# Preface

This module is intended as a reference guide for students, technicians, and professionals in NDT. An overview of each discontinuity provides the following information:

- Description
- Location in Part
- Characteristics/Appearance
- Metallurgical Analysis

Depending on the availability of information, one or more of the following items are subsequently presented in terms of visual testing per discontinuity:

- Rationale – explaining why the method is preferred
- Advantage(s) – highlighting the strong points of the method
- Limitation(s) – detailing any drawbacks associated with the application of the method
- Recommendation(s) – providing procedural tips for a successful outcome
- Precaution(s) – advising what safeguards to take when conducting a test

Please note that this module is intended as a supplement only. It should not take the place of specific codes, procedures, or standards applicable to a specific test.

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## Advantages of VT

- Direct visual testing (DVT) is generally a basic observation of the surface to be inspected.
- Minimal visual aids required, for example, external light sources, scales, magnifiers, and image recording devices.
- Cost of inspection is low compared to the more expensive equipment costs of more sophisticated NDT methods and techniques. The primary cost is the use of qualified personnel.
- Dimensional tests can be precise if adequate tooling is utilized.
- Remote visual testing (RVT) can give access to otherwise inaccessible surfaces utilizing modern technology, such as fiber optics, lens optics, and video borescopes.
- Can be applied to an extremely wide range of applications, industries, and special needs.
- RVT may utilize light beyond the normal human range of visible light, including infrared and ultraviolet light waves detectible by photoelectric sensor arrays.
- Done at an early enough stage, VT can prevent over- and underwelding.

## Limitations of VT

- The human eye and physiological condition make VT subject to certain reliability factors, such as fatigue, visual acuity shortcomings, distortion of views, and inadequate lighting.
- Use of aids may distort views and images.
- RVT may require the use of delicate and expensive devices.
- Inadequately trained and experienced inspectors may make inaccurate evaluations, especially on subjective calls.
- There is a limit to the size of the discontinuity that can be detected with conventional equipment or the unaided eye.

# Precautions with VT

- Be aware of eye fatigue and health of the inspector, which may impact inspection quality.
- Inadequate scanning patterns may allow relevant indications of discontinuities to be missed.
- Careful attention must be paid to the areas of interest, determining areas that may or may not be accessible.
- Avoid glare or other auxiliary lighting problems that may prevent adequate surface tests.
- Proper angle of light incidence is important to maximize visibility. Direct light parallel with the line of sight should be avoided.
- Conventional electrical safety precautions are to be followed with all electrically powered lighting devices.
- Light sources that are heat generating devices are especially prone to dangers in unsafe or flammable environments.
- Where more than one layer of metal filler is being deposited, it may be desirable to visually inspect each layer before depositing the next.
- Surface to be tested should be clean and free of slag.

# Relevant Discontinuities

A discontinuity is any intentional or unintentional interruption in the physical structure or configuration of a part. Nondestructive testing (NDT) is the process by which discontinuities are located. As part of the NDT process, evaluation criteria are applied to determine whether the discontinuities that are discovered may or may not affect the usefulness of the part. Indications (responses to a nondestructive test) are classified as false, nonrelevant, or relevant.

- A false indication is an indication produced by something other than a discontinuity; many times a false indication arises from improper handling procedures.
- A nonrelevant indication is an indication that is caused by a condition or type of discontinuity that is not due to an actual discontinuity. A nonrelevant indication may also result from a misapplied test or may be an indication that is too small to be considered relevant per the specification. Nonrelevant indications usually result from intentional interruptions in a part such as a change in section geometry, thickness or hardness, or by a physical condition that is not a discontinuity.
- A relevant indication is the result of an actual discontinuity and must be evaluated by a qualified inspector to determine the severity of the discontinuity. Finding and evaluating relevant indications at an early stage is a critical step in preventing discontinuities from becoming more serious, causing system or catastrophic failure, while the intended part or component is in service.

## Relevant Discontinuities (continued)

This module summarizes the characteristics of various types of relevant indications, which result from discontinuities that may be detected by VT. Capabilities and limitations of VT when applied for the detection of a specific discontinuity are shown. The discontinuities in this module are divided into four categories: inherent, primary processing, secondary processing, and service-induced.

- Inherent discontinuities originate from the solidification of cast or molten metal, such as pouring an ingot. Inherent discontinuities may also have their origin in other bulk consolidation methods, such as forming blooms, billets, or slabs.
- Primary processing discontinuities arise from the hot or cold working of an ingot into forgings, rod and bar, pipe and tube, and from welding. As with inherent discontinuities, primary processing discontinuities may be found in composite materials as well.
- Secondary processing discontinuities stem from secondary processes and finishing operations such as machining, grinding, heat treatment, and plating.
- Service-induced discontinuities are caused during the use of the part.

The discontinuities discussed in the following sections are only some of the many hundreds that are associated with various industrial products.

# Inherent Discontinuities (Ingot)

This group of discontinuities occurs during the initial melting and refining processes (ingots) and during solidification from the molten state (castings). Such discontinuities are present before rolling or forging is performed to produce intermediate shapes. The following discontinuities are normally internal. They change shape during processing. They are listed here to identify the origin of the subsequent reshaped and renamed discontinuities. Note: this list includes additional VT discontinuities that may be found during testing but are not included in this book.

- Inclusions, nonmetallic (normally internal)
- Pipe (normally cropped off of ingot)
- Porosity (normally internal)
- Fissures (normally internal)

# Internal Nonmetallic Inclusions

**Description**: Found in ferrous and nonferrous ingots (macro-casting) and in rolled material. Commonly known as “stringers” when the subsequent billet or slab is rolled from the ingot into bar stock for further processing. Typically, inclusions are mechanically worked, causing them to deform into elongated shapes and to appear in longitudinal sections as stringers or streaks.

**Location in Part**: Stringers are typically subsurface, semicontinuous straight lines parallel to the length of the bar stock. Hence, they are open to the surface for VT only when machined, ground, or worked to expose what was once subsurface (see figure on page 7). When visible they may be located on the edge of plate steel.

**Characteristics/Appearance**: During refining, additives to the molten metal may collect to form large clumps as the ingot solidifies. After working, nonmetallic inclusions appear as short, straight, thin indications that may be numerous, intermittent, well dispersed, or found in heavily concentrated bands.

**Metallurgical Analysis**: Caused by oxides, sulfides, or other refractory materials and impurities that are entrapped in the molten metal as it solidifies in the ingot mold. They are normally lighter than the metal and the majority of inclusions and slag rise to the top while the metal is still in the liquid state. Most of this material is removed during cropping operations. Nonmetallic inclusions, when further processed, can produce laminations, seams, and cracks in finished material.

# Using VT to Detect Internal Nonmetallic Inclusions

**Rationale:** Surface preparation is critically important for detection.

**Advantages:** VT is only advantageous when inclusions are exposed to the surface after machining, shaping, or working techniques are applied.

**Limitations:** VT will not detect near-surface inclusions and subsequent stringers in ferromagnetic materials.

**Precautions:** NDT should be performed prior to and after further processing. Nonmetallic inclusions may be worked into laminations in subsequent processing after originating in the inherent stage. When laminations processed from nonmetallic inclusions are identified at the edge of the rolled stock (plate), ultrasonic testing should be utilized to outline them for removal.

**Inclusions in bar stock exposed during machining are visible following machining. (Siderius)**

# Pipe and Porosity

**Description**: Found mostly in steel and other metals poured into ingot molds. Forms during liquid stage and solidifies after cooling.

**Location in Part**: Surface and internal.

**Characteristics/Appearance**:

- Pipe appears as conical shrinkage at the top of an ingot.
- Gas porosity takes the form of more or less spherical voids or bubbles that form within the cast metal. Surface-connected porosity produces rounded cavities (flattened, elongated, or spherical) that are normally less than three times as long as wide. Visual indications of gas holes are rounded voids on the surface.
- Blowholes are small holes similar to porosity.
- Large porosity may appear as seams after rolling, forging, or extrusion if exposed to the surface.
- Oxidized porosity in the interior of plates or pipe products will only appear as laminations when cross sectioned for weld preparations before welding.

**Metallurgical Analysis**: In pipe, this portion is cropped and not normally visible in post-cast ingot. For porosity, as molten steel is poured into an ingot and solidification commences, there is an accumulation of gases. These gases rise through the liquid in the form of bubbles and many escape or migrate to the top or cropped portion of the ingot. However, some gases can be trapped in the ingot, forming porosity. Porosity is free from inclusions and normally oxidized. When subsequently processed by rolling or forging, the result is an unbonded flattened condition. It is then classified as a lamination.

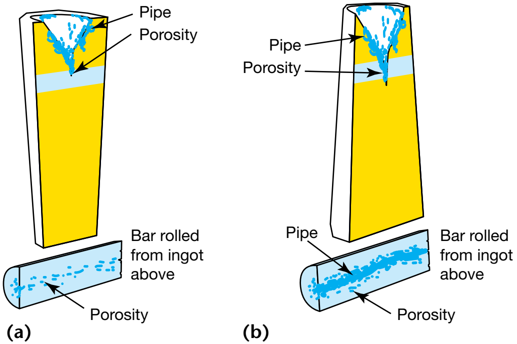
# Using VT to Detect Pipe and Porosity

**Advantages:** May provide a means to eliminate product that has a critical size or surface condition.

**Limitations:** Surface inspection may not give exact depth measurements without excavation. Not seen by VT inspector after cropping.

**Recommendations**: Utilize an auxiliary light source at an angle to the surface and magnifier, as needed.

**Precautions:** Sizing of discontinuities is critical for future applications.




**Longitudinal section of two ingots, showing typical pipe and porosity: (a) detectable; (b) severe.**

# Primary Processing Discontinuities

This group of discontinuities is found or produced by forming or fabrication operations including rolling, forging, and welding. VT is recommended for the following primary processing discontinuities. Note: this list includes additional VT discontinuities that may be found during testing but are not included in this book.

| Joining Processes | Casting | Wrought Processes |
|---|---|---|
| • Welding<br>Arc strikes<br>Undercut<br>Cracks<br>Rollover<br>Misalignment<br>Excessive reinforcement<br>Root concavity<br>Incomplete penetration<br>Excessive oxidation | • Sand casting<br>Blowholes<br>Porosity<br>Cold shuts<br>Hot tears<br>Nonmetallic inclusions<br>Shrinkage cavities (microshrinkage)<br>Cope shift, mold shift<br>Scars and scabs | • Forging<br>Flash line cracks/tears<br>Laps<br>Bursts<br>Flakes<br>Burning<br>• Extrusion<br>Tears<br>Die lines<br>Draw lines |

# Primary Processing Discontinuities (continued)

| Joining Processes | Casting | Wrought Processes |
|---|---|---|
| ● Welding (continued)<br>Porosity (conditions and how created; spherical, elongated, worm-hole)<br>Weld spatter<br>Tungsten inclusion<br>Cold lap/rollover (lack of fusion)<br>Inadequate weld throat<br>Underfill<br>● Brazing<br>Lack of bond<br>Inadequate fillet<br>Porosity (gas)<br>● Soldering<br>Excessive solder<br>Porosity (gas)<br>Cold joint<br>Disturbed joint<br>Balling or bulbous joints | ● Sand casting (continued)<br>Unfused chaplets<br>● Lost wax/investment casting<br>dross | ● Rolling<br>Edge cracking<br>Hydrogen flake<br>Stringers<br>Rolled seams in threads<br>Scabs<br>Laminations (weld end preparation only) |

# Arc Strikes

**Description**: Found in ferrous and nonferrous welded material.

**Location in Part**: Surface. Situated on the surface of the base metal or weld face where a welder has momentarily touched an arc-welding electrode to start the arc, resulting in a localized weld or surface melting at the point of contact.

**Arc strike. (Vona)**

**Characteristics/Appearance**: May appear as a localized molten puddle and/or discoloration if no metal deposited. It may appear as a wide or rounded deposit of metal or mini weld if filler material deposited.

**Metallurgical Analysis**: Arc strikes can cause failure of the affected material. These failures initiate at abnormal structural conditions or soundness produced in the arc strike. Arc strikes often harbor minute cracks, porosity, hard zones, and chemical heterogeneity. The extreme local momentary heat input may cause case hardening at the site of the arc strike. This may cause the metal to become brittle at the surface. This makes the material more subject to cracking when exposed to stress.

# Using VT to Detect Arc Strikes

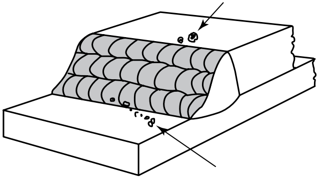
**Advantages:**

- VT is advantageous prior to paint processes and subsequent NDT techniques in order to eliminate problems with finish.
- It is also advantageous to the inspection of surface-critical applications that might be susceptible to service-induced discontinuities.
- This is a workmanship discontinuity and is usually easy to detect by VT.

**Limitations:** Visibility is limited after grinding. Residual deposits of filler material or metallurgical variances may remain, but not visible without acid etching or magnification.

**Recommendations:** Use of various lighting applications may prove beneficial in detection.

**Precautions:** Arc strikes are generally not allowed because the localized heating and resulting pit(s) can become a stress riser and crack initiation site. Arc strikes are indicative of poor workmanship, and are normally detectable by VT.



**Arc strikes on work pieces and portions of multipass weld.**

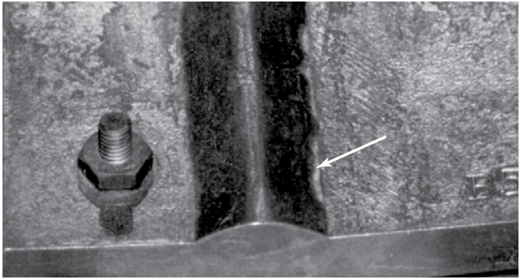
# Undercut

**Description**: Found in ferrous and nonferrous welded material.

**Location in Part**: Found at any point where weld metal and base metal meet. Linear indication adjacent to and following the toe of the weld, whether it is a base metal or previously deposited weld metal. It has some depth below the surface of the base material where the melting occurred. It is noted to not have any straight edge line. Rather, it has a fluid disposition and shaped edge at the base material intersection.

**Characteristics/Appearance**: Undercut is a groove that is melted into the base metal along the edge of the weld and left unfilled by the weld filler metal.

**Metallurgical Analysis**: Undercutting is generally regarded as a serious discontinuity because the result is a reduction in the cross-sectional area of the weld zone and therefore a reduction in its load-carrying capacity. It is therefore a stress riser.



**Undercut.**

# Using VT to Detect Undercut

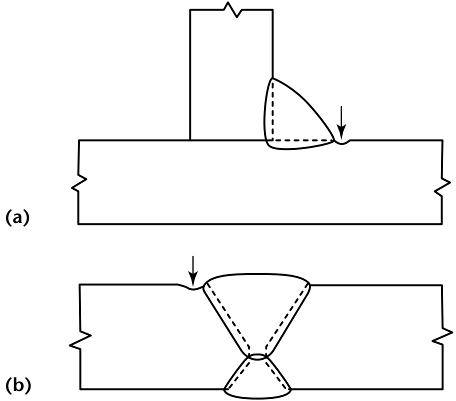
**Rationale**: Inspection is important to reduce effects from stress risers and loss of through-wall thickness.

**Advantages:** VT is a quick detection method for undercut on available surfaces.

**Limitations:** VT may not be beneficial for internal undercut detection when the surface is not accessible.

**Recommendations:** Adequate lighting is a requirement, with a possible need to vary the angle of the light source.

**Precautions:** As a stress riser it may become the initiation point for a crack and subsequent failure of the part.




**Presence of undercut: (a) in fillet weld joint; (b) in butt weld joint.**

# Welding Cracks

**Description**: A rupture of metal under stress with a crack-like or linear appearance.

**Location in Part**: May be located in the base metal, at the toe of a weld, in the weld, along the weld, across the weld, or diagonally in any orientation in the weld.

**Characteristics/Appearance**: Generally multifaceted and linear in shape with its long axis three or more times its short axis. Jagged and irregular in appearance, representing the rupture of the metal. By definition, a tail coming off a rounded indication is interpreted as "crack-like" and also rejected as a crack. Cracks frequently appear at the intersection of changes in section or thickness such as the toe of welds.

**Metallurgical Analysis**: Cracks are the release of internal stresses within a weld that have relieved themselves by rupturing the metallurgical bonds.

**Visual appearance of heat-affected zone crack.**

# Using VT to Detect Welding Cracks

**Rationale:** Crack depths are normally not measurable with most VT applications. This leads to the necessity for rejection of cracks or crack-like indications.

**Advantages:** VT can be used as an early elimination tool for cracked products.

**Limitations:** Due to some surface conditions, cracks may often be misidentified or missed. A crack's width may be extremely small, leading to possible non-detection.

**Recommendations:** With the exception of in-service components, all manufactured parts, components, or systems reject crack or crack-like indications.

**Precautions:** Existing cracks generally lead to further cracking and subsequent failure if the part is exposed to further stresses.

**Multiple cracks on a multipass fillet weld that has been sandblasted and checked with MT for better resolution. (Freeman)**

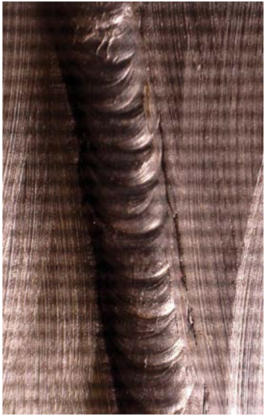
**Close-up of a crack in ground flush weld behind cover plate. (Siderius)**

**Visual appearance of a crater crack.**

# Using VT to Detect Welding Cracks (continued)

In-service toe crack. (Allgaier)

Outside diameter delayed toe crack. (Freeman)



Inside diameter root crack. (Sabolik)

# Rollover

**Description**: Another term for it is insufficient reentrant angle, where the reentrant corner formed by the toe of the weld is less than 90°.

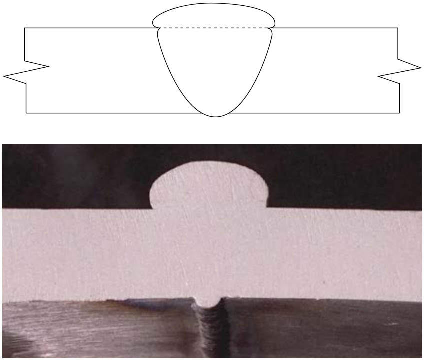
**Location in Part**: Toe of the weld.

**Characteristics/Appearance**: Rounded in appearance or bulging over like a “muffin top.” Rounded edge of the weld meeting the flat face of the base metal.

**Metallurgical Analysis**: The acute angle formed at the intersection of the weld face and the base material creates a stress riser that may result in cracking and joint failure when exposed to sufficient stresses.

(a)

(b)



Rollover of a weld groove: (a) schematic; (b) actual weld.

# Using VT to Detect Rollover

**Rationale**: Rollover also becomes a form of lack of fusion, where the bulging weld metal is not fused to the base metal.

**Advantages:** Rather easy to detect if VT is performed properly and may be assisted with auxiliary lighting.

**Limitations:** Poor lighting and/or a limited angle of inspection in relation to the weld surface may restrict detection.

**Recommendations:** In order to eliminate the stress riser it is recommended that the toe of the weld area be ground to give a radius sufficient to transfer stresses through a radial plane without a sharp intersection.

**Precautions:** Grinding the face only of such a weld profile will not reduce the stress riser at the weld toe.

# Misalignment

**Description**: When two members (plate or pipe or other) are to be metallurgically joined by welding, they may be misaligned at the onset or become warped due to uneven heating during welding.

**Location in Part**:

- The condition always exists at the intersection of two joints and is measured as distortion or offset of one member relative the other member.
- The joined member surfaces are not in the same plane.

**Characteristics/Appearance**: The two members form two surfaces on different planes or, if initially on the same plane, no longer remain oriented on the same plane.

**Metallurgical Analysis**: Offset planes can cause a stress riser, which can yield in failure over time with cyclic loads applied repeatedly. In the case of distortion and resultant angular alignment it may be evidence of residual stresses. These stresses may relieve themselves at a later time and result in cracking. Alternatively, misalignment may result in improper fit-up for subsequent manufacturing or fabrication steps.

# Using VT to Detect Misalignment

**Rationale**: VT is a valuable tool to eliminate future fabrication/erection problems.

**Advantages:** Combined with mechanical aids, it can be beneficial in determining compliance to fabrication limits.

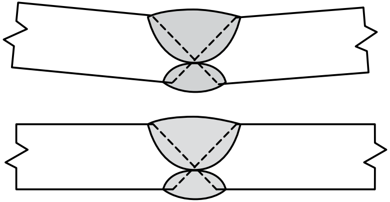
**Limitations:** VT is often performed after weld completion and not in conjunction with in-process welding techniques.

**Recommendations:** Evaluate the misalignment or distortion in comparison to the fabrication criteria.

**Precautions:** Ensure the proper limits are obtained for disposition of the part.

(a)

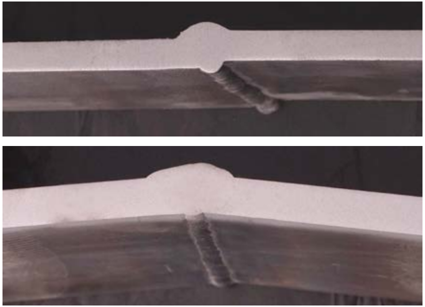
(b)



**Weld alignment: (a) incorrect angular alignment; (b) correct alignment using proper control methods.**

(a)

(b)



**Weld misalignment: (a) linear; (b) angular.**

# Excessive Reinforcement

**Description**: Excessive reinforcement is convex in shape and can exist on the outside diameter (OD) or inside diameter (ID) of a pipe-to-pipe weld or plate-to-plate weld. By definition it is reinforcement that exceeds the dimensional limits specified.

**Location in Part**: Commonly occurs on the surface from which welding and filler material deposit occurs. Can occur on either side of the welded surfaces.

**Characteristics/Appearance**: Excessive reinforcement, also called excessive convexity, is generally rounded in appearance.

**Metallurgical Analysis**: Significant variances in cross-sectional thickness can cause stress risers that can result in failure of the metal under stress or cracking at those locations.

**Excessive ID penetration. (Wright)**

# Using VT to Detect Excessive Reinforcement

**Rationale**: More times than not VT is used for appearance qualities. It may eliminate future problems with joint failure, possible stress risers.

**Advantages:** Use of weld gauges along with quantitative visual aids can determine whether excess reinforcement exists. VT can easily determine whether weld reinforcement is in excess of engineering requirement specifications.

**Limitations:** OD access to the welded surface is most common. Access to ID surfaces might be difficult to perform measurements. The ID of a pipe-to-pipe weld may be accessed by mirror or other remote VT device (for example, borescope). More commonly the ID reinforcement can indirectly be observed through volumetric examination such as radiography or possibly ultrasonic testing.

**Recommendations:** As a minimum it is a waste of time and effort to deposit more metal than necessary to bear the designed load of the metallurgical joint. Additionally, it could lead to joint failure.

# Root Concavity

**Description**: The weld cross section is less than the base metal cross section and has a concave or rounded depression shape. Excessive concavity violates the minimum wall thickness design.

**Location in Part**: Root surface concavity is observed on the inside diameter of a pipe-to-pipe weld joint.

**Characteristics/Appearance**: Compared to the adjacent material or weld the concave area has a sunken or depressed appearance.

**Metallurgical Analysis**: The resultant reduced wall thickness may violate minimum wall dimensions and not meet design criteria for load bearing.

**Concave weld at inside diameter of pipe-to-pipe weld.**

# Using VT to Detect Root Concavity

**Rationale**: Assurance for through-wall weld thickness.

**Limitations:** VT may only provide dimensional data. Volumetric (ultrasonic testing) data may be required to ascertain the actual wall thickness. The standard solution to concavity is to add more weld material.

**Recommendations:** Some concavity within an otherwise convex weld may be acceptable. But generally, concavity on the outside diameter, inside diameter, or opposite side of a plate-to-plate weld would be rejectable when minimum wall dimensions are observed.

**Precautions:** Attention should be paid so as not to confuse concavity with incomplete penetration.

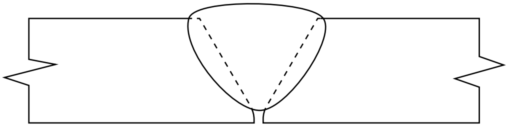
# Incomplete Penetration

**Description:** Found in ferrous and nonferrous weldments.

**Location in Part**: External and on the inside diameter or opposite side of welding for plate-to-plate welds. Normally found where the backside of the weld is accessible and visible.

**Characteristics/Appearance**: The mandatory characteristic is the straight edge or ruler straight edge on one or both sides of the weld joint. It is not irregular and only occurs at the root and runs parallel with the weld.

**Metallurgical Analysis**: Can be caused when insufficient root gap is provided during fit-up operations. This condition is always rejectable due to residual welding stresses that may cause the joint to fail in service.



**Incomplete penetration = root slit is not fused.**

# Using VT to Detect Incomplete Penetration

Incomplete penetration.

**Advantages:** When surface access is accessible, VT can be less expensive than other methods like radiographic testing (RT).

**Limitations:** It is only detectable when the surface is accessible. It is sometimes confirmed by remote VT by means of a dental mirror or borescope (rigid, flexible, or video borescope). By far it is most frequently found by RT.

**Recommendations:** Grinding down to the root and re-welding may be a repair option.

# Excessive Oxidation

**Description**: Excessive oxidation is the "burning" of the metal and the residual crystalline appearing surface left after excessive heat, combined with enough oxygen to cause the metal to burn.

**Location in Part**: Excessive oxidation may occur on the weld or opposite side of the joint to be welded. Generally the weld procedure assumes a protective shielding gas in the welded side to prevent oxidation. That leaves the opposite side or inside diameter (ID) of the weld joint to be oxidized during welding if precautions are not taken, such as purging the opposite or ID side.

**Characteristics/Appearance**: Crystalline appearance is the trademark look. On a radiograph the sharp protrusions and abrupt edges give the appearance of sugar crystals. Hence, its slang term is "sugaring."

**Metallurgical Analysis**: The abrupt nature of the weld profile represents extreme stress risers that may result in subsequent cracking in service. More importantly, the strength attributes of the metal may have been compromised by the extreme heat.

# Using VT to Detect Excessive Oxidation

**Recommendations:** The weld is rejectable and may need to be scrapped upon engineering analysis.

**Precautions:** Prior to VT, ensure proper purging or gas flow to protect the molten metal from burning.


**Excessive oxidation. (Allgaier)**

# Welding Porosity

**Description**: Found in ferrous and nonferrous weldments.

**Location in Part**: Surface or subsurface. (Subsurface porosity may only be visible if surfaces are made accessible through machining or grinding.) The start and stop of welds is a high-risk area for finding porosity.

**Characteristics/Appearance**: Porosity may be:

- rounded,
- elongated, or
- teardrop shaped.

It may or may not have a sharp discontinuity at the point. Porosity can appear alone, scattered uniformly throughout a weld, or isolated in small groups. May also be concentrated at the root or weld toe. Pores may also occur as spherical voids, pockets or elongated tubular voids called “piping porosity” or “wormholes” between weld passes. The length of the wormhole is not normally visible to the visual inspector. Rather, it is detected by radiographic testing.

**Metallurgical Analysis**: Porosity in welds is caused by gas entrapment in the molten metal. These gases may be released by the cooling weld metal because of reduced solubility as the temperature drops, or from gases formed by chemical reactions in the weld. Porosity is also caused by too much moisture on the base or filler metal resulting in gas during heating. Additionally, improper cleaning or preheating procedures may produce porosity during welding.

# Using VT to Detect Welding Porosity

**Rationale**: While porosity might be thought of as a surface discontinuity, it could be a through-wall discontinuity. Detection should lead to elimination.

**Advantages:** Detection is relatively simple and categorized per code requirements.

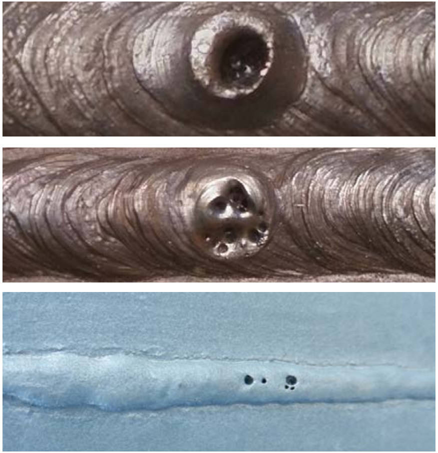
**Limitations:** Normally confined to in-process control of ferrous and nonferrous weldments. In addition, true depth measurement may be unobtainable.

**Precautions:** Caution must be exercised to completely remove porosity prior to repair welding to prevent the entrapped gases from extending into the re-welded weld beads and propagating from one weld pass into the next.

(a)

(b)

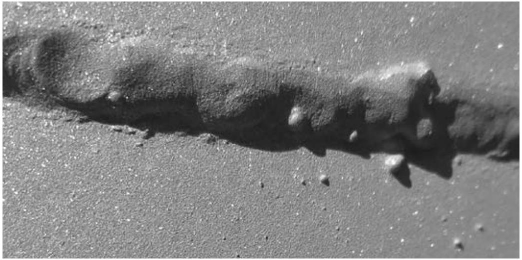
(c)



**Three types of weld porosity: (a) single pore; (b) clustered; (c) aligned.**

# Weld Spatter

**Description**: Globules of molten metal that spatter from an excited weld puddle during welding and adhere to the adjacent base metal or previously deposited weld metal.



**Weld spatter.**

**Location in Part**: Adjacent base metal or previously deposited welded metal near the primary welding site. Sight as well as feel can assist in weld spatter detection.

**Characteristics**: Spatter is variously sized, spherical (“BBs”) in shape and attached superficially to the metal on which it lands.

**Metallurgical Analysis**: The abrupt transition from the spherical globule to the adhering base or weld metal causes stress risers. These may result in metallurgical changes in the properties of the underlying metal into a more brittle condition susceptible to cracking.

# Using VT to Detect Weld Spatter

**Rationale**: Appearance is often more important than serviceability. Craftsmanship is important as well as preventing any future service issues.

**Advantages:** Detection and elimination can assist the use of other NDT methods.

**Precautions:** Concern for any surface metallurgical changes must always be considered.

**Recommendations:** Weld spatter will interfere with subsequent NDT processes and cause future discontinuity development. Therefore, spatter should be removed as a matter of course prior to further welding, testing, or return to service.

**Weld spatter. (Allgaier)**

# Underfill

**Description**: Underfill is a condition where through-wall thickness is not adequate across the width of the weld. It may be found in ferrous and nonferrous welded material.

**Location in Part**: Found where weld metal meets the base metal.

**Characteristics/Appearance**: To qualify as underfill some portion of the base metal must still be visible and not melted.

**Metallurgical Analysis**: The lack of weld metal deposit up the entire face of the end preparation of the plate or pipe results in insufficient metal to meet the design criteria for the weld joint in question. This is true for the middle of the weld area even if the weld covers the entire weld end prep faces but does not sufficiently meet cross-sectional thickness requirements.

**Underfill. (Wright)**

# Using VT to Detect Underfill


Underfill, porosity, and lack of fusion. (Wright)

**Advantages:** Easily detected with adequate lighting and augmented with weld gauges.

**Limitations:** On some weld configurations measurement may be difficult.

**Recommendations:** Add additional filler metal.

**Precautions:** Caution must be made not to trap nonmetallic inclusion or porosity, or allow lack of fusion between irregular weld beads or passes.

# Inadequate Fillet

**Description**: A braze fillet is actually a casting along the outside of a braze joint that shows that the brazing filler metal has melted and flowed along the edge of a braze joint.

**Location in Part**: Braze fillets occur at the joint intersection between base materials.

**Characteristics/Appearance**: Fillets should be concave. The edges should blend or feather out at each edge with the base material. No oxides or contamination should be visible. Porosity or cracks should not be apparent. The braze material should flow completely around the joint.

**Metallurgical Analysis**: Brazing is a metal-joining process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, the filler metal having a lower melting point than the adjoining metal. Lack of fill in a braze joint is undesirable as it may serve as a stress riser and may contribute to joint failure in service.

# Using VT to Detect Inadequate Fillet

**Recommendations:** Adequate flow of the braze filler material indicates proper fit and flow between the base materials. Do not evaluate size for acceptability. The proper fillet should be concave and blend smoothly into the base materials on either side. No more than a 10× magnifier is recommended if at all.

**Precautions:** Do not consider fillet size as an indicator of strength. Fillet size is not a criterion for acceptance. Rather, smooth continuous flow is the objective.

**Braze sample showing inadequate fillet. (Inspec Testing)**

# Blowholes

**Description**: A blowhole in a casting or a weld is caused by gas entrapped during solidification. It is on the surface of the casting and has an irregular shape with some depth due to a steam explosion.

**Location in Part**: Surface of casting part that would have been in contact with the casting mold.

**Characteristics/Appearance**: A blowhole has the appearance of an irregular cavity exposed to the surface of the casting or weld face. It appears rough as an "explosion of steam" would appear in the body of molten metal in a casting. (Note: a weld is a micro-casting.)

**Metallurgical Analysis**: Blowholes are the result of liquid (water) coming into contact with extreme (above boiling) temperature of molten metal in a casting. Their source is frequently the moisture in a sand casting. After solidifying in the casting body proper, the irregular void reduces cross section strength and leaves abrupt edges that are stress risers.

# Using VT to Detect Blowholes

**Advantages:** Early detection may prevent laminations being created during further processing.

**Limitations:** Only those that are open to the surface are detectable.

**Blowhole in a central impression cylinder. (Ravi)**

**Recommendations:** Blowholes are not acceptable in a casting of consequence. They are normally rejected, gouged, or routed out and repair welded if salvageable at all. Otherwise, large blowholes will render the part rejectable. As scrap it is suitable for re-melting and recasting.

**Precautions:**

- Do not confuse porosity (smooth rounded cavities exposed to the surface) with blowholes.
- Microshrinkage is jagged and irregular but without cavernous characteristics. Rather, microshrinkage has fine crack-like patterns connected in a small area.

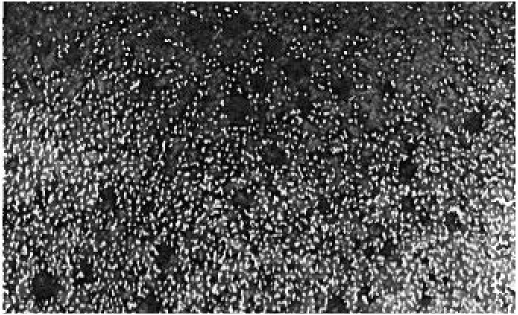
# Sand Casting Porosity

**Description**: Round spherical voids exposed to the surface of the casting.

**Location in Part**: Accessible surfaces of the casting.

**Characteristics/Appearance**: The round spherical voids or porosity may be single, clustered, random or linearly aligned, or any combination.

**Metallurgical Analysis**: Porosity is the creation, or coalescence, of gas within a liquid that forms during solidification from the liquid to the solid state during cooling of a casting.



**Surface porosity in a casting. (MSS SP-55)**

# Using VT to Detect Sand Casting Porosity

**Recommendations:** After comparison to the acceptance standards, porosity may be removed by grinding or machining to reach acceptable levels. Liquid penetrant testing is frequently recommended as a complementary NDT method to detect pores too fine to be detected by VT alone. For the same reason, VT may be aided by magnifiers. Radiographic testing may also be used as a complementary method. Ultrasonic testing (UT) is not recommended since round reflectors deflect the sound, preventing adequate reflection for detection. Large grain structure also diffuses the sound, making UT unacceptable for castings.

**Precautions:** Grinding or machining casting surfaces to eliminate initial findings of rejectable porosity may expose more porosity requiring further evaluation. Note that some specifications or standards codify the minimum size to be evaluated. Pores below a certain limit may be ignored as nonrelevant by definition.

# Cold Shuts

**Description**: Found in ferrous and nonferrous cast material.

**Location in Part**: Surface (internal not visible).

**Characteristics/Appearance**: Generally appear as smooth circular indentations on the cast surface and may resemble a drop of metal entrapped in the casting. If interrupted pouring occurs then the resulting surface appearance may resemble a seam.

**Metallurgical Analysis**: Produced during the casting of molten metal. Cold shuts may result from splashing, surging, interrupted pouring, or the meeting of two streams of metal coming from different directions. Cold shuts are also caused by:

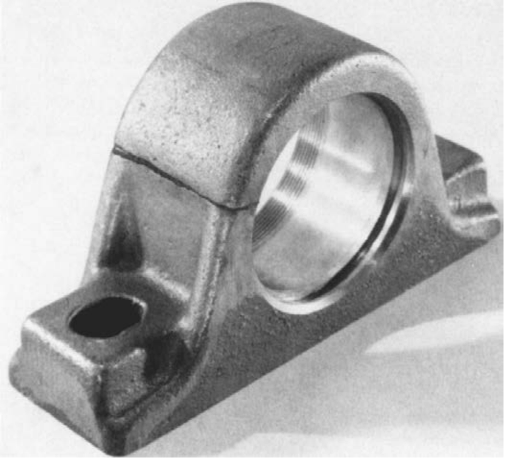
- the solidification of one surface before other metal flows over it;
- the presence of interposing surface films on cold, sluggish metal; or
- any factor that prevents fusion where two surfaces meet.

Cold shuts are more prevalent in castings formed in a mold having several sprues or gates. They are also more prevalent in magnesium castings than aluminum because of the speed with which magnesium sets.

# Using VT to Detect Cold Shuts

**Precautions:** Cold shuts may have two different appearances, circular or linear.

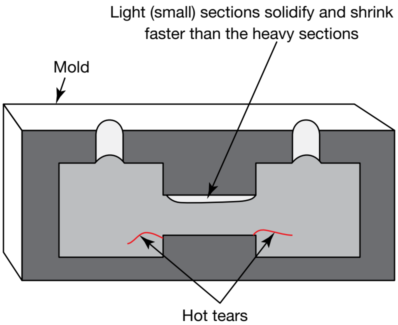
**Limitations:** Location can be determined but often severity cannot.



**Indication of cold shut in a casting, enhanced here with magnetic particles.**

# Hot Tears

**Description**: Found in ferrous and nonferrous castings.




**Schematic of hot tears in a casting. (MSS SP-55)**

**Location in Part**: Visible to the surface and normally found at abrupt change of thickness intersections.

**Characteristics/Appearance**: Hot tears appear as a ragged line of variable width with one or more branches. May occur individually or in groups. They occur at 90° to the longitudinal direction of the stresses between the thick and thin sections.

**Metallurgical Analysis**: Hot tears or cracks are caused by nonuniform cooling, resulting in stresses that rupture the surface of the metal while its temperature is still in the brittle range. Tears may originate where stresses are set up by the more rapid cooling of thin sections that adjoin heavier masses of metal, which are slower to cool.

# Using VT to Detect Hot Tears

**Limitations:** Surface roughness may mask a tight hot tear.

**Recommendations:** Pay special attention to areas where nonuniform cooling can occur (usually at changes of thickness). Supplement with magnetic particle or liquid penetrant testing for confirmation.

**Precautions:** The accompanying photograph shows a horizontal orientation. It is more likely to be vertical or 45° in orientation given the figure's shape.

**Visual appearance of hot tears in a casting.**

# Shrinkage Cavities

**Description**: Found in cast materials, differences in cooling rates after pouring may cause localized microshrinkages. It appears as torn gauze on the surface, that is, a series of micro-tears in the cast metal.

**Location in Part**: Microshrinkage usually appears at the gate of the casting, although it also occurs when molten metal must flow from a thin section into a thicker section of a casting, such as what may occur around slues or gates in the casting.

**Characteristics/Appearance**: Depends on the plane through which the microshrinkage has been cut. Small filamentary voids in the grain boundaries appear as concentrated micro-cracking on the surface of the casting. The appearance varies from a continuous hairline to a massive porous indication.

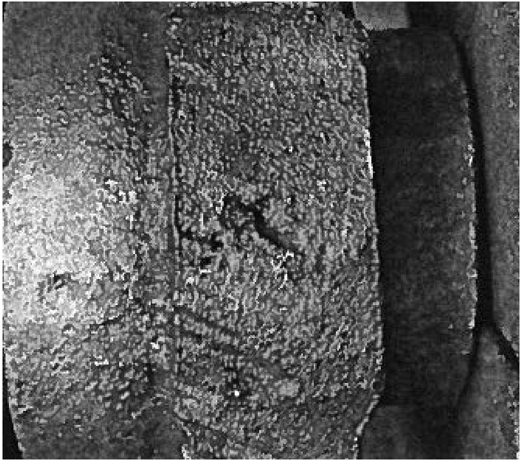
**Metallurgical Analysis**: Shrinkage discontinuities can occur when standard feed metal is not available to compensate for shrinkage as the thick metal solidifies. Found in cast materials, magnesium is especially prone to microshrinkage due to density. Shrinkage cavities are found in ferrous and nonferrous castings. Shrinkage occurs while the metal is in a semi-molten state. If sufficient molten metal cannot flow into different areas, as it cools the shrinkage leaves a void. Microshrinkage is caused by the withdrawal of the low melting point constituent from the grain boundaries.

# Using VT to Detect Shrinkage Cavities

**Limitations:** Microshrinkage is not normally open to the surface. If machining brings the microshrinkage to the surface, it can be detected by VT.

**Recommendations**: Discontinuities like microshrinkage that do not act as stress risers are undesirable, but are judged on the basis of the static test simulating the working loads on the complete part. However, discontinuities that are so aligned as to cause stress concentration warrant immediate cause for rejection.

**Precautions**: VT is useful for initial detection, but it usually supplemented by other methods such as radiographic testing.



**Surface shrinkage in a casting. (MSS SP-55)**

# Scars and Scabs

**Description**: The thin metallic projections with sharp edges are generally parallel to the surface of the casting and have very rough surfaces. They are usually attached to the casting at only a few points and are otherwise loose.

**Location in Part**: Cast surface only. Generally occurs on horizontal or convex surfaces of thin castings.

**Characteristics/Appearance**: Very rough surface. Appears to be “stuck on” the cast surface and not integral even though not removable by mechanical leverage.

**Metallurgical Analysis**: Caused by the expansion of molding or core sand, expansion scabs can occur in ferrous or copper-based castings.

# Using VT to Detect Scars and Scabs

**Limitations:** The depth of the scabs (rolled in material) is undetermined until excavated.

**Recommendations:** Likely a rejectable condition that is not subject to repair.

**Precautions:** Sand is not the cause of this discontinuity. Rather, it is metallurgical.


(a)

(b)

**Scabs: (a) visual appearance of part; and (b) close-up view. (MSS SP-55)**

# Draw Lines

**Description**: Draw lines are longitudinal to the direction of the drawing tension direction.

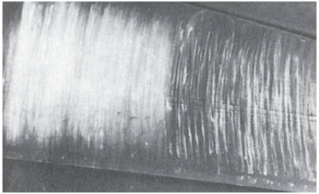
**Location in Part**:

- Only on the surface of the part that had been in contact with the die used for drawing.
- Parallel to the direction of rolling.

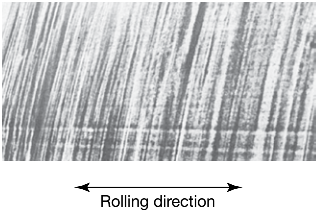
**Characteristics/Appearance**: They have superficial depth and tend to be elongated narrow depressions or barely visible lines.

**Metallurgical Analysis**: Drawing is a metalworking process that uses tensile forces to stretch metal or glass. As the metal is drawn (pulled), it stretches thinner into a desired shape and thickness.

(a)



(b)




**Draw lines are lineal irregularities in surface that develop in drawing. They are parallel to the direction of rolling: (a) first example; (b) second example.**

## Using VT to Detect Draw Lines

**Rationale**: VT is important when the appearance of the specimen is important (parts to be plated, parts near final finish dimension, and so on).

**Recommendations:** Unless the draw lines reduce the cross-sectional thickness of the part substantially, that is, by 5% or more, it is of no consequence. If in doubt, additional measurement should be performed and compared to the minimum material thickness requirement for evaluation.

**Precautions:** Substantial reduction of cross-sectional thickness would normally result in failure during the drawing process and not be visible to the VT inspector.

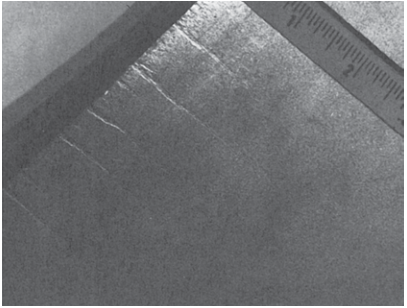
# Edge Cracking

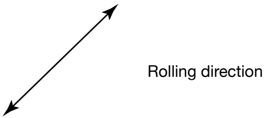
**Description**: The cold edges of rolled steel plate rupture under tensile stress during the rolling process. This is likely due to improper temperatures for adequate ductility to prevent cracking.

**Location in Part**: The edges of the rolled plate.

**Characteristics/Appearance**: The edges of the resulting plate after rolling may have short check marks resulting from the ductile fractures due to compression of the metal.

**Metallurgical Analysis**: Upsetting and rolling a slab or billet into a plate or bar can cause edge cracking perpendicular to the direction of rolling. The tensile pressure at the edge of the plate and at the corner is most likely to cause micro-cracking at the edge.






**Edge cracks (also known as edge breaks) are short creases that extend in varying distances from side edge of temper rolled sheet.**

# Using VT to Detect Edge Cracking

**Advantages:** VT, either direct or remote, is an easy way to detect the surface condition of parts at their edges.

**Limitations:**

- Difficult to detect discontinuities with small crack opening dimensions using VT.
- Difficult to discriminate between scratches, machining marks, and other surface imperfections.

**Recommendations:** Edge cracking needs to be removed by trimming. Detection prior to a welding process is important to prevent possible growth of crack. Ultrasonic testing may be required for locating small dimensional cracks and discriminating between types of imperfection.

**Precautions:** Edge cracking can cause further rupture of the metal product and needs to be removed. Edge cracking could also create a problem in the welding process.

# Laminations

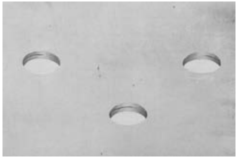
**Description**: Laminations are flattened impurities (nodules of nonmetallic material or oxidized porosity) that are extremely thin. Found in plate, sheet metal, and forgings.

**Location in Part**: Mostly internal. Occasionally observed on edge of plate or end preparation for welding edge of plate.

**Characteristics/Appearance**: Generally aligned parallel to the work surface of the material. May contain a thin film of oxide between surfaces. Found in forged, extruded, and rolled material.

**Metallurgical Analysis**: Laminations are separations or weaknesses that may be the result of elongated pipe, blisters, seams, inclusions, or segregations that are made directional by rolling. This results in weak metal bonds.

(a)


(b)


(c)

**Lamination in rolled plates: (a) visible from end; (b) visible in holes; (c) visible from side.**

## Using VT to Detect Laminations

**Rationale**: Important to detect in weld prep areas, as the welding to be performed does not "cure" the problem of the lamination.

**Advantages:** Easy to access weld bevel areas that have been prepared. Combined with magnetic particle or liquid penetrant testing, detection of lamination is rather successful.

**Limitations**: VT is not capable of detecting laminations unless exposed on the surface of plate or pipe after end preparation ahead of welding. Prewelding fit-up examinations are an opportunity to visually observe laminations in the edge prep. Rarely are they present on a side surface of the plate, as seen in part c of the accompanying figure on page 55.

**Precautions:** Some specifications call for magnetic particle testing of end preparations prior to welding. When found, routing and removal may be required for up to a 0.5 in. (1.27 cm) into the base material. Subsequent repair welding is required. Only then can the original weld activity begin, having thus ensured the inherent discontinuity to the plate will not propagate into the fabrication process weld. Supplemental ultrasonic testing may be needed to determine the full depth or extent of the lamination that is visible on the edge surfaces.

# Secondary Processing Discontinuities

This group of discontinuities is found or produced by forming or fabrication operations including rolling, forging, and welding. VT is recommended for the following secondary processing discontinuities. This list includes VT discontinuities that may be found during testing but are not included in this book.

| Machining Processes | Heat-treating | Anodizing/Pickling/ Acid Etching | Quenching Cracks |
|---|---|---|---|
| • Grinding cracks<br>• Machining tears | • Cracks (lattice cracks, checkerboard)<br>• Discoloration | • Excessive chemical attack<br>• Etching and pickling cracks<br>• Plating cracks | • Intergranular<br>• Any orientation |

# Grinding Cracks

**Description**: Found in ferrous and nonferrous material.

**Location in Part**: Surface. Typically perpendicular to the object surface with sharp crack tips that propagate.

**Characteristics/Appearance**: Very shallow and often forked and sharp at the root. Similar to heat-treat cracks and usually, but not always, occur in groups. Grinding cracks generally occur at right angles to the direction of grinding, although in extreme cases, a complete network of cracks may appear. This pattern is also known as a “checkerboard” pattern. They are found in highly heat-treated parts; chrome-plated, case-hardened, ceramic materials; and weld beads that are subjected to grinding.

**Metallurgical Analysis**: Localized heating of the surface during the grinding of hardened surfaces frequently introduces cracks. The overheating is usually caused by:

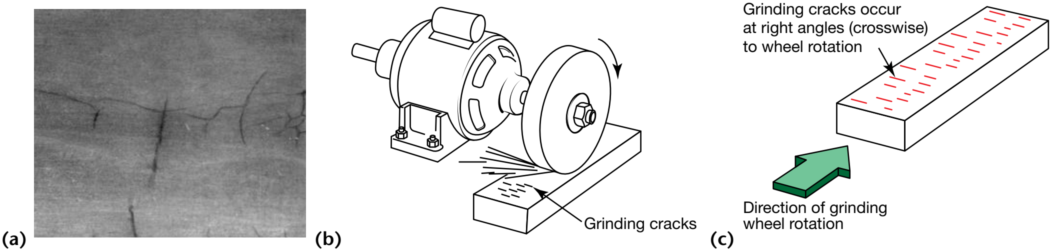
- lack of, or poor, coolant;
- a dull or improperly ground wheel;
- too rapid feed; or
- too heavy cut.

They are critical stress risers that form a potential cause for failure.

# Using VT to Detect Grinding Cracks

**Recommendations:** Auxiliary lighting cast at an angle will produce a crack shadow without glare. A magnifying glass as an aid to direct visual would be helpful. Knowing the grinding wheel direction can be beneficial in differentiating grinding cracks from other discontinuities.

**Precautions:** Grinding cracks are a most difficult discontinuity to observe. Liquid penetrant testing may be necessary to confirm presence and extent. After detection, the repair area needs to be monitored closely so as not to create more grinding cracks in the process.




**Grinding cracks: (a) photograph of grinding cracks in a weld whose crown has been removed; (b) illustration showing the grinding process; (c) illustration showing the effect of excessive grinding.**

# Discoloration

**Description**: Heat-treating (or heat treatment) describes a group of industrial and metalworking processes used to alter the physical, and sometimes chemical, properties of a material. The most common application is metallurgical. Inadvertent overheating during welding of stainless steel can also result in similar discoloration.

**Location in Part**: Surface.

**Characteristics/Appearance**: Discoloration of the steel may occur at locations of heat concentration or over all surfaces if uniform overheating has occurred. Heat-treat discoloration is due to excessive heat-treating of stainless steel. It may leave a telltale blue, green, and black discoloration due to elevated temperatures. In many stainless steel welds the excessive heat may offer a straw-colored band and the blue hues as seen in the weld heat-affected zone in the figure on page 61.

**Metallurgical Analysis**: Stainless steel parts are often heat-treated to anneal (harden) the metal and relieve stress in the parts. While most stainless steels are resistant to oxidation at low temperatures, the various metals in the steel formulation (iron, chromium, molybdenum, and so on) can form oxides at higher temperatures.

# Using VT to Detect Discoloration

**Rationale:** Discoloration is not detrimental to material, per se, but can be an indication of other potential discontinuities.

**Advantages:** Early detection of affected areas using VT can be rectified prior to further processing. VT can be done in comparison with a standard color chart to determine the cause of the discoloration.

**Limitations:** Inspectors with color vision deficiencies can often misidentify this discontinuity.


**Heat-treating discoloration. (Allgaier)**

# Service Discontinuities

This group of discontinuities is related to the various service conditions such as stress corrosion, fatigue, and wear. VT is recommended for the following service discontinuities. This list includes VT discontinuities that may be found during testing but are not included in this book.

| Corrosion | Erosive wear | Fatigue | Mishandling |
|---|---|---|---|
| • General oxidation (rust)<br>• General corrosion/ uniform corrosion<br>• Pitting<br>• Wormhole<br>• Intergranular corrosion cracking (intergranular stress corrosion cracking)<br>• Hydrogen embrittlement<br>• Galvanic corrosion<br>• Crevice corrosion<br>• Hydrogen cracking | • Hydro/fluid<br>• Steam cuts<br>• Cavitation | • Mechanical stress fatigue cracks<br>• Permanent deformation (necking down, bolting)<br>• Thermal stress fatigue cracks | • Tool strikes (chipping hammer and so on)<br>• Service-induced wear (abrasive, erosive, grinding, gouging, adhesive, fretting) |

# General Oxidation and Corrosion

**Description**: General oxidation appears when uniform oxidation occurs at the same rate on the entire surface of a metal. While rust is limited to iron, other metals oxidize with different characteristics. Thinning of the metal cross section reduces the strength and load bearing capabilities.

**Location in Part**: Any metal surface exposed to moisture and oxygen may result in oxidation and should be examined with care.

**Characteristics/Appearance**:

- Rust (iron) appears reddish to orange and has a texture varying between semi-rough to the dust-like coating of iron oxide.
- General oxidation has an overall presence and is defined as wastage of the base material, as opposed to pitting, which is highly localized.
- Aluminum oxidation appears white; copper oxidation appears green.

**Metallurgical Analysis**: There are several forms of rust. Rust consists of hydrated iron oxides or iron oxide-hydroxide. Rust is one type of oxidation process where iron metal and oxygen result in ferric oxide. General oxidation is the taking away of electrons, thus reducing the remaining material cross section or thickness.

**General oxidation. (Allgaier)**

# Using VT to Detect General Oxidation and Corrosion

**Rationale**: VT is often used to monitor oxidation and/or corrosion. It is important to precisely document findings.

**Limitations:** VT is often not performed due to a part's service, thereby in turn limiting the service life of the part.

**Recommendations:** Pay attention to the difference between rust on iron only and oxidation of other materials
(see Characteristics/Appearance on page 63).

**General corrosion of a bolt. (Allgaier)**

**(a)**

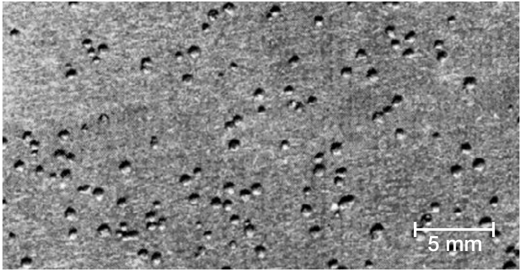
**(b)**

**General corrosion: (a) in a vessel wall; (b) inside surface of boiler tube.**

# Pitting

**Description**: Extremely localized corrosion leads to the creation of small holes or cavities in the metal. These holes may be shallow or deep depending on the duration of the corrosive activity. They may penetrate through walls and result in leakage.

**Location in Part**: Pitting corrosion occurs at a location where the protective coating has been eliminated. It is normally localized and can penetrate the metal rapidly in one area while not affecting some areas adjacent that remain free from corrosion.




(a)

(b)

**Pitting: (a) area with pitting cluster; (b) a single through-wall pit.**

# Pitting (continued)

**Characteristics/Appearance**: Pitting corrosion can form small pits, holes, or cavities from shallow to deep conditions. Pitting can be either hemispherical or cup-shaped. However, it may assume different shapes or multiple pits may form together or in a localized area.

**Metallurgical Analysis**: Localized pitting is the result of a chemical reaction and rapid surface degradation after breaking down of protective oxide films. Any metal that comes into contact with the electrolyte could corrode. The resulting loss of the protective layer may allow local corrosion. High concentration of chlorides such as found in seawater tend to render the protective oxide film less stable, thus opening the metal surface to chemical attack. The location of such chemical attacks can reduce the remaining material cross section or part thickness to the point of through-wall penetration and leakage.

# Using VT to Detect Pitting

**Advantages:** Pitting that has been cleaned and is exposed to the surface can typically be measured under normal lighting conditions using low-power magnification or other optical aids.

**Limitations:**

- Pitting must be visible to the surface.
- Where pitting covers a large surface area, identification of the worst-case pitting is often a lengthy process or ineffective.
- Pitting may be difficult to detect using VT because of narrow surface openings, which are often covered with corrosion products.

**Recommendations:**

- Cleaning with a stiff bristle brush is often sufficient to clean and enlarge pit openings for easier evaluation.
- A plastic grid can be used to more easily determine pitting density.
- *ASTM G46-94: Standard Guide for Examination and Evaluation of Pitting Corrosion* includes a visual chart for rating pitting.

**Precautions:** Prior to VT, avoid cleaning the surface with products that attack the base metal excessively.

# Intergranular Corrosion Cracking

**Description**: Intergranular cracking is a form of corrosive attack that progresses preferentially along grain boundaries. Intergranular cracking is also known as intergranular corrosion, intergranular corrosion cracking, intergranular stress corrosion cracking, intercrystalline corrosion, interdendritic corrosion, and intergranular attack.

**Location in Part**: Intergranular corrosion cracking occurs at the surface where the grain boundaries in corrosion-resistant materials are exposed to corrosive materials. This would be the inside of a pipe joint especially in the heat-affected zone, or the outside of a component or part exposed to the corrosive environment.

**Characteristics/Appearance**: Corrosion between the grains of the metal will follow the grain boundaries. The loss of material between the grains may give it the appearance of splintering wood. Slivers of metal remain while the material between the grains will have corroded away.

**Metallurgical Analysis**: The boundaries of crystallites of the material are more susceptible to corrosion than the individual grains. In nickel alloys and austenitic stainless steels, where chromium is added for corrosion resistance, the mechanism involved is precipitation of chromium carbide at the grain boundaries, resulting in the formation of chromium-depleted zones adjacent to the grain boundaries, thus opening up additional crystalline surface boundaries to chromium depletion.

# Using VT to Detect Intergranular Corrosion Cracking

**Recommendations:** VT can detect the nature but not necessarily the extent of damage. Other NDT methods such as liquid penetrant, magnetic particle, and ultrasonic testing are utilized to enhance detection.

**Limitations:** Intergranular corrosion cracking is difficult to observe with direct unaided VT unless it is gross in nature.

Intergranular corrosion cracking of a chlorinated water valve stem (swimming pool). (Allgaier)


(a)


(b)

Visual appearance of intergranular corrosion cracking: (a) cracking area enhanced by liquid penetrant testing; and (b) magnetic particle testing indications.

# Erosive Wear

**Description**: Erosive wear (or erosion) occurs when particles in a fluid or other carrier slide and roll at relatively high velocity against a surface. Each moving particle contacting the surface cuts a minute particle from the surface. The removal of many particles is called erosion. Erosive wear via cavitation occurs when a bubble implodes close to a fixed surface generating a jet of surrounding liquid or an implosion shock wave striking a solid surface. This causes the solid surface to fragment due to the impact of the shock wave and lose material particles.

**Evidence of erosion by droplets from the nozzle into the tube (internal surface).**

# Erosive Wear (continued)

Two examples of erosion. (Lewis)

# Erosive Wear (continued)

**Location in Part**: Any surface exposed to the solids suspended in fluid flow containing the erosive particles. Junctures where the fluid changes direction are highly susceptible and should be examined with care. Cavitation can be found in any surface exposed to liquids undergoing changes in pressure such as to cause gas to come out of suspension, form bubbles, and then implode back into suspension due to sudden increase in fluid pressure. This may affect the pump casing body by loss of solid particles breaking away on the inside diameter surface.

**Cavitational wear in turbine blades.**

# Erosive Wear (continued)

**Characteristics/Appearance**: A fluid cavity or dishing out appearance is common. This is also known as scalloping. This condition can occur at several locations, typically:

- the heel of an elbow,
- the impingement surface of a "T" joint,
- on the low pressure side of pump impellor vanes (see cavitated turbine blade),
- the downstream side of an obstruction in a pipe, or
- when there is an enlargement of an internal dimensional cavity that allows the liquid to form eddy currents.

These occasions of solid particles suspended in fluid wear against the surfaces, causing the cavity or dished out area on the part, component, or system carrying fluid.

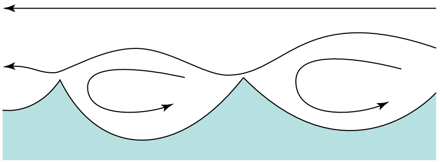
**Metallurgical Analysis**: Minute particles suspended in fluid are driven by flow forces to impinge upon the surface of a material. The combination of pushing force and sliding force will cause abrasion and embrittlement. Cavitation damage is caused by the removal of material due to cracking and pitting caused by high-energy implosions of vacuous cavities in a cavitating liquid.

# Using VT to Detect Erosive Wear

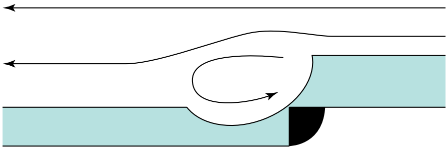
**Limitations:** Impingement areas may not always be easily accessible.

**Recommendations:** Knowing the environment (product flow) helps identify suspect areas. Pay particular attention to the areas of pumps, impellors, fans, steam lines, and nozzles for areas of likely suspended particles impinging upon the part surface. Remote VT by means of borescopes, fiber borescopes, or video borescopes is recommended.

**Precautions:** Direct VT, even aided with a mirror, may not suffice to gain access to affected areas of the component. This is especially true if the pump impellor is left in situ.



(a)



(b)

**Schematic of the flow pattern of a liquid causing erosion: (a) liquid surface; (b) action of liquid on solid component.**

# Mechanical Stress Fatigue Cracks

**Description**: Found in ferrous and nonferrous material subjected to stress. Stress risers combined with cyclic stress can lead to stress fatigue cracks.

**Location in Part**: Surface. Typical locations include cross-sectional change in thickness areas where stress risers can concentrate.

**Characteristics/Appearance**: Cracks range from shallow to very deep and usually follow the grain flow of the material; however, transverse cracks are also possible. Indications of these cracks often appear in a pattern at the area of maximum stress and are easily identified.

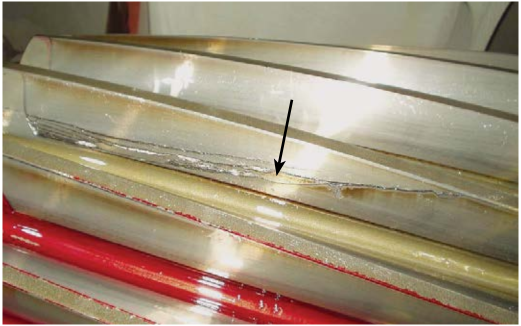
**Metallurgical Analysis**: Mechanical stress is a stress mechanism induced by a cyclically applied stress that is lower in magnitude than the ultimate tensile strength of the material but high enough to initiate a crack or to propagate a preexisting crack.

# Using VT to Detect Mechanical Stress Fatigue Cracks

**Advantages:** VT is a quick, cost-effective method for initial assessment, and can complement other NDT methods for further testing.

**Limitations**: Cannot determine whether additional cracks are propagating below the surface.

**Recommendations:** Magnification is recommended prior to failure and ultimately exceeding the yield point.



**Photograph of cracks in a wind turbine gearbox.**

# Permanent Deformation

**Description**: When a material is placed in tension and stretched past a certain plastic elasticity point it then becomes permanently deformed or necked down.

**Location in Part**: Anywhere in the length of a bolt or other elongated part.

**Characteristics/Appearance**: The cross section of the necked down area is reduced compared to the rest of the part (bolt).

**Metallurgical Analysis**: When bolt is tightened past a certain point (the elastic strain limit), it deforms by stretching, with the result that its diameter is reduced.

# Using VT to Detect Permanent Deformation

**Limitations:** Accessibility is required to ascertain the state of the entire item.

**Recommendations:** This condition is rejectable and requires the bolt to be replaced. Detection is always best before the material exceeds its tensile limits (failure).

**Precautions:** Necking down is most difficult to observe when in situ, especially between two flanges bolted together or between a closure head and cylinder of a pressure vessel.

**Bolt showing deformation (necking down).**

# Thermal Stress Fatigue Cracks

**Description**: Found in ferrous and nonferrous material subjected to stress. Stress combined with a corrosive environment and temperature can create an environment for stress fatigue cracking to occur.

**Location in Part**: Surface. Stress fatigue cracks are not found on parts that have never been placed in service. Stress corrosion cracking (SCC) does not necessarily start from an edge or stress riser.

**Characteristics/Appearance**: Cracks range from shallow to very deep and usually follow the grain flow of the material; however, transverse cracks are also possible. Indications of these cracks often appear in a pattern at the area of maximum stress and are easily identified.

**Metallurgical Analysis**: Three factors are necessary for the phenomenon of stress corrosion to occur: a sustained static tensile stress, the presence of a corrosive environment, and the use of a material susceptible to this type of failure. Stress corrosion fatigue is much more likely to occur at high levels of stress than at low levels. Stresses include residual (internal) as well as those from applied (external) loading. SCC is the growth of crack formation in a corrosive environment. It can lead to unexpected sudden failure of normally ductile metals subjected to a tensile stress, especially at elevated temperature.

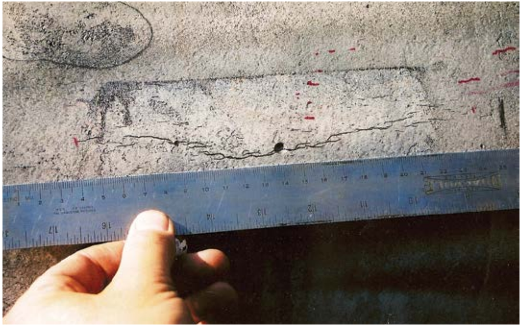
# Using VT to Detect Thermal Stress Fatigue Cracks

**Advantages:** VT is a quick, cost-effective method for initial assessment, and can complement other NDT methods for further testing.

**Limitations**: Cannot determine whether additional cracks are propagating subsurface.

**Recommendations:** Targeting parts or components that have been exposed to high levels of stress at elevated temperature for long periods of time is recommended for the detection of stress fatigue cracking.

**Precautions:** Need to know the history of the part to adequately identify this discontinuity.



**Sample pipeline stress corrosion cracking. (Schraan)**

# Tool Strikes

**Description**: Various mechanical tools are utilized to assist in shaping and finishing parts or components. Often tool strikes are a personnel-induced discontinuity through poor workmanship. Misuse of tools can result in a deformed surfaces taking the shape of the tool used to mark the surface of the part.

**Weld chipping hammer. (Allgaier)**

**Location in Part**: Mishandling marks can be found anywhere the surface of the part is exposed to working processes.

**Characteristics/Appearance**: Permanent deformation of the part will likely appear as a negative impression of the tool utilized to make it, for example: vee-shaped indentations from the chisel end of a weld chipping hammer, the rounded pit for the pointed radius end of the weld chipping hammer, or the rounded indentation from a ball peen hammer. On welded surfaces, tool strikes occur close to the weld.

**Metallurgical Analysis**: Permanently deformed surfaces can create stress risers from which cracks can emanate or create deformed surfaces that disallow the function of the part (threads on a bolt).

# Using VT to Detect Tool Strikes

**Advantages:** Identification of the damaged area may be fairly easy.

**Limitations:** The exact tool used to create the discontinuity is not as easy to detect.

**Recommendations:** Workmanship criteria should be utilized to evaluate the surface condition of parts or products.

**Hammer marks.**

**Mishandling tool strike from a hammer in bolt threads (round edge or ball end of hammer strike could prevent nut travel). (Allgaier)**

# Using VT to Detect Tool Strikes (continued)

**Tool marks from the pointed end of a weld chipping hammer. (Allgaier)**

**Excess needle gun marks. (Vona)**

# Service-induced Wear

**Description**: Wear is the undesired removal of material from contacting surfaces by mechanical action. Wear is usually from the interaction of other components and materials, such as when metal-to-metal contact has repeatedly occurred. Lack of lubrication or poor handling during product movement are the two most often mechanisms to create wear.

**Location in Part**: Wear can occur at any point where contact between two materials may happen.

**Characteristics/Appearance**: Any deterioration of a surface will result in appearances different from the adjacent area not subject to wear. Phonographic grooves may result from circular or radial rubbing or contact. Marring or discoloration may result from limited frictional rubbing of two surfaces.

**Metallurgical Analysis**: The softer of two materials rubbing together will lose the greater material. Wear may be abrasive, erosive, grinding, gouging, adhesive, or fretting in nature. In all cases, loss of material on one or both material surfaces will occur. Other terms for adhesive wear include scoring, scuffing, galling, and seizing. Adhesive wear is the preferred term.

**Part of a rotating machine showing wear (phonographic groove in appearance).**

# Using VT to Detect Service-induced Wear

**Advantages:** VT is a simple and straightforward method for detecting wear, often without the need for equipment.

**Limitations**: Noise levels, inadequate lighting, and an improperly cleaned surface can all affect the inspector's ability to detect wear.

**Recommendations:** Post-wear conditions must be evaluated on a dimensional and functionality basis. Rejection and replacement are typical when repairs are impractical. Addition of materials through welding, cladding, sintering, or the addition of sleeves may be adequate corrective action when excessive wear is detected.

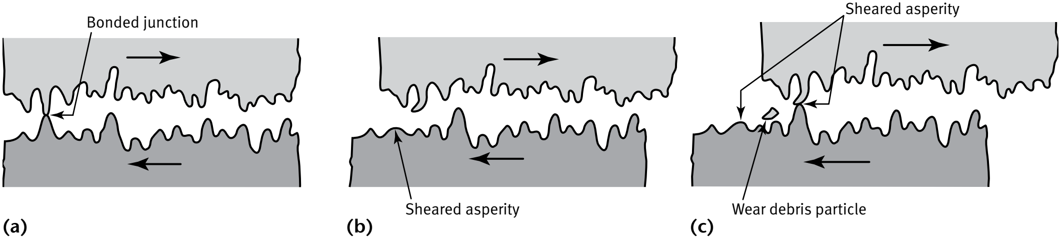



**Illustration of one process by which particle of debris is detached during adhesive wear: (a) bonded junction forms; (b) junction is torn from one peak or asperity; (c) asperity then is sheared off by impact with larger, adjacent peak.**

# Surface Comparators

Surface comparators are used for surface finish recognition by comparing surfaces to be evaluated against known standards. Regardless of the mechanical means to remove material, the resultant pattern on the surface is unique to the method of material removal. In any case, the depth of the groove is represented by a root mean average of deviation from the mean line. This standard deviation is squared and then the square root yields a positive number. This number represents the average distance from the mean line. The smaller the value, the smoother the surface. This value measures (in micro-inches) the average peak and valley variances over the surface of a part. The work piece is then compared to the known sample, that is, the surface comparator, to determine the approximate roughness of the work piece.

**Description**:

## L – Lapping

Lapping is a machining process in which two surfaces are rubbed together with an abrasive between them, by hand movement, or using a machine. Parallel scratches may exist within the width of the lapping tool.

## G – Ground

Grinding is an abrasive machining process in which a spinning wheel covered in rough particles cuts chips of metallic or nonmetallic substance from a work piece, making a face of it flat or smooth. A circular pattern relative to the diameter of the grinding disc will result.

# Surface Comparators (continued)

## BL – Blanchard

The blanchard technique of machining results in especially smooth texture or surface roughness. It is usually achieved by rotary surface grinding which efficiently removes large amounts of stock. Excellent tolerances for flatness and parallelism can be achieved with smoothness up to 63 μm rms. This value is higher for certain materials.

## ST – Shape Turned

Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helix tool path by moving more or less linearly while the work piece rotates. This process is known as lathing or turn shaping.

## M – Milled

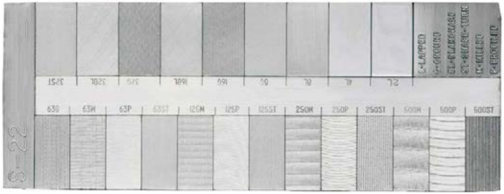
Milling is a form of machining used to remove material and create a variety of features on a part. Features such as holes, slots, pockets, and 3D contours may result. The cutting tool may cut from the end face or long axis of the tool. The grind pattern depends on the size and contour of the cutter.

## P – Profiled

Profiling is an effective technique of eliminating burrs, folds, inclusions, and other abnormalities through electropolishing. This electrolytic process, the opposite of the plating process, is designed to remove metal without smearing or folding. This action produces a smoothing and rounding of the surface profile. The pattern is extremely smooth and not easily detectable.

# How to Use a Surface Roughness (Finish) Comparator

1. Determine the material removal (machining) process that was utilized to give the surface finish under testing.
2. Place the comparator next to the surface to be compared with emphasis on the machining process most likely used.
3. Move the comparator up and down until estimated surface roughness similarity observed. (The larger the number, the rougher the surface in micro-inches.)
4. It is common practice for technicians to drag their fingernail across the standard's surface and the test specimen's surface to detect similar resistance by feel.
5. Record the surface roughness thought to be most similar to the appropriate standard rating. Clarify in report document as smoother than "X" or rougher than "X."



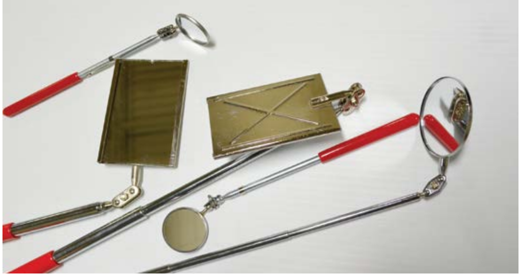

**Surface comparators.**

## Direct VT Versus Remote VT

**Direct Visual Testing (DVT):** a VT technique where there is an uninterrupted optical path from the observer's eye to the test area. This technique can be performed either unaided or aided via mirror, lens, endoscope, or fiber optics. Usually this is defined as less than 24 in. (61 cm) and more than 30° offset from the surface under test.

**Remote Visual Testing (RVT):** VT where there is an interrupted optical path from the observer's eye to the test area. RVT covers the use of photography, video systems, automated systems, and robots. Usually this is defined as more than 61 cm (24 in.) and/or less than 30° offset from the surface under test.

**Magnifying glasses and loupes.**



**Mirrors used in VT.**

# Direct VT Versus Remote VT (continued)

Video borescope in use.

Rigid borescope in use.

Fiber optic borescope in use.

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Magnaflux, C.E. Betz, *Principles of Magnetic Particle Testing*, Chapter 3 Sources of Defects, 1967.

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† AWS should be referred to as the common source for welding discontinuity terminology.

‡ ASTM should be referred to as the common source for terminology for indication (relevant, nonrelevant, recordable, reportable), discontinuity, and defect.

# Figure Sources

**Allgaier:** Michael Allgaier

**Freeman:** Robert Bradley Freeman

**Inspec Testing:** Inspec Testing Inc.

**Lewis:** Oscar Lewis

**MSS SP-55:** Manufacturers Standardization Society *ANSI/MSS SP-55-2011*

**Ravi:** B. Ravi, IIT Bombay

**Sabolik:** Mark Sabolik

**Schraan:** Joel Schraan, Coast to Coast NDE

**Siderius:** S. Siderius, S+S NDT LLC

**Wright:** J.M. Wright

**Vona:** Paul Vona

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# SI Derived Units

| Quantity | Unit | Symbol | Relation to Other SI Units |
|---|---|---|---|
| Capacitance | farad | F | C/V |
| Conductance | siemens | S | A/V |
| Energy | joule | J | N·m |
| Frequency (periodic) | hertz | Hz | 1/s |
| Force | newton | N | kg·m/$s^2$ |
| Inductance | henry | H | Wb/A |
| Electric charge | coulomb | C | A·s |
| Electric potential (electromotive) | volt | V | W/A |
| Electric resistance | ohm | Ω | V/A |
| Magnetic flux | weber | Wb | V·s |
| Magnetic flux density | tesla | T | Wb/$m^2$ |

# SI Derived Units (continued)

| Quantity | Unit | Symbol | Relation to Other SI Units |
|---|---|---|---|
| Plane angle | radian | rad | 1 |
| Power | watt | W | J/s |
| Pressure (stress) | pascal | Pa | $N/m^2$ |
| Solid angle | steradian | sr | 1 |
| Temperature degree | celsius | °C | K |
| Volume | liter | L | $dm^3$ |

# Conversion to SI Units

| Quantity | Non-SI Unit | Multiply by | To Get SI Unit |
|---|---|---|---|
| Angle | minute (min) | $2.908\,882 \times 10^{-4}$ | radian (rad) |
| | degree (deg) | $1.745\,329 \times 10^{-2}$ | radian (rad) |
| Area | square inch ($in.^2$) | 645 | square millimeter ($mm^2$) |
| Distance | angstrom (Å) | 0.1 | nanometer (nm) |
| | inch (in.) | 25.4 | millimeter (mm) |
| Energy | British thermal unit (BTU) | 1.055 | kilojoule (kJ) |
| | calorie (cal), thermochemical | 4.184 | joule (J) |
| Power | British thermal unit per hour (BTU/h) | 0.293 | watt (W) |
| Force | pound force | 4.448 | newton (N) |
| Torque (couple) | foot-pound (ft-lbf) | 1.36 | newton meter (N·m) |

# Conversion to SI Units (continued)

| Quantity | Non-SI Unit | Multiply by | To Get SI Unit |
|---|---|---|---|
| Pressure | pound force per square inch ($lbf/in.^2$) | 6.89 | kilopascal (kPa) |
| Frequency (cycle) | cycle per minute | $60^{-1}$ | hertz (Hz) |
| Mass | pound (lbm) | 0.454 | kilogram (kg) |
| Temperature (increment) | degree fahrenheit (°F) | 0.556 | kelvin (K) or degree celsius (°C) |
| Temperature (scale) | degree fahrenheit (°F) | (°F – 32) ÷ 1.8 | degree celsius (°C) |
| Temperature (scale) | degree fahrenheit (°F) | (°F – 32) ÷ 1.8 + 273.15 | kelvin (K) |