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Root Opening Considerations for Fillet Welds

The challenges and risks associated with the fillet weld root region are demonstrated

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When designed, fabricated, and inspected properly, fillet welds have been demonstrated to be an economical alternative to other welded joint types or mechanically fastened connections in many applications. That being said, this joint type does have challenges and risks that are unique to it. In this article, we cover the challenges and risks associated with the fillet weld root region.

Not Too Much, Not Too Little

There are two phenomena associated with the root gap, or *root opening* in official American Welding Society terminology, at the fillet weld root region that can cause undesirable weld performance. First, a root opening that is excessively large can cause reduced strength and accelerate in-service degradation. This occurs due to a reduction of metal at two key possible failure planes in the fillet. An illustration of a root opening and the two most common failure planes, the effective throat and leg length, are illustrated in Fig. 1. A plane with a reduced area means there is less fillet weld metal available at the key location in the weld to transmit loads and load cycles from one member to the other. The weaker plane will depend on the joint geometry and strength of the base vs. weld metal. An example of an actual fillet weld with a failure through the fillet throat is shown in Fig. 2.

In the authors' experience, failures due to an excess opening are rare in practice; however, when it does happen, it is often in situations where the fillet weld joins plates or members that are connected at a skewed angle. When problems occur, it is usually because the skew geometry's implications on the required fillet weld size were missed, either during design or fabrication. Usually, either the plate or member wall faying surface should have been beveled to be parallel with the mating surface on the other member, or the weld size should have been increased on the obtuse angle side, but for some reason, these options were missed. The result is that the fillet weld on the obtuse angle side can have a much smaller effective throat and leg

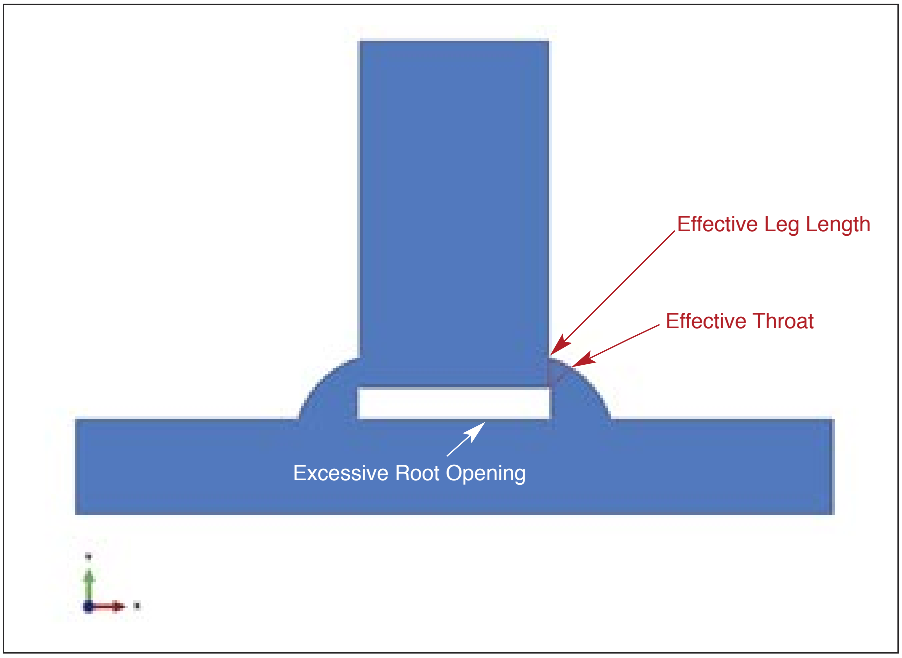

Fig. 1 — Illustration of a fillet weld cross section with excessive root opening.

length than what was needed. An example is illustrated in Fig. 3.

The second issue associated with the opening is the other extreme where no opening is present when welding begins (i.e., the plate or member surfaces are parallel and in contact before welding begins). When no opening is present, it, in combination with other factors, can cause solidification cracking, sometimes referred to as weld metal hot cracking. A root crack is illustrated in Fig. 4.

In high-restraint situations, such as when the deposited weld bead is a small fraction of the base metal thickness and the opposite side of the joint has already been welded, or the weldment is rigidly fixtured, virtually all of the shrinkage strains from solidification and cooling are forced to occur in the weld metal. This increases the risk of weld metal hot cracking. The risk is further increased if one or both base metal members are carbon, low-alloy, or stainless steels containing more sulfur than is permitted by present-day specifications or when the base metal surface is contaminated with a sulfur-containing substance. Often, the cracking is easily detected when it traverses the entire fillet weld throat, but when the crack extends only partway through the throat, it can be very difficult to detect and is often missed unless destructive testing is used. This can be somewhat of a non-intuitive trend since smaller cracks are almost always thought to have less long-term integrity risks vs. larger cracks for the same weld geometry.

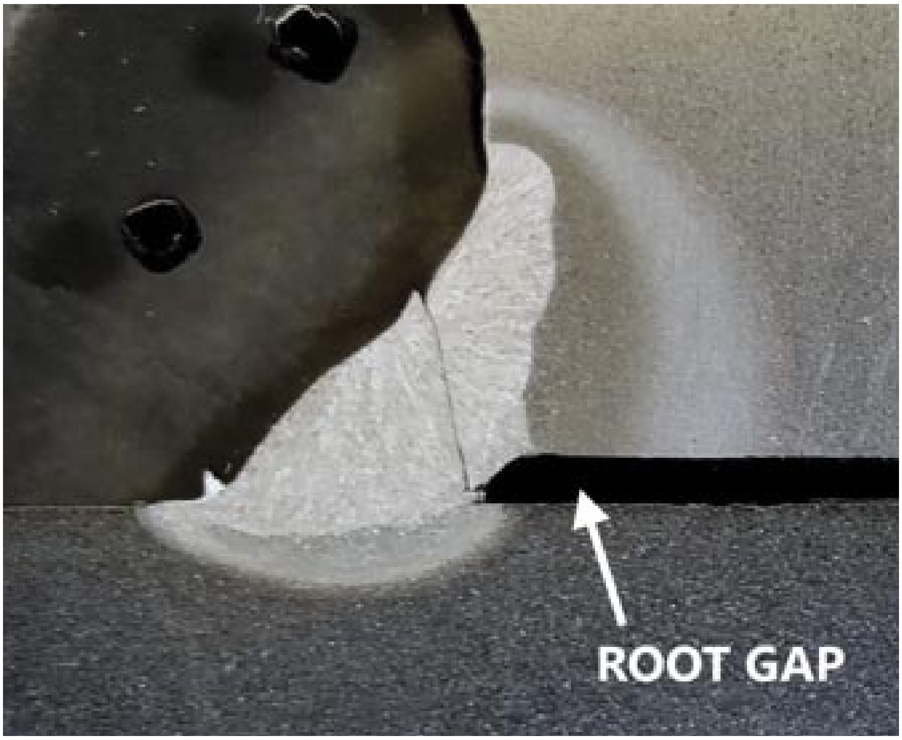

Fig. 2 — Example of a fillet weld with a crack.

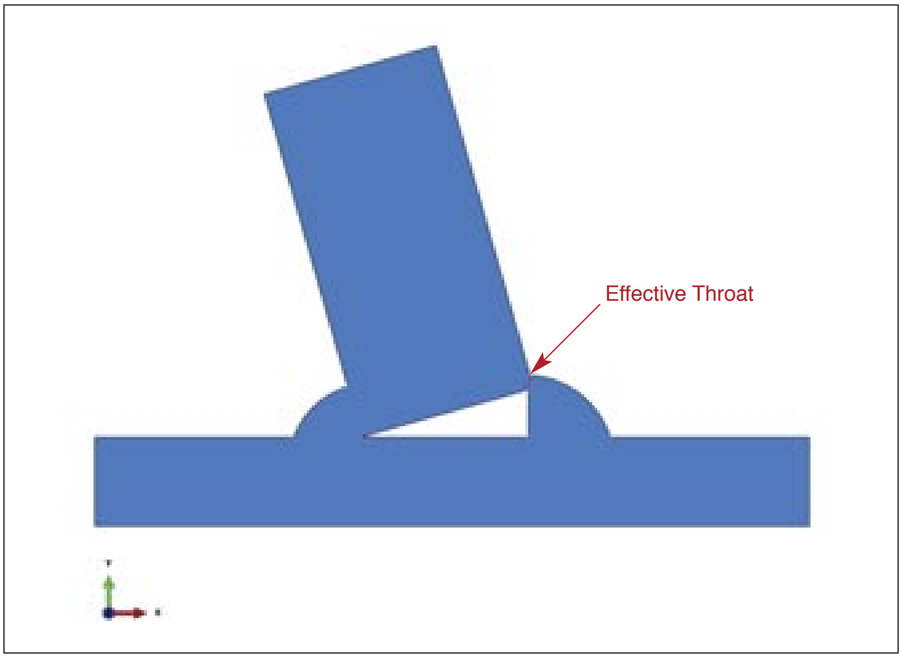

Fig. 3 — Illustration of an improper fillet weld at skewed joint.

Best Practices

To control the negative effects of an overly large root opening, welding codes and proprietary practices typically include a maximum allowed gap. In some applications and industries, if the opening is larger than the specified limit, the welder is permitted to increase the fillet weld size beyond its specified value to compensate for the opening. There is usually an upper limit on the extra amount that the fillet weld can be built up in these cases. In the remainder of the applications, no resizing of the fillet weld is allowed, and the only allowable corrective action is to reduce the opening before welding the joint. The degree to which an inspector monitors and measures the fillet weld opening before fitup also can vary appreciably by industry and application.

Once the fillet weld is deposited, for the most common joint geometries, the opportunity for measuring the opening is limited to the space adjacent to the fillet welds. However, for the joint geometries where the fillet welds cover the entire perimeter of a plate or other member, it is usually no longer possible to directly measure the opening.

For the scenario of no root opening (i.e., the base metal faying surfaces are fit tightly against each other), or negli-

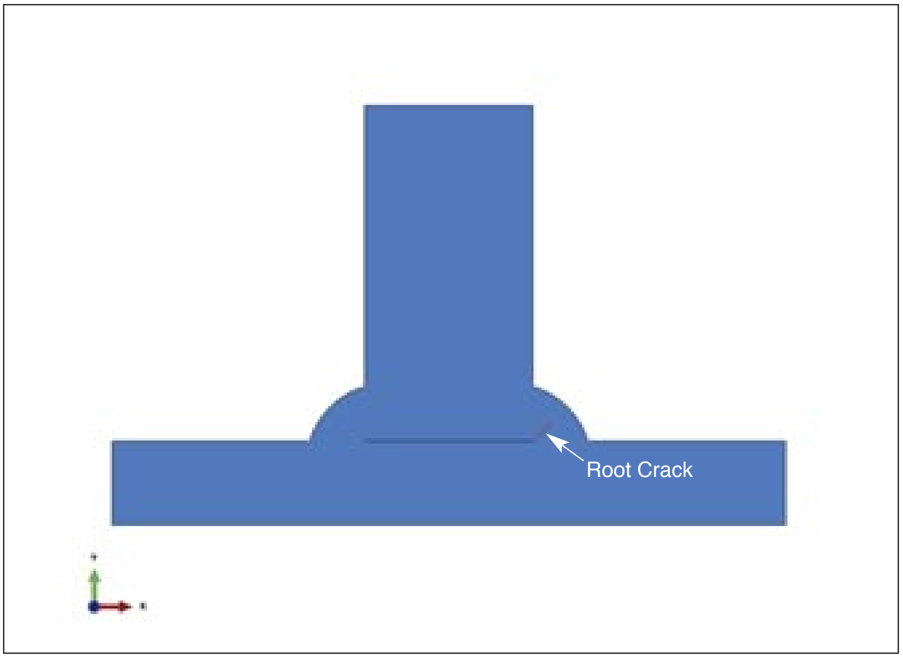

Fig. 4 — Illustration of a root crack where no opening is present.

gible root opening, avoiding problems is usually more dependent on welder craftsmanship and experience. In the authors' experience, it would be rare for a project specification to explicitly define a minimum allowable opening and rare for an inspector to be explicitly required to measure it.

Future Research and Development Needs

Imagine a project scenario in which hundreds or even thousands of fillet-welded connections have been fabricated, and then subsequent creditable doubts are raised as to whether the root opening exceeded maximum allowable tolerances. This, in turn, raises questions about the fillet welds' strength, fatigue resistance, or both. Imagine a second scenario where late in the project root cracks spanning only part of the throat were found. And similar to the first scenario, questions are raised about the previous welds that are the same or similar.

In the authors' experience, such situations, while relatively rare, occur in the real world. Sometimes this is because one fillet weld fails prematurely in service, exposing the undesirable characteristics. Other times, an inspector somehow detects the issue near the end of a fabrication project, which upon further investigation eventually leads to creditable questions being raised as to whether unacceptable welds were missed earlier in the project. When completed welded joints of various types are called into question, part of the investigation often includes a new round of nondestructive examination (NDE). However, when questions about the fillet weld root region are raised, both conventional NDE methods and the relatively new proprietary methods offer limited or no help. In these types of situations, it would be ideal if an NDE method could provide an in-situ gap measurement for any position along the length of the fillet weld and another method that could delineate small root cracks emanating from the gap region. To the authors' knowledge, unfortunately, no such methods exist for accurate broad general use. This would appear to be an unrealized opportunity for a new NDE method or repurposing of an existing method. Only time will tell if such a method comes to market. Certainly, any claim that such a method has been discovered would need to be backed up by a robust blind test program.

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