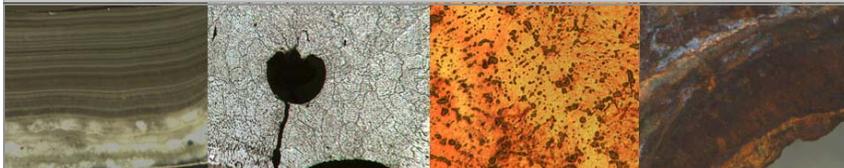


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WELD DISCREPANCIES

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Welcome to New Hampshire Materials Laboratory

Welds are very common within today's society as they are a main part within the steel fabrication industry. These welds can be responsible for holding the majority of the structures we see today together such as bridges, cars, tractors, cranes, buildings, etc. Industries like construction and steel manufacturing can be directly effected by welding flaws whether it be related to safety or a critical part of their operation. This article discusses the various types of welding flaws you may come across along with various methods of detecting them visually verses a destructive route.

Tim Kenney
Laboratory Director

Weld Discrepancies: Revealing Flaws Visually

by Tim Kenney

Quality in the welding process assures the product's structural life and safety. One element critical to a weld quality system is the final examination of the weld. Many fabricators have come to rely on scientific techniques such as radiography or ultrasonic inspection to confirm weld integrity. These high-tech methods have their place, but deficient welds can often be identified through visual inspection.



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Visual weld inspection has the benefits of the following:

1. In house production.
2. Minimal production delays.
3. Immediate feedback to welders and designers.

However, while visual weld inspection can be used to detect indications of subsurface weld problems, it is not conclusive. Additional testing may be required, such as radiography and ultrasonic testing. For effective visual weld inspection, try the following suggestions:

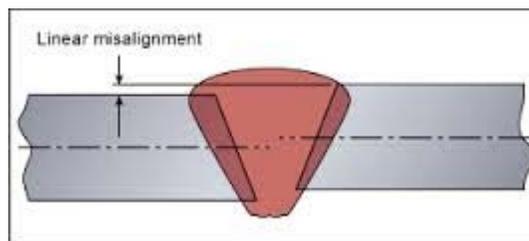
1. Work in a well-lit area.
2. Use a low-power magnifier to help you see subtle variations in the weld surface.
3. Use dental mirrors to examine hard-to-reach areas.
4. Use a borescope to evaluate the back side of tube welds.

Dimensional Discrepancies

Dimensional discrepancies can be found by verifying the structure against drawings or specifications. Defects often include warpage, misalignment, incorrect joint presentation and weld size or profile discrepancies. Even if dimensional discrepancies pass a “fit” check, they can create serious performance problems by introducing stress where little stress is expected.

Centerline mismatch, for example, may create a stress riser which in certain applications could exceed the design strength of the assembly. Likewise, specialized (or forceful) weld fixturing can be used to compensate for imprecise dimensioning. Under these conditions, stress is locked in the weld itself, increasing the potential for weld failure.

Dimensional defects can be avoided by the proper application of fixtures, welding sequences and preforms. Be sure to check the structure specifications before you begin; many document the amount of centerline mismatch which will be tolerated. The best method to eliminate a particular dimensional discrepancy will depend on the size, shape and type of material used in the part. These issues should be addressed with the design or manufacturing engineers.



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Weld Undercut

Weld undercut is characterized by a notch between the weld and the base metal. This undercut notch is likely to be in a stress-sensitive location in the weld. Here, the mechanical properties of the metal have been altered by being in the heat-affected zone (HAZ). When microstructural changes from the base metal's exposure to heat are combined with the reduction in cross-sectional area caused by the notch, the mechanical strength can be dramatically reduced. This is especially critical in applications that involve impact, low-temperature, or fatigue conditions. A weld with an undercut should be repaired (see **Figure 1**).

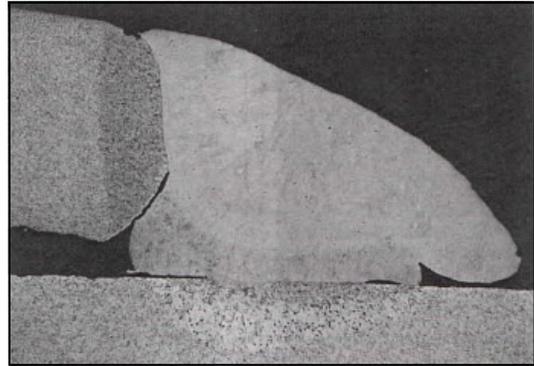


Figure 1

Shown here is a cross section of a weld. Undercut, overlap, and lack of fusion on both legs can be seen.

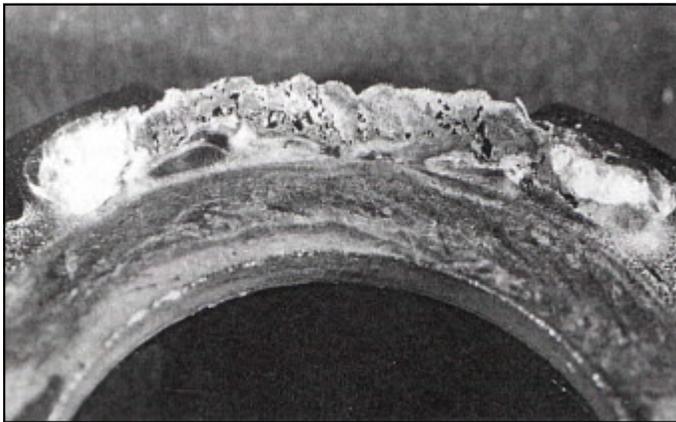


Figure 2

This fractured fillet weld exposed the internal porosity of the weld. This weld was found in a pneumatic tool assembly.

Surface Porosity

Like a weld undercut, surface porosity can often be detected by the eye. Gas bubbles trapped in the weld material cause this porosity. When these bubbles escape and burst at the surface, a rough, crater-like surface porosity results (see **Figure 2**). Surface porosity indicates porosity throughout the weld.

Porosity can be thoroughly examined metallographically by taking a cross section of the weld, polishing the surface, and examining it under a microscope.

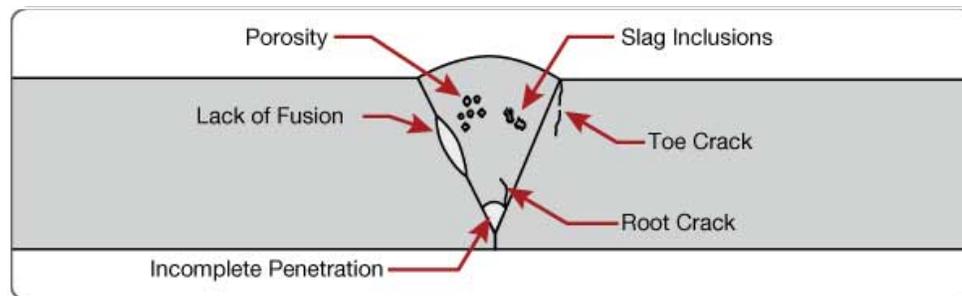
This is described in the American Society of Mechanical Engineers (ASME) Section IX. Under these conditions, a porous weld is distinguished by its "Swiss-cheese" appearance.

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The gas may come from low-quality or gassy metal or from interaction among weld metals. However, it is more commonly caused by oils or rust left on the weld surface. In most cases, minor internal porosity does not significantly affect weld performance; however, surface porosity is a serious condition.

Since almost all fatigue fractures begin at the surface of the metal, anything that interrupts the surface is a fatigue crack nucleation point. This includes the craters created by surface porosity. In addition, excessive porosity can hinder the identification of most significant weld defects, such as undercut and lack of penetration (LOP). Welds with surface porosity should always be replaced.



Slag Inclusions

Like porosity, slag inclusions replace the weld metal with a nonmetallic component. These slag inclusions resemble black shards of glass on the top of the fillet. These solids are lighter than the metal and tend to rise to the surface of the molten metal. If the slag inclusions cannot escape, they become trapped in the weld. The number and size of these inclusions and their distribution determine the impact of the weld strength.

Electrode or flux debris and nonmetallic inclusions from the metal itself produce slag. Slag may also be retained from earlier passes in a multi-pass weld. These entrapped particles reduce the strength of the weld, affecting performance in static and some fatigue conditions by reducing tensile strength and tensile ductility.

Slag inclusions can be introduced to the fusion line in over head and vertical welding. Under these conditions, gravity impedes the ability of the slag to separate from the molten metal. Close attention should be paid to properly working the molten puddle to ensure that the slag surfaces.

The risk of slag inclusions can be reduced by preparing the weld surface. This may include grinding metal protrusions to ensure that no slag is caught in undercuts and gaps. Time should

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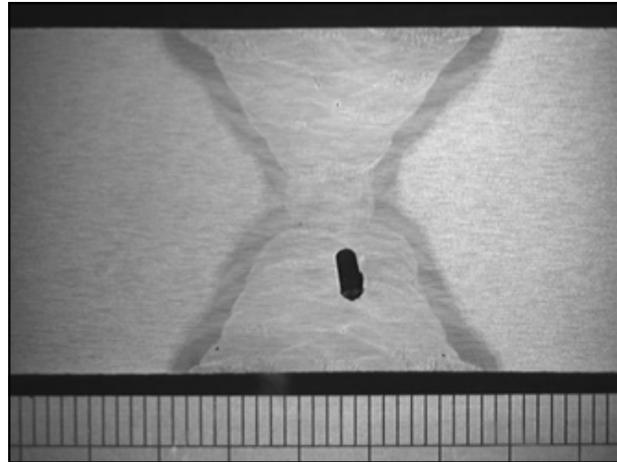


be allowed for the slag to rise to the surface of the molten metal. Rapid solidification is most likely to trap the inclusions.

Flux has a significant influence on the type of foreign materials that may form in the weld. If you find slag inclusions reoccurring, you may want to explore flux alternatives. A more fluid-like flux will enable the slag to reach the surface before it is solidified.

Slag inclusions weaken the weld because of a lack of metal homogeneity. LOP and lack of fusion (LOF) weaken the weld because the metal fails to bond. Where the weld metal does not complete the joint, a gap will remain (LOP).

LOF occurs when the base metal fails to melt or mix with the weld metal. This is often caused by surface oxides, such as rust or scale, which block the penetration of the weld metal. On some alloys, these oxides behave like ceramics, with melting temperatures that exceed the melting temperature of the base metal. Unless these oxides are removed, LOP/LOF become likely. In some cases, these discontinuities can be identified by a small gap between the fillet and the base metal or along the toe edge. LOP and LOF are often masked by the appearance of a solid weld. They can also be hidden by other discontinuities like porosity, overlap, and excessive convexity (see Figure 1).



Cross section of a slag inclusion defect

Nondestructive testing (NDT) methods such as radiography and ultrasonic inspection are most successful in determining the degree of penetration when porosity is present. If porosity is not present, the results of NDT may be less reliable. In most cases, if no visual discrepancies are observed and if proper material preparation and welding practices are used, it is generally assumed that the weld is solid. Fortunately, most design engineers use a “weld efficiency” factor to provide a margin of safety when specifying the weld requirements. This allows some tolerance for potential internal LOP/LOF and other defects that may not be visible. However, observable LOP/LOF reveal a significant problem and usually exceed this margin of safety.

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Weld Cracks

Weld cracks are serious defects that have little margin of safety. The two types of cracking most likely to occur are **hot cracking** (just after the weld has solidified) and **cold cracking** (which occurs near room temperature after the weld has cooled) (see **Figure 3**).

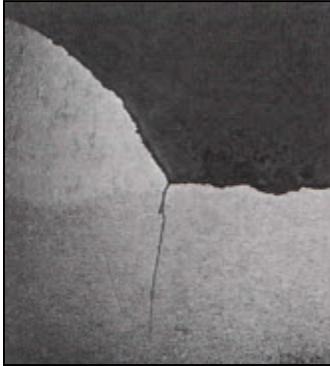


Figure 3

This structure suffered a toe crack. Notice the slight color shift (microstructure change) in the HAZ of the weld.

Most weld cracks are caused by hot cracking, with the weld being pulled apart during cool-down. Microscopic fissures can develop under low strain conditions in certain steels as a result of physical changes in the microstructure of the metal. If the configuration of the part does not allow the weld area to contract as it cools, the hot cracking becomes likely. If the width-to-depth ratio in the weld cross section is too high, edge cooling can pull the bead apart, causing centerline cracking.

Hot cracking is common when high phosphorus, sulfur, or lead content is present in the base metal. Chromium steels are particularly sensitive to microcracking, but this can be helped with appropriate preheating procedures

As a result of high strain, hot cracks will usually develop in the weld metal or the HAZ of the base metal. Under a microscope, these cracks are seen as intergranular fractures with a crystalline or grainy appearance. These cracks tend to be more open than hydrogen embrittlement cracks (see cold cracking). Methods to control or eliminate hot cracking are usually detailed in work instructions or weld procedures. Variables such as the type of alloy or type of weld can affect the weld sequence and the part's susceptibility to cracking.

In general, microcracking is less of a problem in metals that show good elongation in tensile tests. If you work with certified materials, be sure the elongation measurements of the lot meet or exceed the elongation specification for the type/grade of material. This ensures that the material has the ductility to withstand the welding and some strain. If you do not use certified materials, consider testing the sample to see if the weld performance is what the design engineer expected. Weld two pieces of metal together and secure one end in a vise. Bend the other end over to see how far it will bend before the metal cracks. If you know how a good metal performs in this test, you will be able to detect a bad one.

Unlike hot cracking, which occurs right away, cold cracking can occur in the weld metal (or the HAZ of hardenable steels) hours or days after welding. A single visual part inspection

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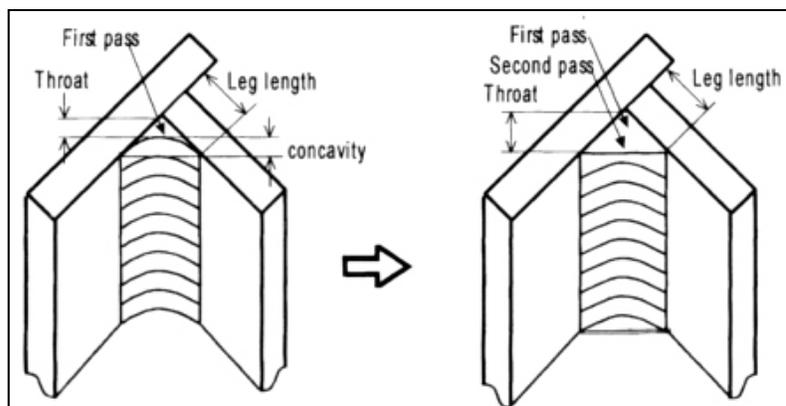


made directly after a weld may not be adequate to detect cold cracking.

The most damaging form of cold cracking is hydrogen embrittlement, which occurs when hydrogen is absorbed into the metal. Hydrogen embrittlement is usually associated with rust and dirt that has accumulated on the weld surface or from using a damp electrode. This embrittlement is extremely harmful in alloy steels, and it often happens in carbon steels. Structures suffering from hydrogen embrittlement lose their toughness and often fail. If you suspect hydrogen embrittlement, especially if porosity is present in an alloy steel, invest in a metallographic examination of a weld sample. This test can either confirm the integrity of your welds or help you to address a weld cracking problem.

Insufficient Throat

Insufficient throat reduces mechanical weld strength. The structure can fail under both static and dynamic (fatigue) loads. A profile with a notched center is especially susceptible to fatigue failure from the increased stress in the notch. All weld repairs should be approved by the engineer responsible for the design. However, in most cases, an insufficient throat with a centerline notch can be repaired by laying another weld bead to fill it in. Be sure the surface is properly prepared for this new metal. Failure to clean the notch may result in weld porosity or other weld discontinuities.

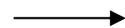


This illustration represents a concave bead with the first weld causing an insufficient throat. To solve this problem, two-layer welding is recommended as depicted in the following figure.

Insufficient Leg

Insufficient leg reduces the static and dynamic strength of the weld. As with an insufficient throat, the weld may be too small to meet service strength requirements. This profile can often be repaired with an additional pass.

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Excessive Convexity

The opposite of insufficient throat is excessive convexity, which is distinguished by a thick, rounded fillet. Often, this convexity has a sharp approach into the toe of the weld (angles greater than 45 degrees). In some cases, the weld material can approach at nearly a perpendicular angle. This sharp edge creates a stress riser that may initiate fatigue failure of the part (see **Figure 4**).

In butt welds, this extra metal creates a stiff spot. This stiffness may cause a failure in dynamic (fatigue) conditions. The rounded weld shape creates stress risers at the toe of the weld. If the toe is too sharp, it may be necessary to grind and redo the weld. If the angle into the base metal is shallow, engineering may permit the excess material to be removed to reduce the effect of the stiff spot.

In convex welds, LOF and bead edge cracking cannot be detected by nondestructive X-ray examination. This fillet must be removed and replaced by a proper fillet to ensure adequate NDT sensitivity at the joint. If the approach to the toe of the weld is acceptable to engineering, there may be little need to address the convexity.

It is important to remember that fillet welds are designed to handle stress; therefore, the stress introduced by excessive convexity may be tolerable. On the other hand, the butt weld may not have been designed for a stress concentration. The weld convexity may induce a stress concentration that cannot be accommodated by the design, and it may encroach on the actual design strength of the assembly.

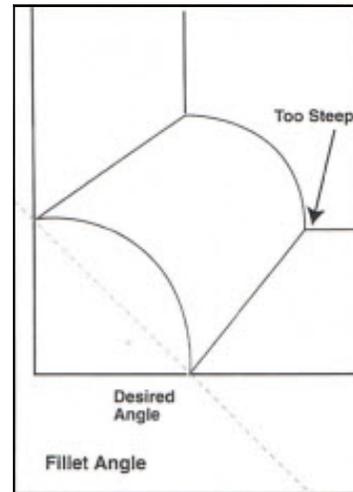


Figure 4

This illustrates the desired angle as compared to a weld with a sharp angle of approach.

Overlap

Like convexity, overlap is a condition in which the weld metal extends beyond where it belongs. Overlap is often found in welds that are under-filled because the molten metal seems to fall off the base metal. Overlap is often a symptom of LOP/LOF. This profile creates a crevice, which may act as a stress riser and an area for crack initiation. In the long run, this crevice can collect moisture and corrosives, which may result in premature failure as seen in

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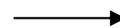




Figure 5

This sample is cross-sectioned and also shown in Figure 1. The rusted areas along the toe of the weld are overlap. The white marks outline where a material sample would be taken.

Figure 5. Unfortunately, overlap can also mask the detection of other defects. X-ray examination may be unable to detect cracks under the bead. In most cases, the weld must be replaced.

Standing Seam Welds

Unlike butt and fillet welds, **standing seam welds** have unique profiles. These welds are found on small and mid-size tanks and in structural applications such as fabricated “I” beams formed out of channels with top and bottom caps. They are subject to several types of profile discrepancies, which can all be detected by visual inspection.

A **thin flat bead** does not have the normal convex shape of a sound weld bead. This may be the result of poor preparation (such as poor fit-up) or poor technique (such as moving too fast with a MIG torch). This lack of material weakens the weld. It may not be able to withstand normal operating stresses (see **Figure 6**). Thin flat beads on thick sections can often be repaired by adding more metal. However, since standing seam welds are used in pressure-sensitive applications and weld access is usually good, it often makes sense to replace the weld completely.

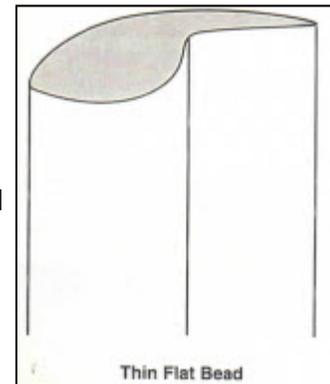


Figure 6

This illustration represents the general appearance of a thin flat bead.

The process of visual inspection requires that the weld be reviewed for discrepancies after it is finished. This examination is best performed by an experienced welder or one who has been trained in detecting subtle discrepancies. The most demanding part of the process is making the commitment to inspect.

The **centerline groove** is the result of a poor fit-up of the weld members. It is often caused by the members being too far apart. The weld must bridge them together. IF the weld is wider than normal,

To Be Continued on Page 10



the centerline groove creates a weak spot in the weld. Welds with this profile often fail under an excessive static pressure condition (see **Figure 7**).

Summary

Visual inspection needs good lighting, low-power magnification, a dental mirror, possibly a borescope, and a conscientious attitude on the part of the examiner. Of the greatest value is prompt feedback to the welder to recognize good work and enhance quality in the future. Additionally, weld rejection during visual inspection avoids added expense down the road.

The techniques and issues surrounding weld inspection are broad. If you suspect a problem, check it out. It is always better to err on the side of caution. Many resources are available for more information. Start with your resident engineers. Contact your welding equipment suppliers or the American Welding Society (AWS). Certified welding inspectors are available to help you, and nondestructive and destructive weld testing services are available from reputable laboratories throughout the country. The routine confirmation of welds and practices will help you ensure a safe, reliable product is reaching your customer.

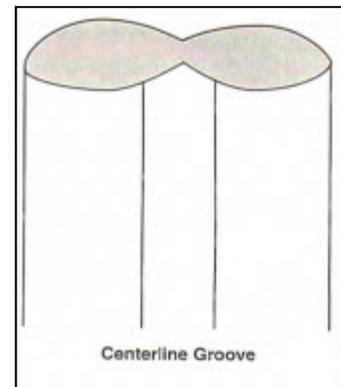
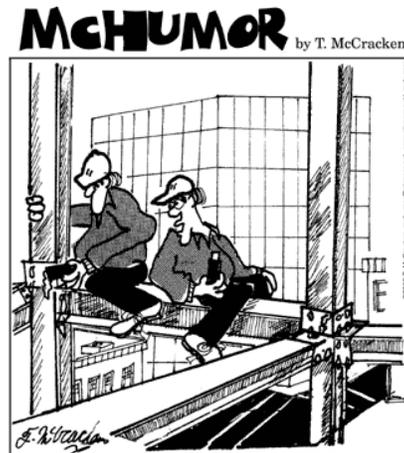
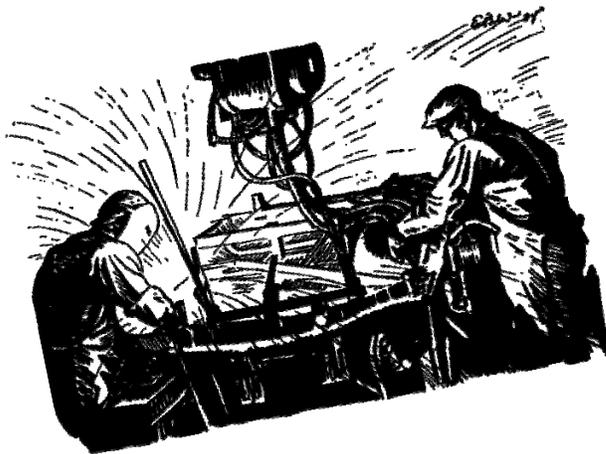


Figure 7

This illustration represents the appearance of a standing seam weld with a centerline groove.



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