



Welding Technology Institute of Australia

TGN-RT-05

**A Guide for the Welding, Assessment
and Inspection of
Fillet and Tee Butt Welds**

1. Introduction

Fillet welds are the predominant arc welded joint in Australia. They are straightforward to inspect and, because they are incomplete penetration welds, they are easy to weld. Tee Butt welds are complete penetration welds where full strength is achieved by complete penetration of the vertical member. In addition to fillet welds and tee butt welds a third category of Deep Penetration fillet welds is available. Known as Compound welds, these achieve full strength (but not necessarily complete penetration) by a combination of fillet weld and butt weld. It is important to be able to differentiate between these weld types as shown in Figure 1.

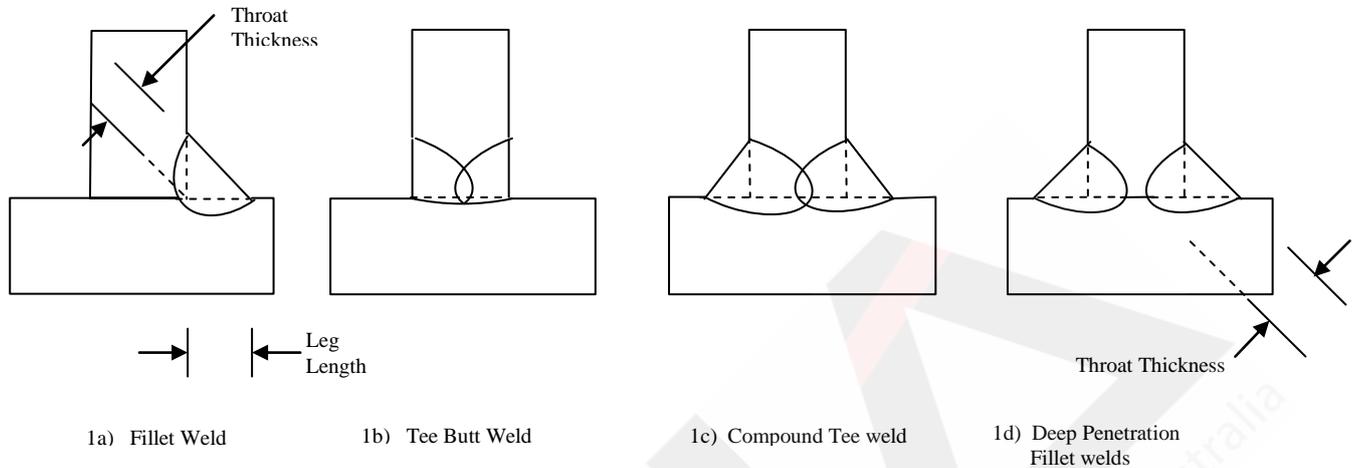


Figure 1 – Fillet, Tee Butt, Compound and Deep Penetration Fillet Welds

- Fillet Weld – Incomplete Penetration, generally not a full strength weld
- Tee Butt Weld – Complete Penetration full strength weld
- Compound Tee Weld – more than strong enough
- Deep Penetration Fillet – Incomplete Penetration (generally) full strength weld

2. Structural Integrity

The load bearing capacity of a fillet weld is based on its throat thickness depicted in Figure 1(a). Indeed in some countries the size of a fillet weld is given in terms of throat thickness. In Australia the size of a fillet weld is given in terms of leg length. For an equal leg length fillet weld,

$$\text{Throat Thickness} = \text{Leg length} / 1.41 = 0.71 \times \text{Leg Length}$$

Even though fillet welds are incomplete penetration welds they can be designed to provide full strength load bearing capacity. Two fillet welds are required each with leg lengths at least 70% of the thickness of the vertical member (total 141%). Such welds are relatively large so they are seldom used. Generally, when full strength welds are required, tee butt welds or deep penetration welding techniques are used. Those methods reduce the weld volume needed, Figures 1(b) and 1(d). AS/NZS 1554 *Structural steel welding - Welding of steel structures* only allows the design to take advantage of this extra strength if the welding is fully automatic.

3. Measurement of Fillet Leg Length

The size of the fillet leg length is the side of the largest triangle which can be inscribed inside the fillet weld. Generally this is a right angle triangle. This triangle is reduced in size if there is a root gap (See Figure 2).

Special tools are available to measure fillet leg length (and throat thickness) although an engineers ruler and straight edge can also be used. Fillet welds made with manual or semi-automatic welding methods will vary somewhat from the design leg length. For a nominal leg length of x mm, expect leg length measurements to vary locally from $x - 1$ to $x + 1$ mm. However 90% of measurements should be at least equal to x . Automated and mechanized welding systems provide more consistent leg length dimensions. The welding specification (eg AS 1554.1) will have specific requirements for the size tolerance of fillet welds.

When checking leg length of concave welds, use an appropriate gauge as in Fig 3d.

4. Pre-weld check

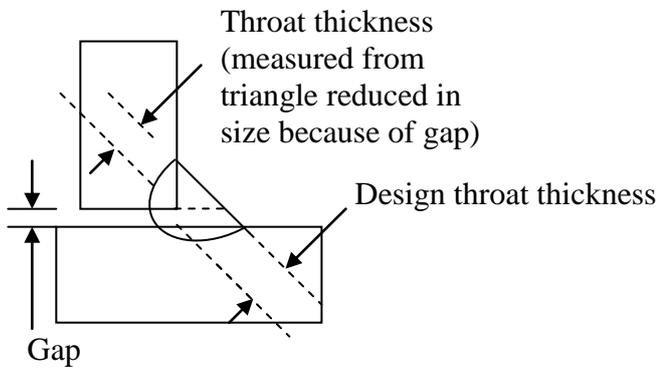


Fig 2a – Effect of gap on throat thickness

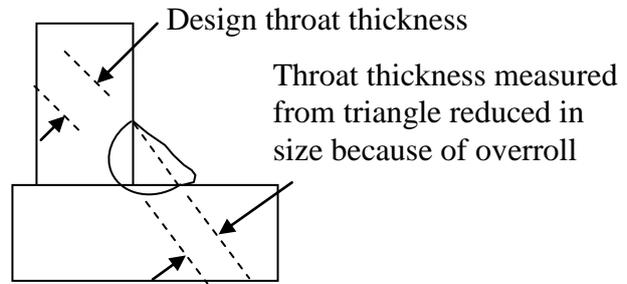


Fig 2b Effect of overroll on throat thickness

Any gap between the two parts to be joined effectively reduces the throat thickness of the weld and the load bearing capacity, Figure 2. Most codes have limits on the maximum gap permissible for fillet welds. Note that the gap is not apparent when checking the leg length of a completed fillet weld. It is thus important to ensure control of gap is maintained during fabrication.

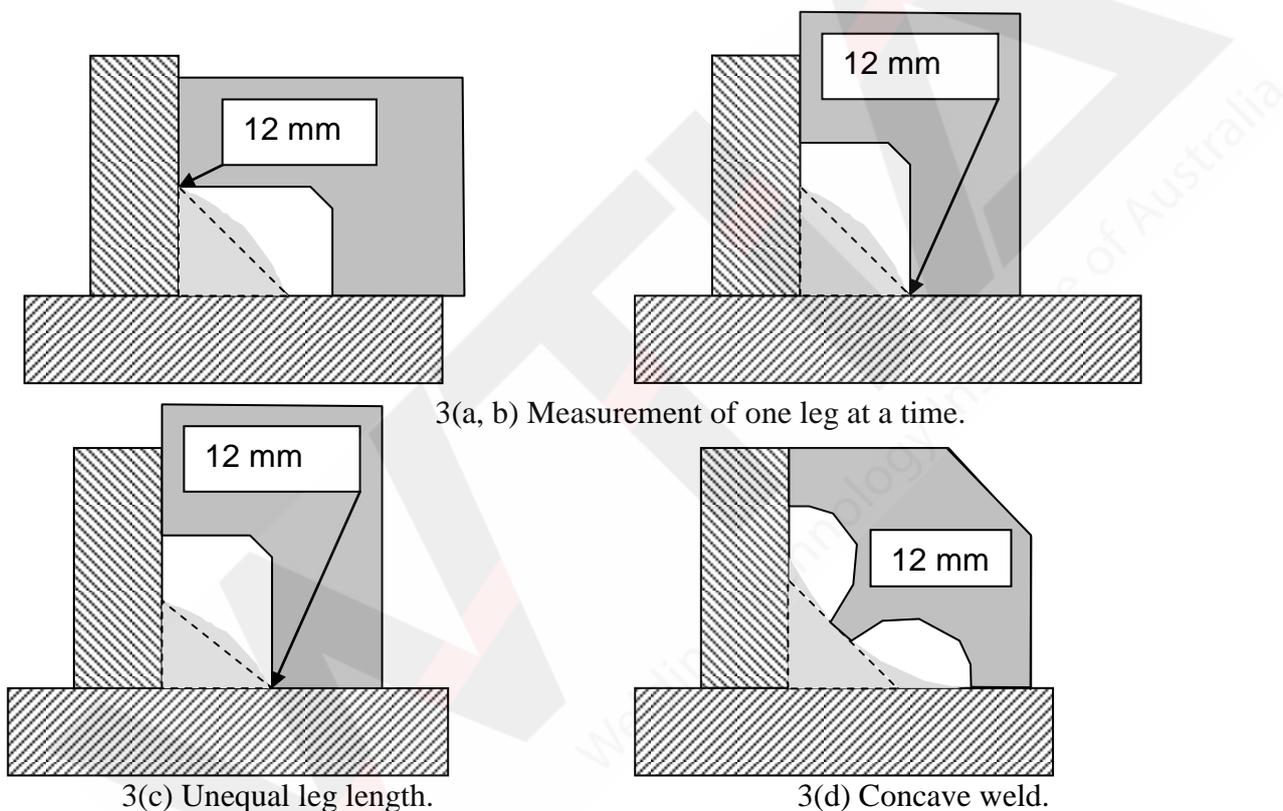


Figure 3 Measurement of leg length on convex fillet welds – One leg at a time, equal or unequal leg lengths and a different gauge for concave welds.

5. Non Destructive Testing of Fillet Welds

Because fillet welds are incomplete penetration welds they have inherent lack of fusion between the two parts. For this (and other) reasons neither ultrasonic nor radiographic testing are generally carried out.

Magnetic Particle Inspection (MPI) is occasionally carried out on ferritic steel fillet welds where there are concerns about Hydrogen Assisted Cold Cracking (HACC). Such cracking which will manifest itself as under-bead cracking or toe cracking. Only use MPI when HACC is an identified threat.

Dye Penetrant Testing may occasionally be carried out on Aluminium welds where there is risk of hot cracking although such cracking is generally visible with naked eye.

6. Confirming structural integrity of fillet welds – Destructive tests

In addition to measuring the leg length it is necessary to confirm that there is full fusion between the fillet weld and parts to be joined. This achieved by carrying out weld macro tests (AS 2205.5.1) or mechanical testing (various parts of AS 2205) at three stages of fabrication;

a) *Welding Procedure Qualification*

As part of the procedure qualification process a weld macro would likely have been carried out to demonstrate that the welding procedure can provide the necessary fusion. For each welding process there is an upper limit on fillet weld sizes that can be reliably achieved in one pass. Care is required to avoid trying to produce a fillet weld in one pass that is too large for the process. For welds requiring more than one pass the size of the individual passes must be optimized to produce the desired weld size in a minimum of passes.

b) *Welder Qualification*

During welder qualification weld macros are carried out to demonstrate the welder is capable of achieving the necessary fusion. The applicable welding codes provide requirements for welder qualification.

c) *In-process Macros*

Confirmation that full fusion is being achieved during production can be demonstrated by performing macros at the ends of the welds in situations where the weld runs to the end of the structure. Alternatively, test pieces can be welded together using the production procedure to confirm fusion is being achieved.

Visual inspection of the weld may not provide an indication of internal fusion. However welds should exhibit a good profile; achieve the required throat thickness without excessive convexity, and have a smooth transition from the weld toes to the parent metal with an absence of overroll (Fig 2b).

d) *Mechanical Tests*

In addition to macro tests, fracture tests performed either on run-off/run-on tabs or test pieces can be used to demonstrate full fusion between the weld and parent metal. When subjected to fracture tests there should be no fractures or tears associated with the fusion line.

7. Welding Thick Sections

As the thickness of the parts to be joined increases cooling rates increase and the tendency for lack of fusion also increases. This is the case for steel and particularly for aluminium. When developing fillet weld procedures be sure to test them on the thickest parts to be joined. Also note that increased preheats are often required when welding thicker sections – this applies to aluminium as well.

8. Deep Penetration Fillet Welds

Since fillet weld strength is based on throat thickness, advantage can be made of deep penetration welding processes such as submerged arc welding, fig 1(d). Where such deep penetration welds are incomplete penetration welds it is necessary to confirm penetration depth using macro tests throughout the fabrication process. Inspection of these welds includes a measurement of the depth to width ratio of the weld bead to ensure the risk of hot cracking is avoided. There will be a tendency for hot cracking if the depth to width ratio of the weld bead exceeds its width. AS 1554.1 Clause 5.6 refers.

9. Special Cases

9.1 I-Beams

An incomplete or complete penetration weld used to join webs to flanges can be a compound weld for the purpose of smooth transition from the web to the flange. The fillet here does not need to be equal to the height of the weld face. For example, a 32 mm thick web would only need fillets 12 mm in size.

9.2 Lamellar Tearing

Fillet welding can be preferred to butt welding in steels which are prone to Lamellar Tearing. For example modification of beams and columns in buildings in Australia built before 1960. In this case

fillet welding is preferred because it widens out the area of high through-thickness shrinkage stress. A root gap is also preferred in these cases. A soft wire to which is compressible to allow weld contraction is also recommended in such a root gap.

9.3 Tee Butt Welds

Tee butt welds require complete penetration between the two members. Macro tests are needed to qualify the welding procedure and the welder. Production macro tests also provide assurance of complete penetration.

However for full fusion welds, ultrasonic inspection can be used to confirm full fusion by utilization of compression probes on the reverse side of the flange, fig 4.

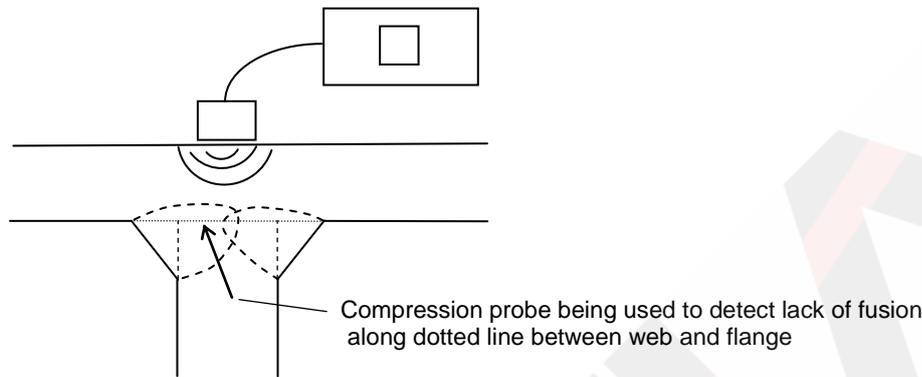


Fig 4 – Ultrasonic Testing of Tee Butt using Compression Probe

10. Designing and Fabricating Tee Butt Welds

No matter what the welding process is, Tee Butt welds need to be carefully designed to ensure full fusion is consistently obtained. When producing Tee Butt welds by welding from both sides (recommended for arc welding processes) the land and bevel angle need to be designed so that the welding process can consistently achieve 70 – 80% penetration of the land from one side, Figure 5.

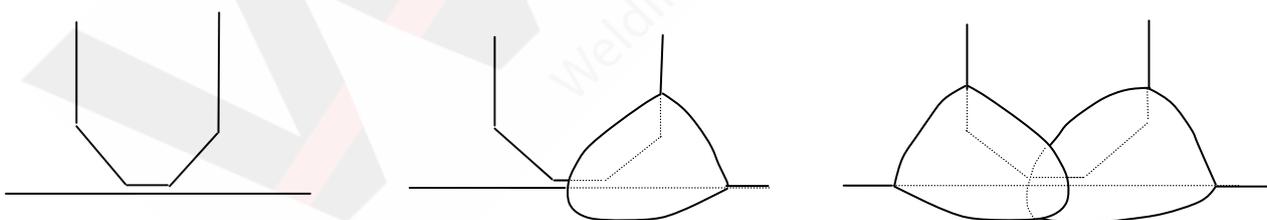


Figure 5. Designing bevel and land dimensions to achieve penetration overlap during welding.

Note that thicker parts will require more arc energy heat input in order to provide full fusion. A complete penetration butt weld designed for welding a 10mm web to a 20mm flange will not necessarily work for welding the same 10mm web to a 40mm flange. The 40mm flange provides more of a heat sink and therefore higher heat inputs will be required. Again thicker sections may require increased pre-heat to maintain penetration. Additionally variations in root gap will affect the amount of penetration achieved. For ease of fabrication it is recommended to have no root gap whenever possible.

When producing full penetration Tee Butt welds it is imperative to:

- Control the size of the land to close tolerances;
- Control the size and angle of the bevel when required;
- Achieve consistent fit-up every time (preferably zero root gaps);
- Use mechanized welding processes that can replicate amperage, voltage and travel speed;
- Maintain constant contact tip to work distances;

- f) Use a consistent pre-heat temperature;
- g) Ensure the power source can operate at 100% duty cycle at the nominated current and voltage.

11. Designing and Fabricating Fillet welds and Deep Penetration Fillet Welds

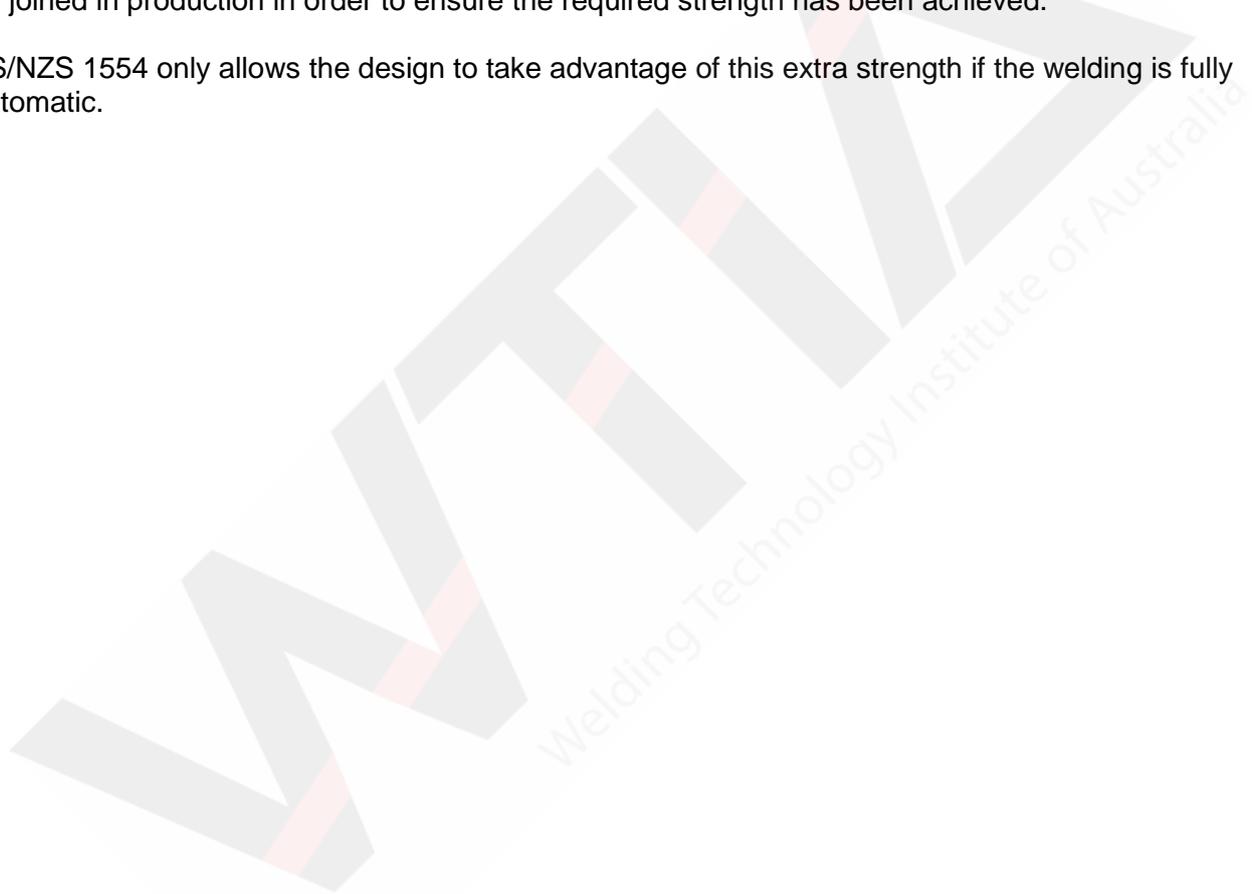
The same principles that apply to Tee Butt welds are applicable to Fillet and Deep Penetration Fillet welds. Both these weld types are classed as incomplete penetration welds so full fusion of the web is not required. However with deep penetration welding techniques it is necessary to demonstrate that the required throat thickness is being consistently achieved. This can only be verified with a production macro test. Sophisticated NDT techniques by experienced operators can confirm throat thickness or adequate side wall fusion when incomplete penetration welding is being employed.

12. Conclusion

Deep penetration fillet welds provide a way of making efficient Tee joints with a minimum of added weld metal.

Visual inspection needs to be augmented with macro tests when producing fillet welds and deep penetration fillet welds. Welding procedure development should be carried out on the thickest parts to be joined in production in order to ensure the required strength has been achieved.

AS/NZS 1554 only allows the design to take advantage of this extra strength if the welding is fully automatic.



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As a valued technology expert in this area we would like you to be part of the Technology Expert Group to review this note. Please complete this questionnaire so that we can gauge the success of meeting this need.

Objective 1: Identify the need for guidance on fillet and Tee butt welding.

Fillet welds are the most common weld in Australian construction. This guidance note is intended to provide the steel fabrication industry with guidance on designing, making and testing fillet welds and Tee butt welds in steel structures. How well does the document explain this subject?

poor average good very good

Comments:

Objective 2: Identify appropriate technology receptors in the Road Transport Industry

This document was written for designers, fabricators and inspectors. Are these people the appropriate individuals we should be targeting?

yes no

What other types of companies and/or personnel do you suggest we target?

Objective 3: Identify current best practice for fillet and Tee butt welding?

The document was written to reflect current best practice for fillet and Tee butt welding? Do you envisage opportunities for the use of this technology in the industry?

yes no

If yes, what and where, if no why not?

Objective 4: Is the information provided clear, concise and accurate?

yes no

If not, why?

Objective 5: Broad dissemination of technology to the Road Transport Industry

Please indicate how best to disseminate this Technical Guidance Note to the appropriate Road Transport Industry Recipients

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