*A SunCam online continuing education course*

# A Practical Design Guide for Welded Connections

# Part 1

# Basic Concepts and Weld Symbols

by

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# Course Overview

This course is divided into 2 parts. Though it provides some basic concepts of welded connection and welding methods, **part 1** of this course largely focuses on the foundational knowledge of welding symbols. It is critical for engineers and designers to understand the proper use of welding symbols because they serve as communication between the designer and the fabricator. Part 1 is not an exhaustive coverage of welding symbols, but it focuses on the most common applications of welding symbols used in mechanical applications.

**Part 2** provides the essential information on analysis and design of welded joints. The section covers the two main types of welded connections, fillet welds and groove welds, as they make up nearly 95% of all welded joints used in mechanical applications. Direct loading applications and eccentrically loaded applications are covered.

# Basic Concepts of Welded Connections

## Welding Applications

Welding can be used in many applications in structural and mechanical engineering. Examples for mechanical applications can include gears, sheaves, sprockets, linkages, machine bases, frames, support brackets, and more. Weldments can often serve as an alternate to cast or forged parts, especially in smaller quantities. Welding is often used to repair machine parts or make field repairs. Due to the versatility of welded connections, it is critical that engineers have a solid understanding of the analysis and design of such connections.

## Welding Methods

Welding, in the most basic definition, is the joining of parts by fusion. There are many variations of welding methods. Though the details of each welding method is not a primary focus of this course and as an engineer it is not essential to know all the details of the different methods, you should know the basics of the methods so you know when each should be used.

**Gas welding** is a method where pure oxygen is burned in combination with other gases (commonly acetylene) to get high flame temperatures. The heat of the gas flame melts the work metal and the hand-fed filler rod. Oxyacetylene welding is often performed in small shops, and the equipment is inexpensive and portable. One disadvantage of gas welding is that the heated area is large (not as concentrated as other methods), which can cause distortion of the workpiece.

Another category of welding methods is **arc welding**. In arc welding an electric arc is the source of the heat. The arc is formed between the metal being welded and a metal rod called an electrode, and the arc is maintained in a gap in the electrical circuit. In arc welding the filler rod functions as the electrode. The arc is shielded, as shown in Figure 1, by flux or inert gas to control the arc.

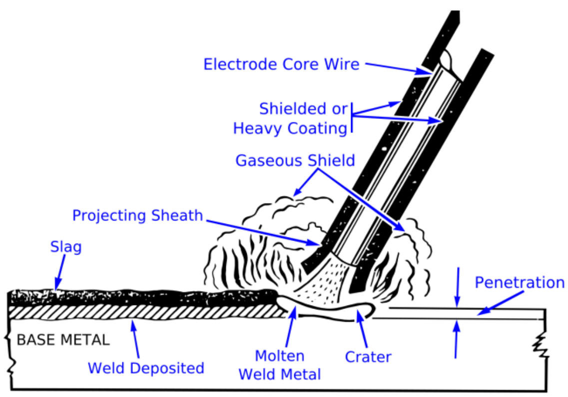

**Figure 1** Arc welding

There are several variations of arc welding, and the most commonly used arc welding methods are listed below with some basic details of each:

- Shielded-arc welding (commonly called stick welding)
    - Most common method
    - Arc melts both the electrode and base metal
    - Electrode has same basic chemical composition as base metal

  

  - Welding rods (electrodes) are numbered to identify different types
- Gas-metal-arc welding (GMAW)
  - Also called MIG (metal inert gas)
  - Has higher welding speeds
  - Welds all metals including aluminum and stainless steel
- Gas-tungsten-arc welding (GTAW)
  - Also called TIG (tungsten inert gas)
  - Used for aluminum, stainless steel, and other nonferrous alloys
  - Not often used for thick plate but easier than MIG for thin plates
- Submerged-arc welding
  - Sometimes called hidden arc
  - Arc cannot be seen so no need for welding helmets
  - Fast and efficient for long flat joints

## Welding Electrodes

Electrodes used as the filler metal for shielded arc wielding are designated by a capital letter E followed by two numbers. The E stands for electrode and the numbers represent minimal tensile strength of the weld in kips per square inch. For example, an E60 electrode will have a strength of 60 kips (1000 pounds) per square inch. Steels with yield strengths between 36 ksi to 60 ksi are generally welded using E70 electrodes (70 ksi strength). Additional numbers may follow the two designating weld strength. If so, they represent information such as allowable welding positions and electrode coatings. Part 2 of this course will cover more details of the electrode strength as it is very important for calculating the strength of welded connections.

## Advantages and Disadvantages of Welded Connections

As an engineer you often need to decide between using bolted and welded connections. Each connection type has its own unique advantages and disadvantages. Below is a list of some common **advantages of welding**:

- Properly made welds can be stronger than the part on which it is used
- No holes needed for bolts
- Welding equipment is inexpensive and portable
- Allows considerable freedom in design

  

- Easier to make changes and correct errors during fabrication
- Wide range of applications
- Welded structures are more rigid
- Saves weight over bolted connections (no need for gusset plates or splice plates)

Below is a list of some common **disadvantages of welding**:

- A good welding job requires a skilled operator
- Each part of a weldment must be cut to size and shape before it can be welded
- Jigs and fixtures are often needed to hold parts (added expense)
- Distortion from high temperatures

# Basics of Welding Symbols

## Introduction

There are a lot of terms and symbols used on drawings to give the welder exact instructions of how to weld the connections. Welding symbols are basically a shorthand language that allows the engineer or designer to clearly indicate the weld required and they can provide a lot of information in a small space on a drawing. Welding symbols seem confusing, but they are standardized by the American Welding Society (AWS). So just learn the standards and you will be fine. You will also find that the symbols consist of basic elements, and you just need to understand how the elements get put together to form a specific welding symbol.

In the most basic form, a welding symbol will have an arrow pointing to the area to be welded, a leader line, a horizontal line (known as the reference line) with the appropriate weld symbols (on top, bottom, or both), and an optional tail with additional information. However, a welding symbol can include many other types of supplementary information. The list below contains the elements used in a welding symbol, but keep in mind that not all are always required.

1. A reference line
2. An arrow
3. Tail
4. The basic weld symbol
5. Dimensional data

6. Finish symbols or other supplementary symbols
7. Information about welding process

To start we will focus on the first three items which are shown in Figure 2; These elements are the basic components of a welding symbol. The **reference line** is the main part of the welding symbol and contains all the information about the weld type. The reference line is required for all welding symbols and is always oriented horizontally. The **arrow** points to the desired location of the weld. The **tail** contains additional reference information. The tail is omitted if no additional information is needed.

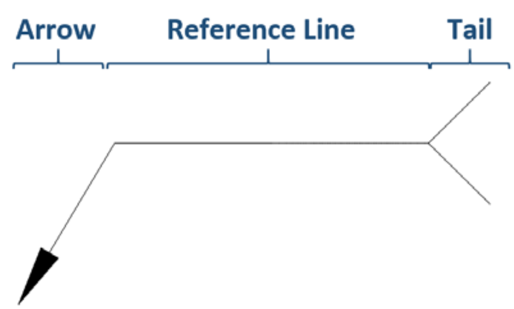


**Figure 2** Basic components of a welding symbol

Items 4 through 7 on the list above will be discussed throughout the remaining sections of Part 1 of this course. The critical points for any welding symbol are proper communication of weld type, weld size, and joint preparation. You will learn more about each in the remaining sections.

## Arrow Side, Other Side, or Both Sides

In welding symbols, the arrow points to one side of the joint known as the arrow side of the joint. The side opposite the arrow side is known as the other side of the joint. Welding symbols can indicate which of those sides (or both) will contain the weld. Proper understanding of arrow side, other side, or both sides is critical for engineers using welding symbols.

  

All the information below the reference line corresponds to the **arrow side** of the joint, and all the information above the reference line corresponds to the **other side** of the joint. Figure 3 illustrates the concept of arrow side and other side. If a welding symbol contains information on both the arrow side and other side (both below and above the reference line) then the weld will be on **both sides** of the joint.

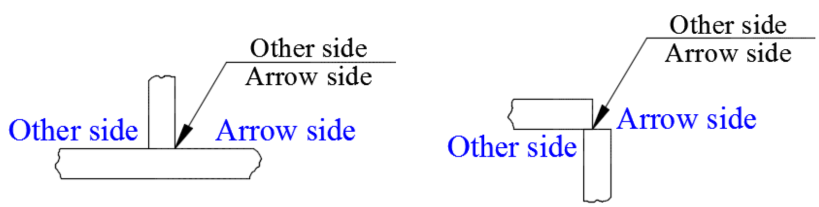


**Figure 3** Arrow side vs. other side

Figure 4 shows a general example of using arrow side and opposite side. The welding symbol used in the upper left figure indicates a desired fillet weld (the triangular symbol on the reference line is a weld symbol for a fillet weld) to be placed on the arrow side. The lower left welding symbol indicates the desired fillet weld should be on the opposite side (weld symbol above the reference line). Both will result in the weld shown on the right.

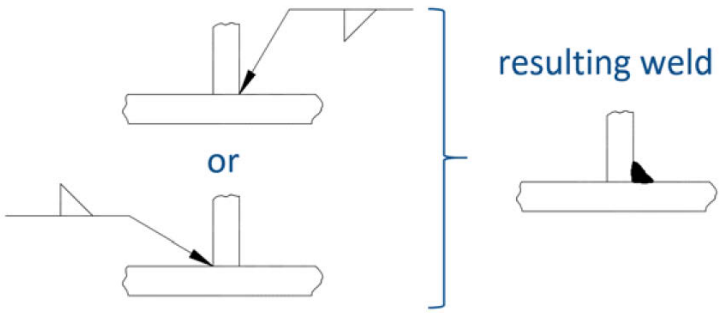


**Figure 4** Example for using arrow side and other side

  

Figure 4 also illustrates another important concept. The lower left welding symbol has the arrow extending off the right end of the reference line. Note that the concepts of arrow side and other side do not change regardless of which end of the reference line contains the arrow. More examples will be provided through the rest of this section.

## Field Weld and Weld All-Around Symbols

**Field welds** are welds not made in the original place of construction (such as a shop). A field weld is indicated by a field weld symbol, which is a flag shaped symbol located at the intersection of the reference line and arrow. Figure 5 shows the basic symbol for a field weld.

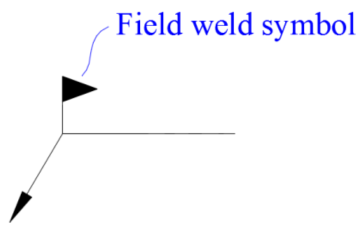


**Figure 5** Field weld symbol

It is common for welds to extend completely around a joint. Such a weld can be designated with the **weld all-around** symbol, which is a circle located at the intersection of the reference line and arrow. Figure 6 shows the symbol indicating a weld-all around the joint.

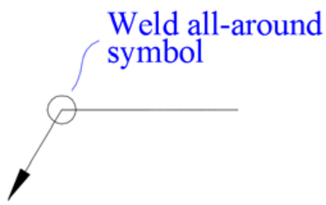


**Figure 6** Weld all-around symbol

  

# Fillet Welds

## Basic Concepts of Fillet Weld Symbols

Fillet welds are the most common weld type and are used on tee joints, lap joints, and corner joints (basically any joint where the parts are at a 90° angle). The weld symbol for fillet welds looks like a triangle, as shown in Figure 7. In fillet weld symbols the perpendicular leg of the symbol is always on the left side, regardless of the orientation of the overall symbol.

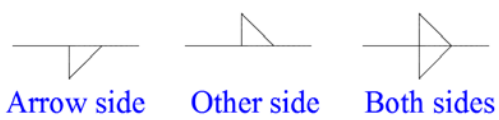


**Figure 7** Weld symbol for fillet welds

A fillet weld will have an approximate triangular shape as shown in Figure 8. The important terminology refers to the leg dimensions and the throat dimension. The leg dimension is the general 'size' of the weld, which will be discussed next. The throat dimension will be important for that actual design strength of the weld, which will be discussed in Part 2 of this course.

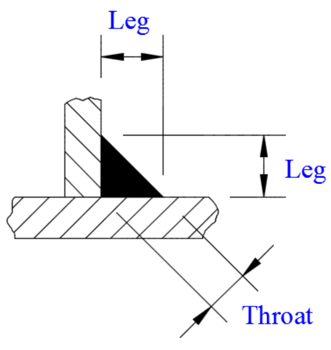


**Figure 8** Fillet weld terminology

## Indicating Fillet Weld Size

Fillet weld dimensions are shown on the reference line to the left of the fillet weld symbol. The size called out on the welding symbol refers to the leg dimension shown in Figure 8. The weld symbol shown in Figure 9 (a) calls for a ¼" fillet weld on the arrow side (because it is below the reference line) and a ½" fillet weld on the other side (because it is above the reference line). Figure 9 (b) shows the resulting welds.

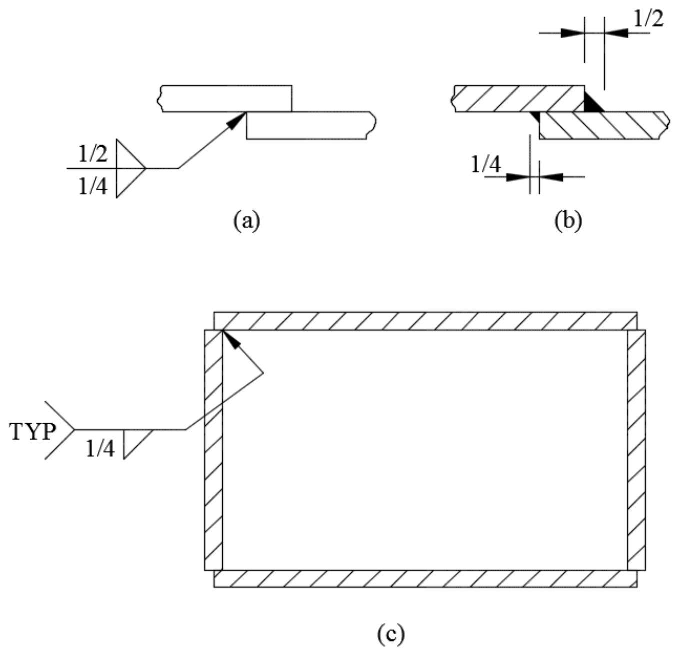


**Figure 9** Fillet weld size examples (a) weld symbol (b) resulting weld (c) usage of welding tail and typical callout for multiple welds

It is common to have a machine element or structural frame that requires many welds, often of the same weld size. In such cases it is common to have a drawing note such as ALL WELDS TO BE ¼" FILLET WELDS UNLESS NOTED OTHERWISE. Using the drawing note saves time for creating the drawing and provides a less cluttered drawing. Another method for calling out multiple welds of the same size is shown in Figure 9 (c). The tail is used with a note TYP (stands for typical), which indicates that the weld is typical for all four corners of the box shown.

Determination of the required weld size is based on factors such as the required strength of the weld and plate sizes to be welded. Topics on the design of the weld and determining the required weld size will be discussed in Part 2 of this course.

## Indicating Fillet Weld Length and Pitch

If necessary, information on the fillet weld length and pitch is shown on the reference line to the right of the fillet weld symbol. Figure 10 (a) shows where the information is located on the welding symbol for size, length, and pitch. The size was defined in the previous section. The weld length and pitch terms are indicated in Figure 10 (b) and need to be indicated on the welding symbol for intermittent welds.

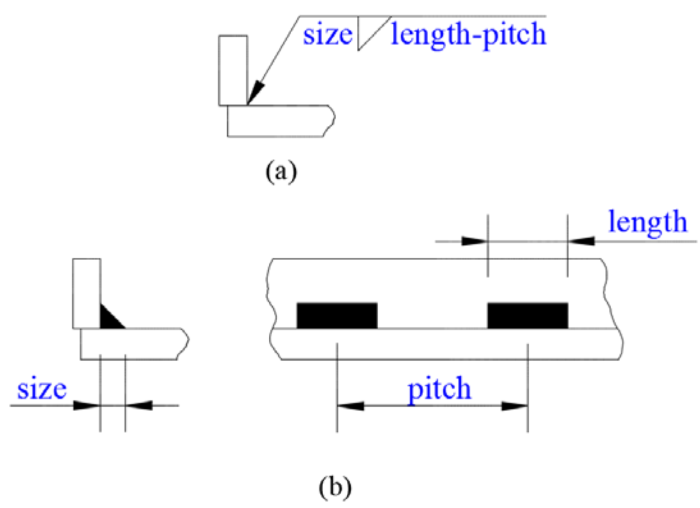


**Figure 10** Fillet weld size, length, and pitch terminology

An intermittent fillet weld (also called a stitch weld) is a discontinuous weld. Stitch welds are not as strong as continuous welds (sometimes called seam welds), but they cause less heat distortion. Due to the lower costs and reduced distortion, stitch welds should be used if a continuous weld is not required. Welding floor plate to a walkway structure, for example, would likely use stitch welds. Keep in mind that there may be other benefits of continuous seam welds other than strength. Stitch welds do not provide a weather tight seal, for example, that may be required in some situations.

Figure 11 shows another general example of the use of intermittent fillet welds. Figure 11 (a) shows the welding symbol and the resulting weld is shown in Figure 11 (b). The welding symbol in Figure 11 (a) also shows that welding symbols can have more than one leader line and arrow for welds required in multiple locations.

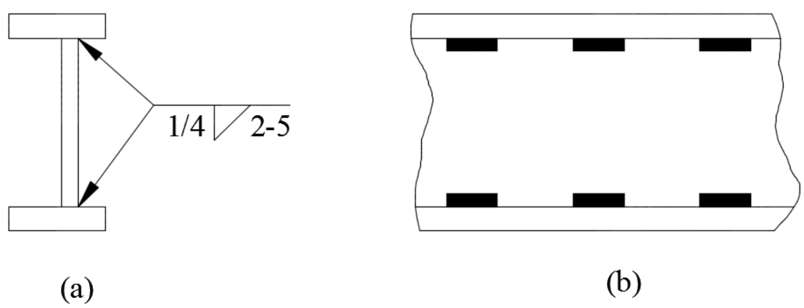


**Figure 11** Example of an intermittent fillet weld

Intermittent fillet welds located on both sides of a joint can either be oriented in-line or staggered as shown in Figure 12. The top figure shows the welding symbol with the fillet weld symbols aligned for both sides (the vertical lines on the triangular fillet weld symbols are aligned for the top and bottom symbol). The bottom welding symbol has the fillet weld symbols offset for the arrow side and other side (the vertical lines on the triangular fillet weld symbols are not aligned for the top and bottom symbol). The resulting intermittent welds are shown to the right of each welding symbol. Staggered intermittent welds can reduce heat distortion and can avoid a concentrated area of residual stress after welding.

  


In-line intermittent weld


Staggered intermittent weld

**Figure 12** Welding symbols for in-line and staggered intermittent fillet welds

# Groove Welds

## Introduction

Next we will examine weld symbols for groove welds, which are the second most common welding type. Welding symbols for groove welds can seem more complicated than fillet welds because several types of groove welds exist. The basic groove welds are shown in Figure 13. The figure shows the symbols on the arrow side; but the same rules for arrow side, other side, and both sides discussed for fillet welds also apply to groove welds. Groove welds are very common for butt joints, but they can be used for corner joints. Other applications of groove welds include joints with rounded corners. Examples for each of the groove weld types and symbols will be discussed next based on the type of joint.

  

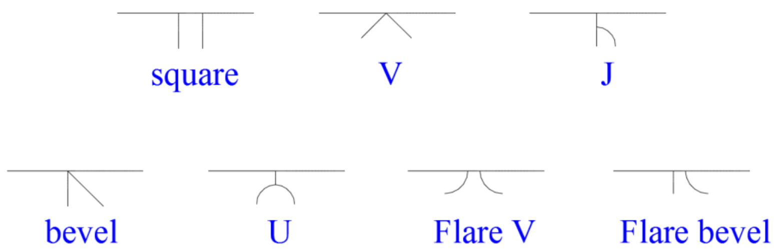


**Figure 13** Basic groove weld symbols (arrow side shown)

## Groove Welds for Butt Joints

For butt joints, the square groove weld should only be used for thinner plates (up to around 5/16" thick). Thicker plates require a single or double V groove. Figure 14 shows a common example of a full depth single V-groove weld and Figure 15 shows a common example of a full depth double V-groove weld. The groove is cut from the base metal before welding to form a channel to accommodate the weld material. The type of groove weld basically indicates the shape of the channel (V, J, or U shaped). For example, the V-groove weld has a preparation that forms a V shaped channel.

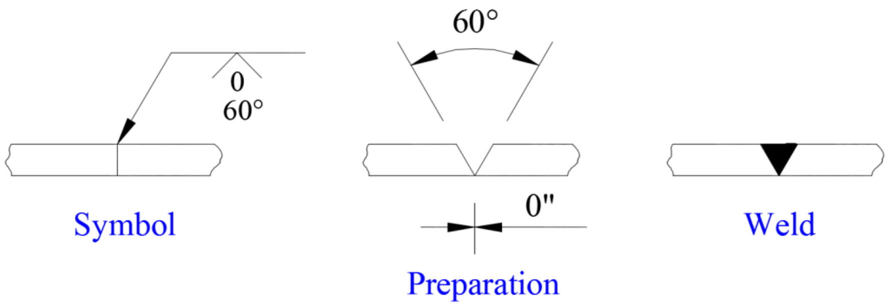


**Figure 14** Full depth V-groove weld (one side)

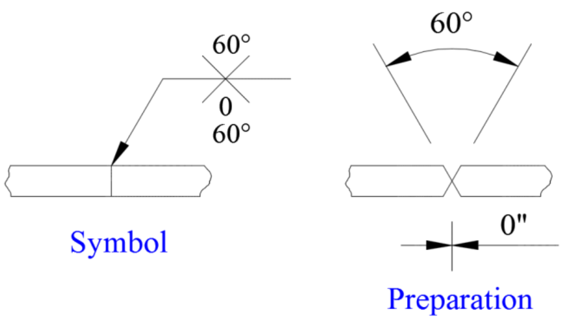


**Figure 15** Full depth V-groove weld (both sides)

V-groove welds can be called out at a particular depth if a full penetration weld is not desired. If required, the depth of the weld is called out to the left of the weld symbol as shown in Figure 16.

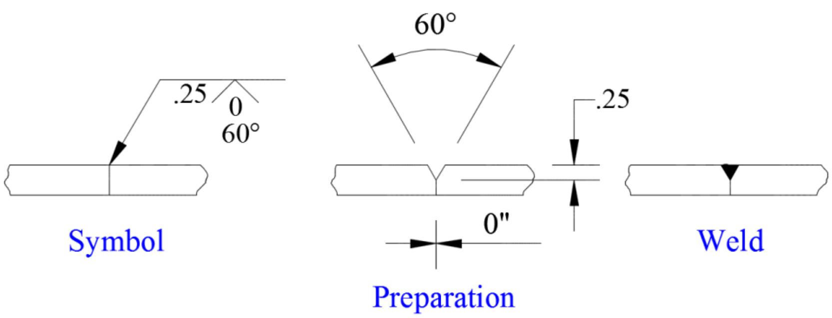


**Figure 16** Partial penetration (or partial depth) V-groove weld

Bevel welds can also be used for butt joints. A bevel weld is similar to a V weld, but the notch (or bevel) is only cut on one plate. As illustrated in Figure 17, the bevel is cut on the plate pointed to by the weld symbol arrow.

  

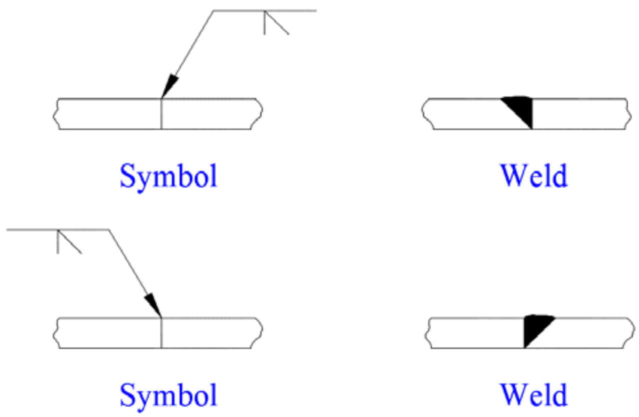


**Figure 17** Bevel weld for butt joints

U-welds can also be used for butt joints, as illustrated in Figure 18. The weld symbol dimensions are similar to those used in V-groove welds. U-welds are not as common due to increased difficulty of the material preparation (the channel has a U shape which is more difficult than a basic V shape), and they offer little benefit over the simpler V-groove weld. The main advantage of U-welds would exist for thicker plates, where a V-groove would have a very large opening and require more weld material to fill.

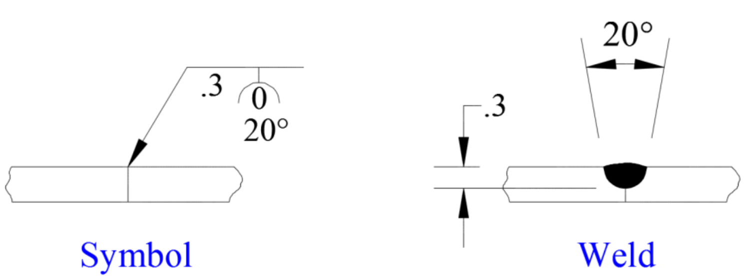


**Figure 18** U-welds for butt joints

  

## Groove Welds for Corner Welds

The welds discussed for butt joints can also be used for corner joints. An example is shown in Figure 19 using a bevel weld. The rules discussed for butt joints also apply for corner joints.

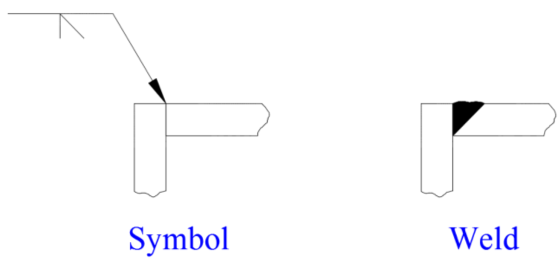


**Figure 19** Bevel weld for a corner joint

It is also possible to use combined weld symbols for corner welds. Figure 20, for example, shows a combination weld of a single bevel on the arrow side and a fillet weld on the opposite side.

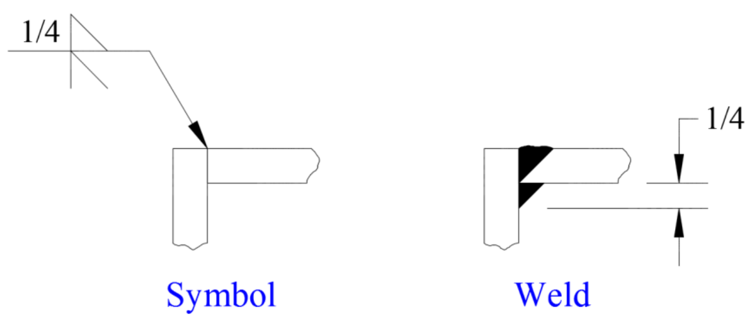


**Figure 20** Combination corner weld with single bevel and fillet welds

  

## Groove Welds for Joints with Rounded Corners

Flare groove welds are commonly used for corner joints with rounded edges. Figure 21 shows applications for flare V and flare bevel welds. Again, the weld symbol basically mimics the shape of the channel that exists to accommodate the weld material.

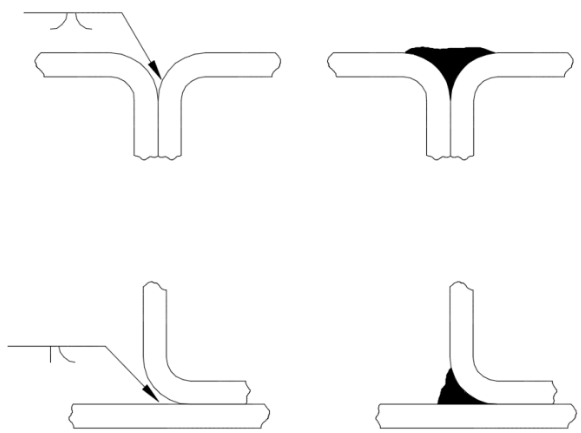

**Figure 21** Flare V and flare bevel welds for rounded corner joints

Flare groove welds are also used to connect round bar to flat plate, as shown in Figure 22.

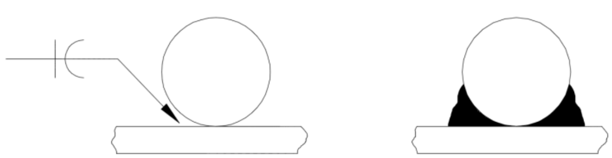

**Figure 22** Flare bevel weld for connecting round bar to flat plate

  

# Additional Topics

## Finishing of Welds

If finishing other than typical cleaning is required, **contour symbols** must be added to indicate the required weld finish. The final contour of a weld can be called out as flat, convex, or concave. Examples of the symbols used for these contours are shown in Figure 23 for fillet welds.

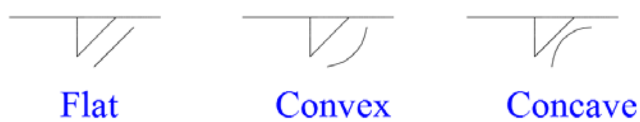


**Figure 23** Flat, convex, and concave symbols (used on a fillet weld symbol)

The finishing method can also be designated. Table 1 gives the letters used for finishing methods. An example for grinding flat is shown in Figure 24 for a bevel weld.

**Table 1** Letter designation for finishing methods

| | |
|---|---|
| G | Grinding |
| C | Chipping |
| M | Machining |
| R | Rolling |
| H | Hammering |

  

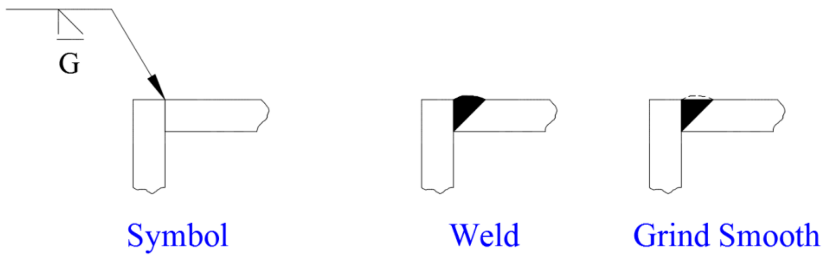


**Figure 24** Application of grinding a bevel weld to a flat contour

## Basic Ideas of Weldability

Weldability refers to the ease or difficulty of developing a satisfactory weld joint free of cracks. Low carbon steel (0.16 to 0.20% carbon) is the most common material for welded machine parts. Low carbon steel is inexpensive, readily available, and easy to weld. Higher carbon steels have a higher tendency to crack when welded. Thicker plates also tend to have higher carbon content. Preheating can be used as a preventative measure for cracking because it will retard the cooling of the base metal in the area around the weld. Heat treatment can also be used as a stress relieving measure. High strength steels may have some chemical component causing difficulty for welding. As a design engineer you only need to be aware of some possible issues of weldability; You can rely heavily on the experienced welder to provide advice.

## Fatigue of Welded Connection

Full coverage of fatigue loading and its effect on welded connections is beyond the scope of this course. It is important, however, to have a very basic understanding of ways to improve fatigue life in welded structures. Fluctuating loads occur commonly in mechanical applications. Axles and shafts loading in bending will have cyclic stress changes during rotation. Pressure vessels and tanks will have changing loads. It is important to minimize stress concentrations in parts where anticipated fatigue conditions exist. Welded connections generally have abrupt cross-sectional changes. As an engineer you have a large amount of control to minimize the stress concentrations. Grinding or machining welds smooth is critical in areas of fluctuating stress.

  