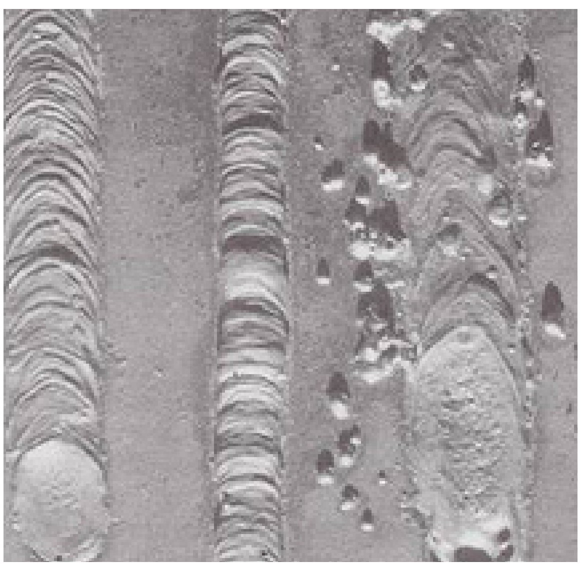

# Weld Defects and How to Avoid Them

Although welding is a straightforward process, metal is a dynamic material, so you can expect many twists and turns along the way. Your work pieces will expand when heated. The grain structure may weaken and cause brittleness. And the metal's shape may deform, causing cracks that will spread over time and potentially break the weld.



**The Good, the Bad and the Ugly - Welding beads along a practice plate illustrate what can go wrong when a welder uses inproper technique, incorrect machine settings, or the wrong consumeables.**

Needless to say, such grisly possibilities keep inspectors on their toes and engineers lying awake deep into the night wondering if their designs correctly anticipated everything that might go wrong.

Low-carbon (*aka* mild) steel is widely used for structural work, since it's more likely to retain its ductility when overheated than other metals. Even if you quench it in water too quickly, it manages (most of the time) to survive the shock of the sudden chill. But life is not so breezy for aluminum, cast iron, titanium, stainless or high-carbon steels.

In addition to brittleness, other common weld defects like cracks, porosity, lack of penetration and distortion can compromise the strength of the base metal, as well as the integrity of the weld.

Consequently, codes and standards developed by the American Welding Society specify exactly how a joint must look when the job is completed. Depending on the application, other groups may have a say in the project, such as the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), and the American Society for Nondestructive Testing (ASNT). Simply put, when the codes are followed, events like the failure of gusset plates along the I-35 bridge in Minneapolis in 2007 might not have occurred, causing the structure to collapse. Even more deadly was the collapse of two skywalks at the Hyatt Regency Hotel in Kansas City in 1981, which claimed 114 lives. (See photos below.)

Code specs for welding address the finished shape, dimensions and extent of any anomalies in the finished weld. A single crack is considered a defect, automatically failing an inspection. However, other problems, known as ***discontinuities,*** may be minute enough to escape the heavy hand of justice. What's acceptable to the inspector is spelled out in the code.

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**The skywalk collapse in Kansas City was attributed to engineering design mistakes excaserbated by further changes made on site during construction. The welds and other fasteners failed to sustain the weight of people crowding onto the walks during a tea dance.**

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In the photo below, you find a relatively uniform weld with good tie-in, a slighly convex face and no spatter, craters or other visible defects. Creating welds like this requires practice, the right machine settings, and an understanding of how metals react to heat, oxidation and other impurities.

**Welding aluminum is more difficult than other metals, since the metal is sensitive to heat. Aluminum also has a propensity to develop a hard oxidized crust on its surface. (In fact, it's so hard, this oxide is the basis of sand paper and grinding discs.) TIG and MIG welding are the processes most often used for aluminum.**

To master code welding, you should also get on a first-name basis with the defects that cause welds to be rejected. Keep in mind that most problems you'll encounter have a single cause and solution. Moreover, that cause may have nothing to do with your ability to lay down a welding bead. Instead, the culprit may be traced to one of the following:

- poor joint design or fit-up
- incorrect settings or a machine deficiency
- wrong shielding gas or flow rate
- inadequate pre or post-heat treatment
- using the wrong (or a defective) rod /wire
- a hot or cold ambient temperature, high humidity, or other atmospheric condition

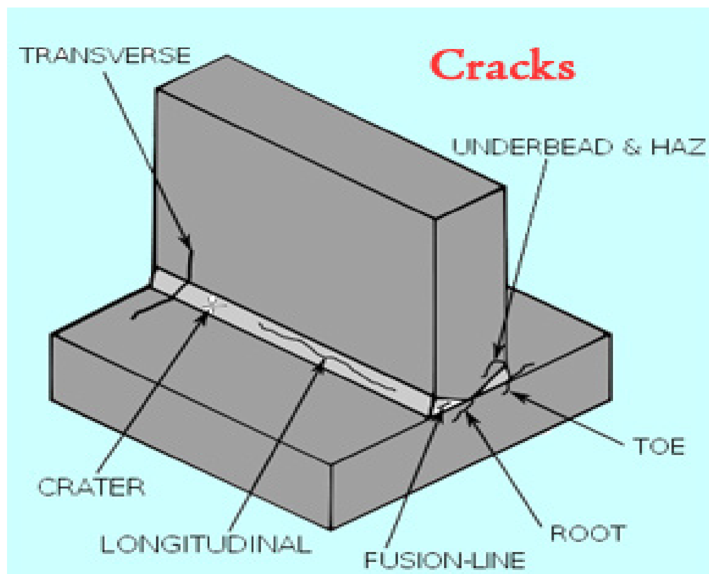
As you acquire proficiency with various welding processes and work materials, you'll learn to troubleshoot these variables and make quick adjustments. Until then, be sure to stop welding as soon as you notice something's wrong. Consult with a fellow worker, supervisor or your instructor before resuming work. Remember, the more heat you apply to metal, the more its molecular or chemical structure becomes compromised. Do-overs should therefore be avoided whenever possible.

## Cracks

No matter how small, every crack is considered a defect, and it takes just one to fail a weld inspection. That's because over time a crack has the potential to become the next Grand Canyon. And unlike carpentry, you can't just fill the gap with a little glue and sawdust. Cracks must be ground out with a file or grinder, and then a new weld performed. Here are four common types to watch for:

**hot cracking** - This crack appears soon after welding, usually inside the weld, as a result of something called ***hot shortness***. Poor fit-up or design may be responsible, but the presence of sulphur in the base or weld metal can likewise cause problems, as can different rates of cooling within the weld. Often, the crack forms along the axis (center) of the joint as the two sides pull apart.

**cold crack** - This doesn't show up at first, but within a day or so of welding. It's induced by hydrogen absorbed into the weld via the weld puddle.




**Different classifications of cracks in welding. "HAZ" refers to the "heat-affected zone", an area of the base metal altered chemically by the heat of a weld.**

Hydrogen may be present due to moisture seeping into an electrode prior to welding. In stick welding, it's important to keep low-hydrogen rods in an oven until they're needed. Another cause for a cold crack is base metal contamination, so be sure to clean off any millscale, grease, water or other soiling of the metal before starting to weld.

**microfissure** - This is more of a future scenario that unfolds during the life of the weld. It can be generated by a seismic disturbance, metal fatigue or stresses in the heat-affected zone (HAZ). Low hydrogen electrodes and wire were developed specifically to limit the occurrence of microfissures. Heat treatment of welds can also minimize the risk.



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**crater crack** - This crack may develop whenever a welder neglects to backfill a crater left behind when welding stops. It's standard practice to weld a little past the end of the joint, or to go backwards and weld over the top to prevent a crater.  Tack welds and previous stopping points should be melted and rewelded before proceeding forward along a joint.

Needless to say, proper fit-up and tack welding are essential to achieving crack-free welds. When two sides of a joint are unevenly or widely separated, never assume the gap can be eliminated by adding extra weld metal. To reiterate, metal is a much different animal than wood. It expands when heated, making it difficult to compensate here and there for sides that don't fit together well. Even though the joint might look OK immediately after you weld it, more often than not your work plates will reassume their original orientation once the weld cools. Like people, metal has a memory.  To avoid cracks:

• Spend the necessary time grinding, cleaning, filing and/or deburring the edges of the plates so they easily fit together .
• Preheat both sides of the joint (if necessary).
• Clamp and/or tack your plates together.
• Before welding, test your machine settings to see if you have the right amount of heat dialed up.

**Porosity in welds leads to cracks, sometimes visible, sometimes not.  Certified welding inspectors often find these little holes in X-rays and ultrasound testing.**

## Porosity

Porosity is the technical term for gas bubbles. These develop inside or on the face of welds because metal in a molten state is highly vulnerable to impurities entering the mix. For this reason, some form of shielding gas (or dry flux ingredients in rods) are used in most welding processes. Porosity is usually caused by one of the following:

• The flow meter setting on the shielding gas tank is too high.
• You're using the wrong gas mixture or rod/wire.
• The weld puddle is contaminated due to unclean metal, surface moisture or contact between dissimilar metals.
• Your welding travel speed is too fast, not allowing enough time for the shielding gas or flux ingredients to do their job.
• A breeze or draft is blowing the gas away from the weld puddle.

Oxygen and hydrogen are the two big enemies of welders. Oxidized surfaces - which appear as rust, corrosion or millscale in ferrous metals - should be removed from all weldable areas just prior to welding (and not the day before). Remember, water is composed of two parts hydrogen, one part oxygen. Once the hydrogen gets inside metal, it can create a condition known as ***hydrogen embrittlement***.

A clogged gas nozzle on a MIG welding gun can also prevent shielding gas from reaching the weld puddle, so be sure to clean the orifice often. In stick welding, electrodes should be stored away from any source of moisture. In particular, low hydrogen rods like E7018 must be placed in a rod oven set to 250 degrees F, a the box containing them has been opened. (Don't heat other types of rods, however, as this will cause their outer coating to crumble.)

In MIG welding, always check the flowmeter setting before starting your first weld, and make sure the gas mixture (argon, $CO2$, etc.) is the right one for your application.

**GoWelding.com**

**This weld lacks both penetration into the base metal and fusion with either side.  Thus, it won't serve its purpose of providing a solid, lasting connection between the two plates.**

## Lack of Penetration and Fusion

Depending on the joint, you may have to weld all the way down to the bottom or your plates to achieve what's known as Complete Joint Penetration (CJP). Most fillet welds, on the other hand, require only Partial Joint Penetration (PJP). Either way, you'll have to set your welding machine so there's sufficient voltage and current to get the job done.

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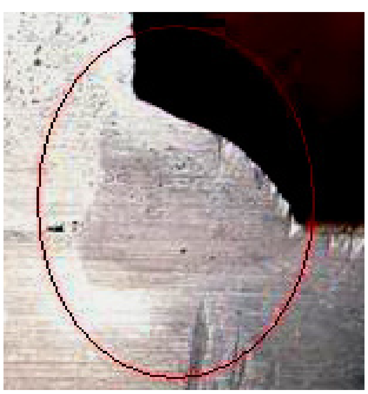
A weld bead that simply rides the surface of the base metal is easy to spot because it looks like a bullet train. Deep penetration is only achieved when there's enough heat to melt the base metal. For thicker metals, a beveled groove is typically cut or ground on either side of the joint to create a wider pocket. The welder then performs multiple passes, methodically filling the space so no gap is left behind. Too fast a travel speed, or holding your torch too high above the joint, will limit penetration. (Heat-sensitive metals such as aluminum and stainless steel require more fine tuning of the machine than carbon steel. Switching the current polarity may also be necessary.)

**There's no penetration or fusion here with the bottom plate. On the standing plate, you see uneven penetration and a gap at the bottom.**

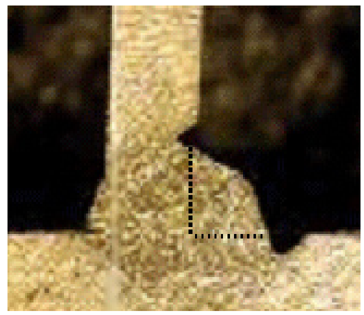
***Fusion*** refers to tying the borders of the weld to the base metal so that there's no dividing line. This requires more time and attention for groove welds with an open root, since there's a lot of space there to fill. Any gap will produce cracks. The cracks will eventually expand and result in leaks (in the case of pipe) or detachment and inability to support a load (in the case of structural steel).



**In this weld, a much better job is done penetrating and fusing the sides of the base metal. The weld's face is slightly convex, which is generally preferred over a flat or concave shape.**

To fuse the sides of a joint, a welder must pause briefly on each side while depositing the weld metal. After pausing, you must move quickly across the center of the joint to avoid piling up weld metal in that area. The sides of joints are prone to undercutting because metal edges melt faster than areas where heat can be conducted away in any direction. So pausing is needed to prevent gaps from forming. In a typical weld, a flat or slightly convex bead is deposited with good tie-in at the toes on either side of the joint.

In stick welding mild steel, E6010 or 6011 electrodes are the standard rods used, because they're designed for deep penetration. The welder then switches to another rod type, often a low-hydrogen E7018 for the filler and cap passes.



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**The toes of this weld are badly undercut. This is-caused by the welder not pausing long enough on each side of the weld as he proceeds along the joint. This weld also penetrated clear through the standing plate, which suggests that too much heat (or current) was applied to the plates.**

## Undercutting

As noted earlier, failure to get good tie-in with both toes of a weld can result in undercutting. That's because metal melts faster at its edges than in the middle. On a T-joint, like the one shown above, the standing plate is most often welded on its edge, where it's more susceptible to meltthrough. Since the bottom plate is welded at the middle, it makes sense to focus more heat on it as you move along the joint. Many entry-level welders forget this basic rule of thumb about how metal responds to heat.

You can also undercut the toe on the bottom plate by not spending enough time welding on that side of the joint. So in addition to focusing more heat on it, be sure to manipulate your electrode laterally, pausing on each toe, so the weld puddle covers both

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**Correct side-to-side movement insures fusion with the base metal on each welding pass. When you reach the final pass (cap), make sure the weld puddle reaches and covers either toe.**

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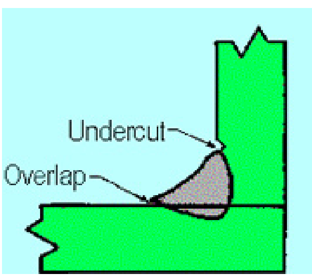
those edges of the joint. This is an essential skill to master, as it will come up repeatedly in almost every type of welding assignment you undertake.

## Overlap

This is the opposite extreme from undercutting. Here, the weld metal flows across the base metal at the toe without producing any fusion between the two. This may be caused by insufficient heat to melt the base metal, and/or improper manipulation of the electrode. Make sure your torch work angle is correct when pausing on each side; otherwise the heat won't be directed at the toes.

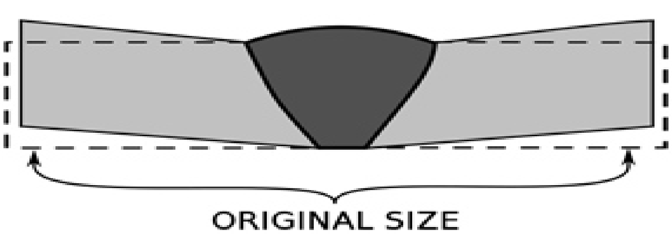



**Whereas too much heat causes undercut, too little creates overlap, where two separate layers of metal are left behind along the toe. Welding to code requires thorough fusion with the base metal.**

## Distortion

Because metal expands when heated, then shrinks after cooling, the two sides of a joint may shift position in the course of welding. That's why tacking and/or the use of clamps is an integral part of many weld operations. Stainless steel is especially prone to movement.

On groove or other multi-pass welds, the two base plates may likewise start to shrink and fold in the direction of the joint, regardless of tacks or clamps. Control of heat (i.e. correct machine settings, a brisk travel speed, etc.) will help prevent distortion.




**Multiple weld passes will cause the work piece to fold inward towards the face of the weld unless clamped into place. Sometimes you can pre-position your plates with a little tilt in the opposite direction to compensate for the anticipated shrinkage.**

Changing the sequence of welds, or the location of the joint, or making fewer passes, can also help reduce the risk.

On occasion, you may decide to start your first weld with the plates slightly tipped away from the direction you expect them to fold. That should make up for the inevitable bending inward. As a rule, the bigger the weld, and the smaller the plates, the greater the chance for shrinkage, twisting or warping.

When prevention doesn't work, try a post-heat treatment to relax any thermally-induced distortion. Sometimes you can get the plates to bend back to the way they were. And sometimes you can't.

## Spatter, Arc Strikes and Other Surface Disruptions

When welding to meet code requirements, maintaining an unblemished surface on your work plates or pipe is critical. Even a single burr left behind after grinding can interfere with a mechanical assembly or catch another worker's clothes or skin and cause injury. (Burrs can also block the flow of weld metal during a welding operation.)

A dent in the metal left by a wayward arc strike could be the start of a transverse crack. So always strike your arcs inside the joint ahead of your weld, or on the edge of your work plates, or in another area that can be ground or removed later.

Spatter describes the bits of molten metal that are sent flying up out a weld when using an arc welding process. This material hardens into little balls that affix to the surface of your weld plates. In stick welding, spatter is caused by excessive voltage or too long an arc. In MIG welding, too high a setting on the wirefeed will generate the same result. In some cases, you can grind or sand off any blemishes on metal surfaces before calling over the inspector. For other jobs, you can only use hand files and brushes to dress up the metal.

Discoloration around welds is common and not usually considered a defect. However, with more heat-sensitive metals like aluminum and stainless steel, excessive discoloration in the HAZ may indicate that the metal has been overheated. This can alter its mechanical properties or chemical composition. If this is the case, grinding off the color won't eliminate the problem. Consult with a supervisor or instructor on how to correctly resolve this issue.

*- Rosemary Regello*