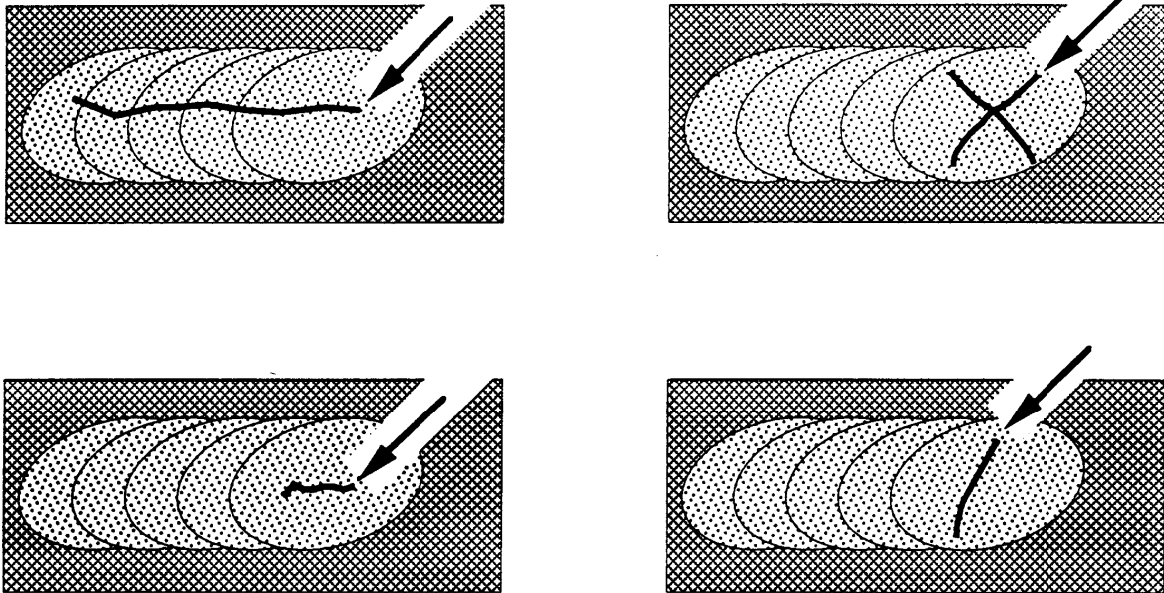


Figure 3-13 Crater Cracks

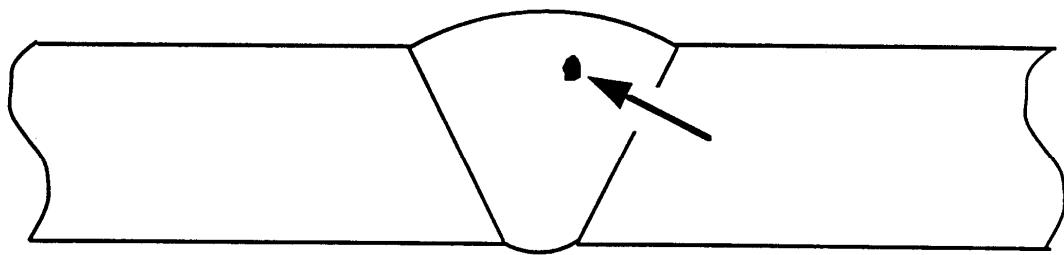


Figure 3-14 Isolated Porosity

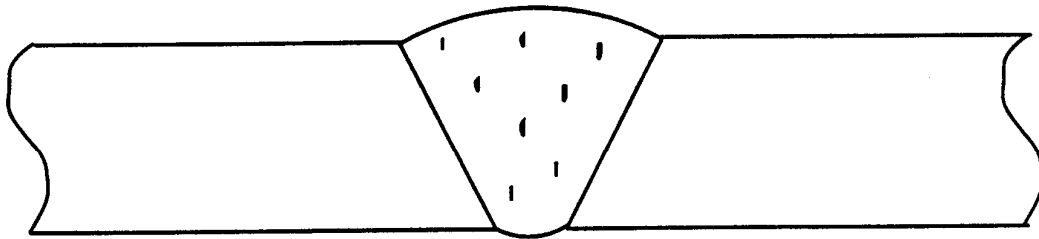


Figure 3-15 Uniform Scattered Porosity

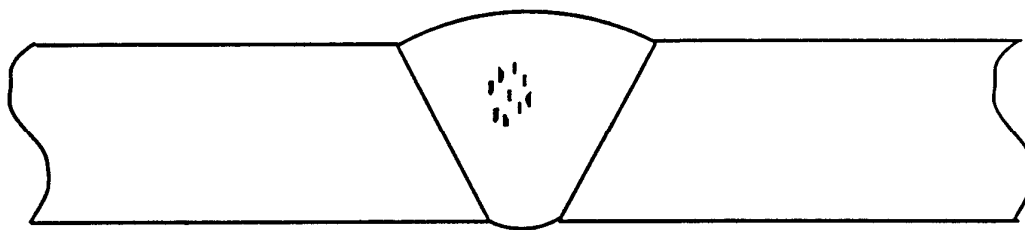


Figure 3-16 Clustered Porosity

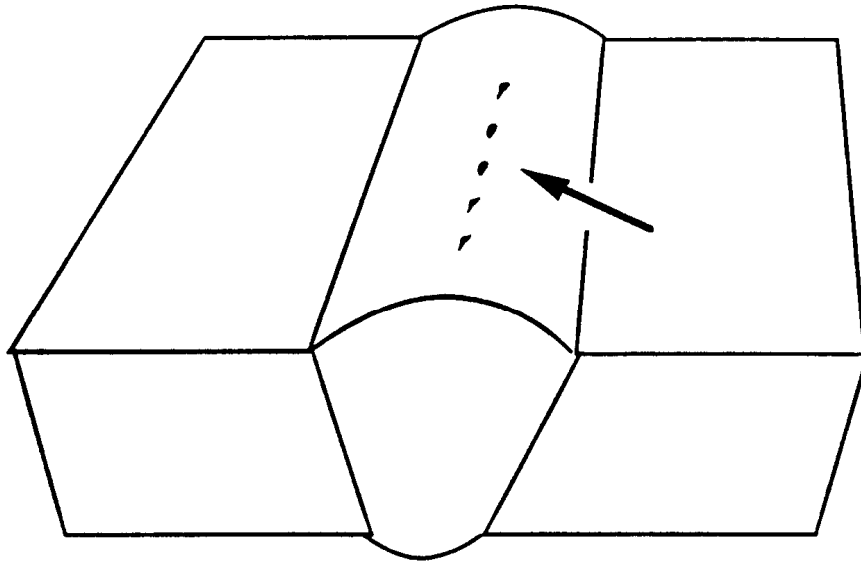


Figure 3-17 Linear or Aligned Porosity

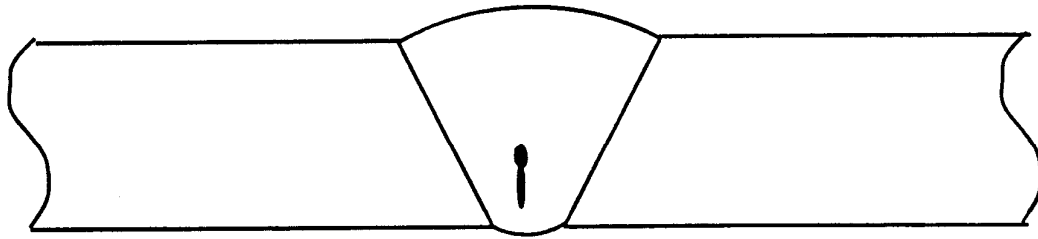


Figure 3-18 Piping Porosity

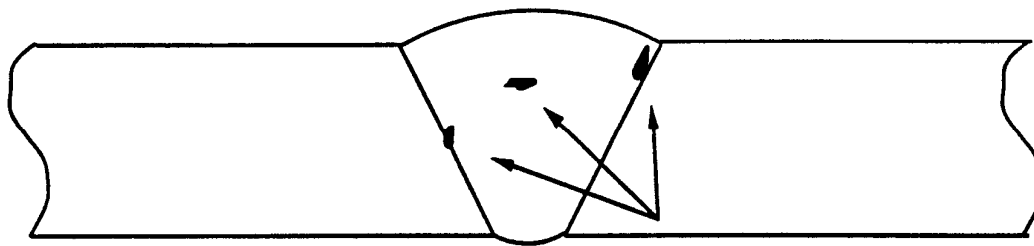


Figure 3-19 Slag Inclusion

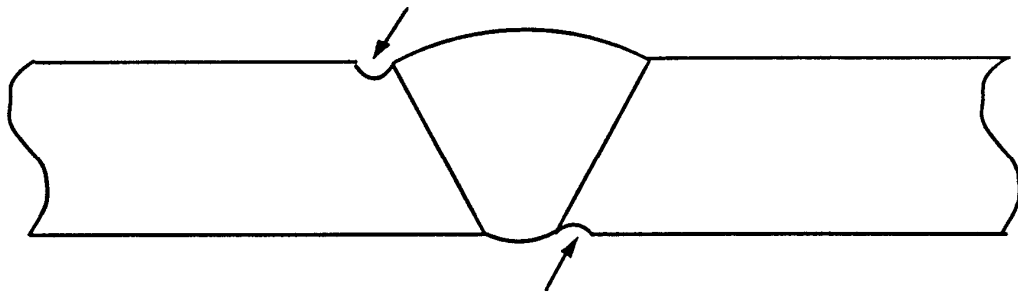


Figure 3-20 Undercut

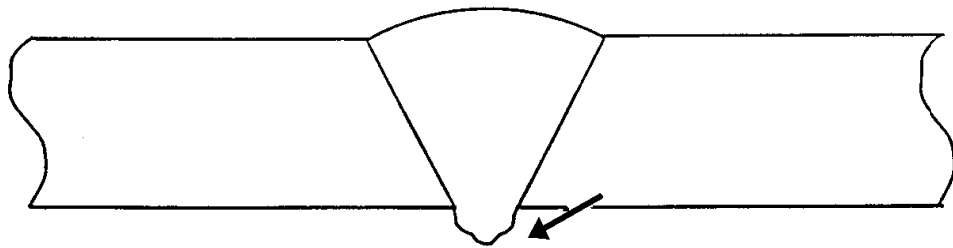


Figure 3-21 Burn Through/Convexity