Design File

Consider Penetration When Determining Fillet Weld Size

Practical Ideas for the Design Professional by Duane K. Miller, Sc.D., P.E.

Introduction

A flat-faced, equal-legged fillet weld in a 90° T-joint has a theoretical throat dimension of 0.707 ω, where ω is the leg size (Figure 1). This assumes fusion is achieved to the root of the joint, but not necessarily beyond that point.

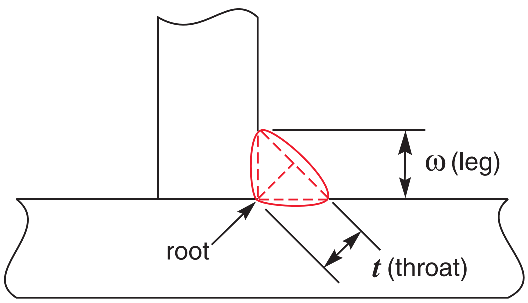

Figure 1. Fillet weld dimensions

When the welding process and procedure achieve a depth of penetration beyond the root, then the effective throat dimension is increased for fillet welds with equal leg sizes. The effective throat dimension, t_{eff}, is then equal to the theoretical throat, t_{th}, plus some additional value due to penetration (Figure 2). Therefore, if penetration beyond the root is achieved, the leg size can be reduced and the same weld strength can be achieved. This reduces the required quantity of filler metal and, if the penetration fillet weld can be made at the same or higher travel speeds, welding costs can be reduced.

It is possible for the designer to use this increase in throat size due to penetration when sizing welds, but the effort must be coordinated with manufacturing. If a consistent depth of penetration can be obtained, then leg size can be reduced without sacrificing weld strength. There are several practical issues that must be addressed, however, such as applicable welding code provisions, penetration capability and consistency through process and procedure control, geometric effects, and metallurgical characteristics. It is not always practicable to utilize this concept; however, engineers should consider penetration when determining fillet weld size.

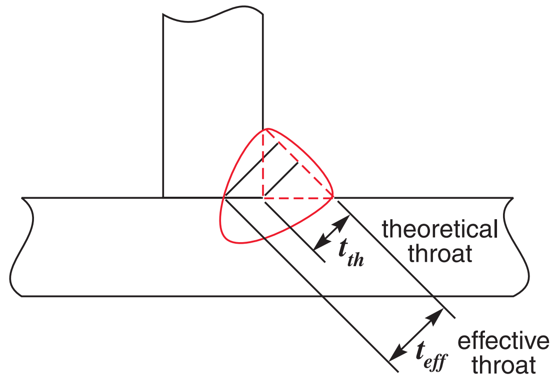

Figure 2. Effective throat dimension with significant penetration.

What Do the Codes Say?

Currently, the *AWS D1.1-98 Structural Welding Code – Steel and the AASHTO/AWS D1.5-96 Bridge Welding Code* do not account for penetration when determining fillet weld sizes. However, several codes do have provisions permitting reduced fillet weld sizes.

In general terms, the AISC LRFD specification permits consideration of penetration when sizing fillet welds made by submerged arc welding (SAW), while the other codes listed below all permit consideration of penetration when the welding procedure is qualified by test, regardless of which process is used.

Code	Application
AISC LRFD	Buildings and other structures
AWS D14.1-85	Industrial mill cranes and other material handling equipment
AWS D14.2-86	Metal cutting machine tool weldments
AWS D14.3-94	Earth moving and construction equipment

Table 1. Codes permitting reduced fillet weld sizes due to penetration.

Specifically, section 8 of AISC LRFD reads as follows:

> "The effective area of a fillet weld $A\omega$ is the product of the effective length of the fillet weld times the effective throat thickness of the fillet weld. Except for fillet welds made with the SAW process, the effective throat thickness of the fillet weld is 0.707ω, where ω is the weld size. The deep penetration of fillet welds made by the SAW process is recognized in the LRFD Specification Section J2.2a wherein the effective throat thickness is considered to be equal to the weld size for 3/8-in. and smaller welds, and equal to the effective throat thickness plus 0.11 in. for fillet weld sizes over 3/8 in."

For example, assume a weld throat of 0.45 in (11 mm) is required. A standard 5/8 in (16 mm) fillet weld will achieve this result. According to AISC LRFD, if SAW is used, a fillet weld with a leg of 1/2 in (13 mm) could be used, resulting in a throat of 1/2 in (0.707) + 0.11 = 0.46 in (12 mm). The volume of weld metal required would decrease from 0.195 in^3/linear in (125 mm^3/linear mm) to 0.125 in^3/linear in (80 mm^3/linear mm), resulting in a 56% savings. However, the savings will often be even more significant with fillet welds under 3/8 in (10 mm) where the effective throat is considered to equal the leg size.

Other codes do not restrict this concept to SAW, or to particular weld sizes. For example, *AWS D14.1-85*, Table 5, footnote (b) states that

> "The intent of this table is not to establish the arc welding processes that provide deep penetration, but rather, to establish the typical allowable decrease of fillet weld size, provided the manufacturer can demonstrate that the required effective throat can be obtained by the qualified welding procedure in accordance with Section 7."

AWS D14.2-86, section 4.4.2, stipulates:

> "No allowance for penetration into the plate surfaces at the root of a fillet weld shall be made when computing the effective throat, except when sectioned test pieces show that the welding procedure gives penetration $\geq$ 3/32 in. (2.4 mm) beyond the root of the joint. Then the effective throat may be considered to extend from the root of the weld to the face of the weld ..."

AWS D14.3-94, paragraph 2.3.1.1, reads as follows:

> "Design values based on depth of penetration or effective throat, or both, which are beyond the root of the joint shall only be used when the values have been determined from a significant number of cross-sectioned samples which reflect the range of materials, material thickness, and welding conditions."

All four specifications imply that some restrictions on the use of this concept are warranted to ensure repeatable results. Regardless of code treatment, the principle is sound, but control of welding conditions is essential.

Practical Considerations

Consistency is a must. To make this approach work "off the drawing board" and in the shop, there must be tight controls over all the variables which affect penetration. Some of these include:

- Welding procedures
- Electrode placement, which can be influenced by the helical nature of coiled electrodes
- Fitup and alignment
- Welding position
- Polarity
- Electrode diameter
- Current and current density
- Voltage
- Wire feed speed
- Travel speed
- Preheat and interpass temperature

Traditionally, this principle has been applied to SAW, but other welding processes, such as FCAW-g and GMAW, are capable of achieving this penetration too (see Figure 3). Two GMAW weld samples in Figure 3 reveal the potential for significant penetration. Also, it must be noted that SAW

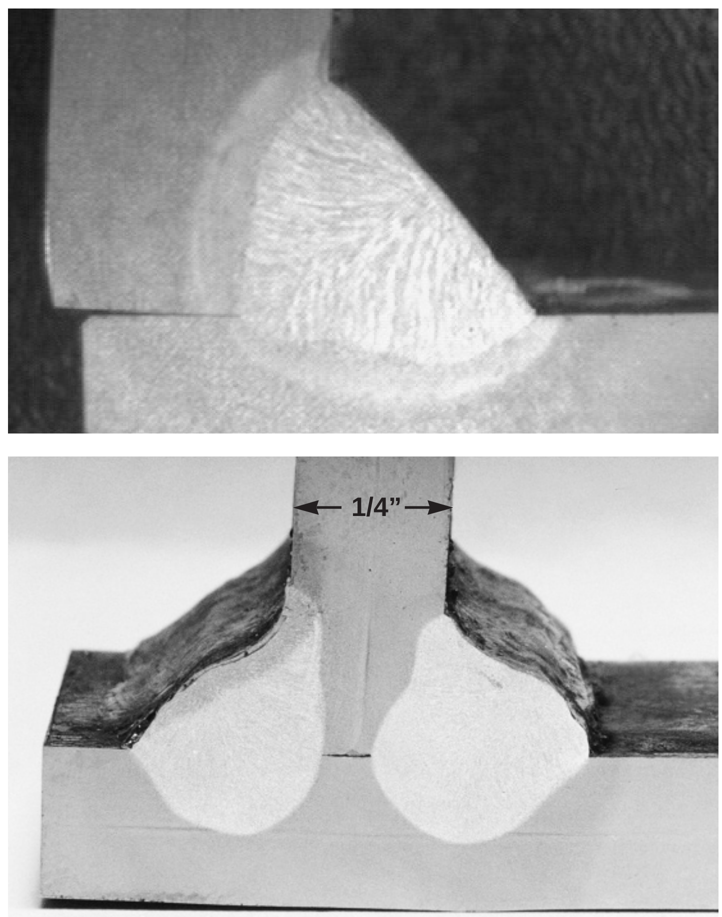

Figure 3. Penetration beyond the root is not limited to SAW, but can be achieved with other processes such as GMAW shown here.

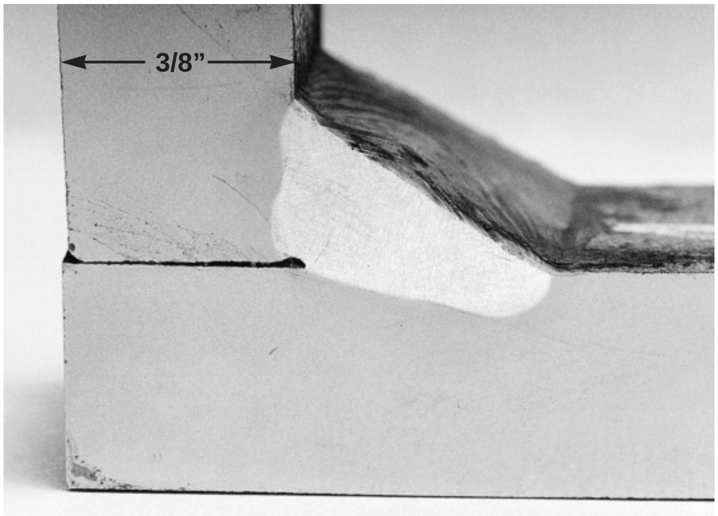

Figure 4. The use of SAW does not guarantee penetration beyond the root.

does not always achieve this penetration as revealed in Figure 4. Although this is an unequal-legged fillet, notice that there is no penetration beyond the root.

Some applications lend themselves to this approach more readily than others. For example, penetration can be optimized where high currents are employed, high current densities are used, and fitup is consistent, and where welding operations are easily controlled. However, if a hand-held, semi-automatic SAW fillet weld is made with DC– polarity and a long stickout, penetration beyond the root may not be consistently achieved.

Caution Regarding Width-to-Depth Ratio

A balance must be maintained between the depth of penetration and the width of the root pass. As penetration increases, the width-to-depth (w/d) ratio becomes more critical. In order to help prevent centerline cracking, the w/d ratio should exceed 1.2 (see Figure 5).

Caution Regarding Metallurgical Issues

Admixture can pose problems when penetration is increased. As the base metal is melted and combined with the welding electrode, elements such as carbon, copper, sulfur and phosphorus can enter into the liquid weld pool from the base metal. Since these elements have lower solidification temperatures, they are often pushed to the center of the weld. While the reminder of the weld is solidified, these low melting point materials can remain in the joint and contribute to unacceptable cracking. More rigorous control of the base metal chemistry may be warranted when deep penetration is desired.

Recommendations

The possibility of lowering welding costs by reducing fillet weld sizes due to penetration beyond the root should be considered in some situations. When the weldment is to be fabricated with high currents, high current densities, consistent fitup and alignment, automated welding operations and controlled procedures, then it may be a candidate for this approach. Under less controlled conditions, however, the designer should not rely on penetration for calculating weld strength or determining weld sizes.

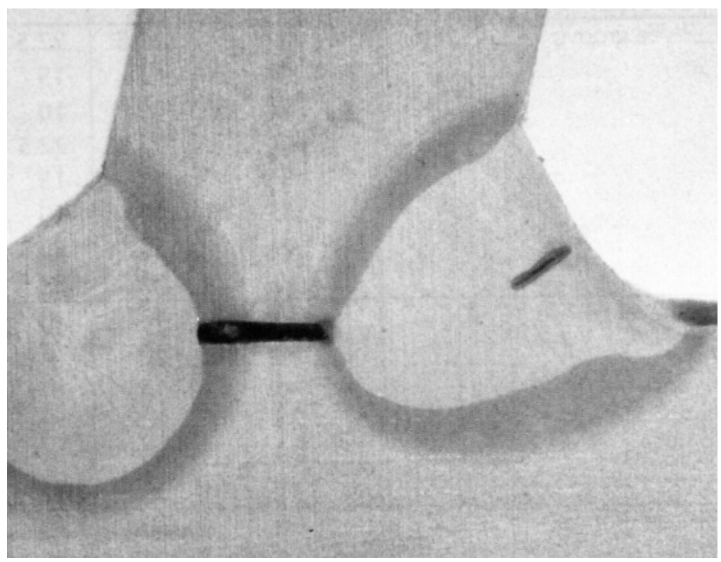

Figure 5. A weld that cracked due to an insufficient width-to-depth ratio.