

VII. Joint Design and Types of Welds

A weld joint is the term used for the location where two or more pieces of metal will be or have been welded together. Figure 7.1 shows the five basic weld joint designs.

To obtain a quality weld and cost-effective use of filler metal, joint design must be considered in any type of weldment. This will depend upon several factors including material type, thickness, joint configuration and strength required.

It is quite possible that a welder would have little to do with how a particular joint is designed. However, a good welder should be familiar enough with joint design to carry out a welding job.

A proper joint design will provide the required strength and the highest quality weld at the most economical cost. The joint design selected will dictate what type of weld is required.

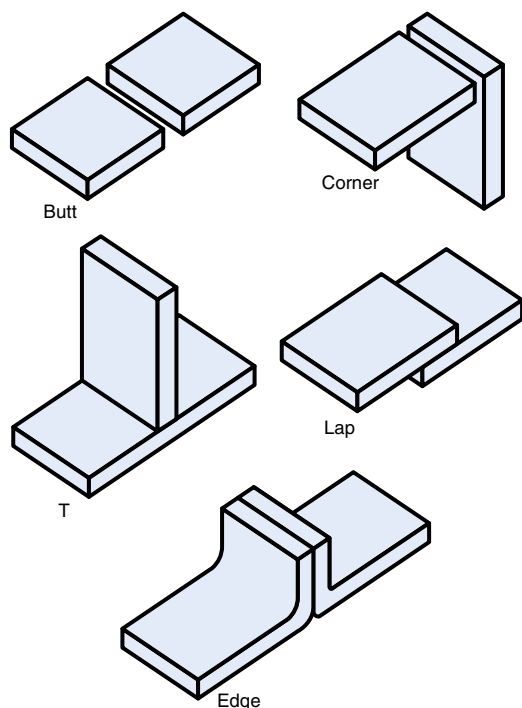


Figure 7.1 Five basic joint designs.

The five basic joint designs are typically welded with the TIG process using either a groove or a fillet weld. Groove welds are those made into a prepared joint to get deeper penetration. To prepare the joint, material must be removed and replaced with weld metal. Groove welded joints are very efficient but are more expensive than a fillet welded joint. Groove welds generally require some form of joint preparation while fillet welds are made on joints requiring no joint preparation. When the edge or surface of joint members come together at a right angle to each other, the resulting weld, which is triangular in shape, is called a fillet weld. Fillet welds on lap or T-joints are commonly used in the welding industry.

A few considerations for joint design are specific to GTAW. Naturally the weld joint must be accessible to the GTAW torch, making it possible for proper torch movements. Weld joints should not be too narrow, so as to restrict access of the gas cup. In some cases, using a narrower gas cup, or a gas lens with the electrode extending up to an inch beyond the gas cup will help.

Edge Joints

Edge joints are often used when the members to be welded will not be subjected to great stresses. Edge joints are not recommended where impact or great stress may occur to one or both of the welded members. An edge joint occurs when the edges of parallel or nearly parallel members meet and are joined by a weld. Figure 7.2 shows different types of edge joints. Figure 7.2 demonstrates the various types of edges that can be applied to the joints. If required, the joints can be altered by grinding, cutting or machining the edges into a groove. The groove can be a square, beveled, V, J, or U. The main purpose of the groove is to allow proper penetration or **depth of fusion**. See Figure 7.3.

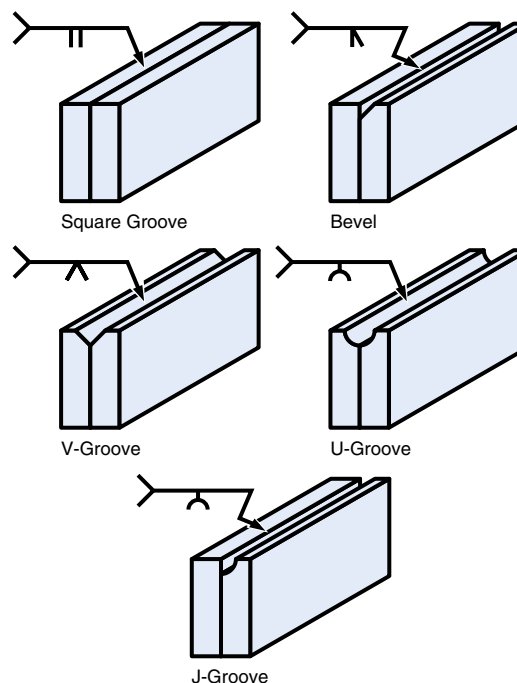


Figure 7.2 Edge Joints

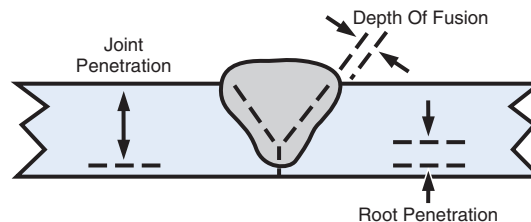


Figure 7.3 Depth of fusion and types of penetration. Complete joint penetration refers to weld metal that extends completely through the groove and has complete fusion into the base metal. What is shown is a partial joint penetration, which if not intended is referred to as incomplete joint penetration.

Butt Joints

A **butt joint** occurs when the surfaces of the members to be welded are in the same plane with their edges meeting. Figure 7.4 shows butt joints with various types of grooves. Butt joints are often used to join pressure vessels, boilers, tanks, plate, pipe, tubing or other applications where a smooth weld face is required. They generally require more welding skill than other joints. Butt joints have very good mechanical strength if properly made. They can be expensive joints since a prepared groove is generally required to get the proper penetration and weld size. This involves the extra operation of joint preparation, removal of material to open up the joint and then welding to penetrate and fill the groove.

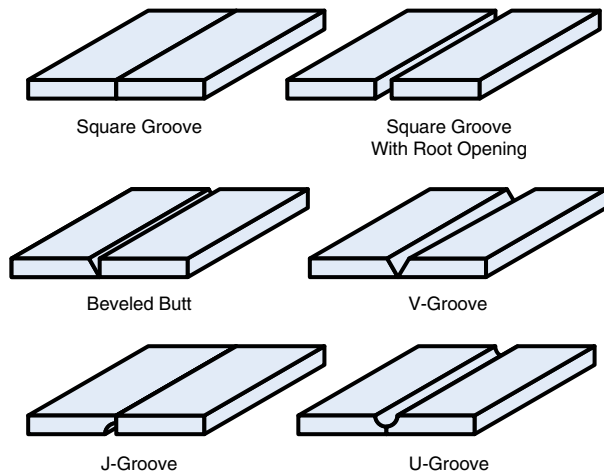


Figure 7.4 Butt joints.

Distortion and **residual stresses** can be problems with butt joints.

Butt joints can be designed in various ways. They may be welded with or without a piece of metal or ceramic backing the joint, usually referred to as a “backing bar” or “backing strip”. The edges can be prepared into a groove that is square, beveled, V, J, or U grooved. Edges may be held tight together or a small gap known as a root opening may be left between the edges.

Figure 7.5 shows the various parts of a V-groove butt joint. Note the groove angle, groove face, root face and root opening. The groove angle is the total included angle of the joint. If two 37.5° bevels are brought together, they form a 75° V-groove. The groove face is the surface of the metal in the groove, including the root face. The root face is sometimes called the “land”. In this example, the root face is 1/8" and the root opening is 3/32". The main purpose of the various grooves and root openings is to allow proper penetration and depth of fusion.

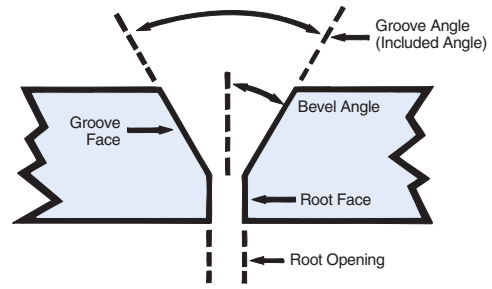


Figure 7.5 V-groove butt joint.

If material thickness is less than approximately 1/8" thick, square edges butted tight together (no root opening) can be used. (Aluminum would probably require a small root opening.) Plate thicknesses 1/8" and greater generally require single or double V-groove and root openings for proper penetration and depth of fusion. Joint preparation before welding will depend upon the joint design and the equipment available to do the edge preparation. The oxy-fuel torch, carbon arc gouging or plasma arc cutting/gouging is often used to cut a bevel-, J-, U-, or square-groove edge on steel plates. Aluminum is best prepared with mechanical cutting tools or the plasma arc cutting/gouging process.

Lap Joints

Another joint design used a great deal in the welding industry is the lap joint. Various types of lap joints are shown in Figure 7.6. As can be seen in the figure, lap joints occur when the surfaces of joined members overlap one another. A lap joint has good mechanical properties, especially when welded on both sides. The type of weld used on a lap joint is generally a fillet weld. If a groove weld is called for, it can be applied as shown in the figure with a single or double bevel. The groove weld may or may not be followed with a fillet weld. This would be indicated by the appropriate welding symbol. The degree of overlap of the members is generally determined by the thickness of plate. In other words, the thicker the plate, the more overlap is required.

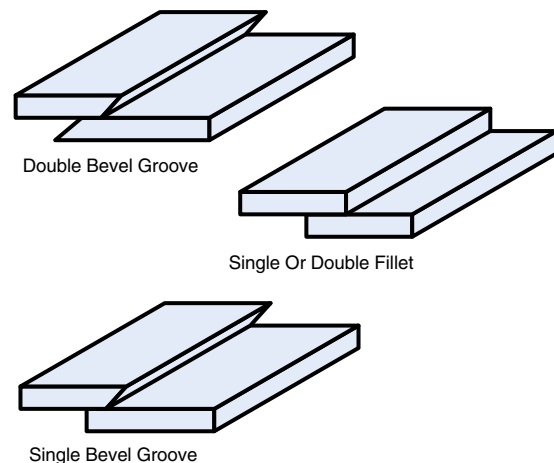


Figure 7.6 Lap joints.

Corner Joints

When members to be welded come together at about 90° and take the shape of an “L”, they are said to form a corner joint. Several types of corner joints and grooves are shown in Figure 7.7. Welds made on the inside of the “L” are considered fillets and welds made on the outside of the “L” are considered groove welds. Corner joints are quite easily assembled and require little if any joint preparation. After welding, the welds are generally finished, that is, ground smooth to present a smooth attractive appearance. When this is the case, all effort by the welder should be made to prevent overlap (weld material rolling onto one of the members and not fusing), high spots, low spots and undercut. These problems can all mean more work since additional grinding time, rewelding and regrinding may be required.

There are two main types of corner joints, open corner and closed corner. On lighter gauge material, it may be necessary to increase travel speed somewhat, especially on open corner joints where excessive melt through is a possibility.

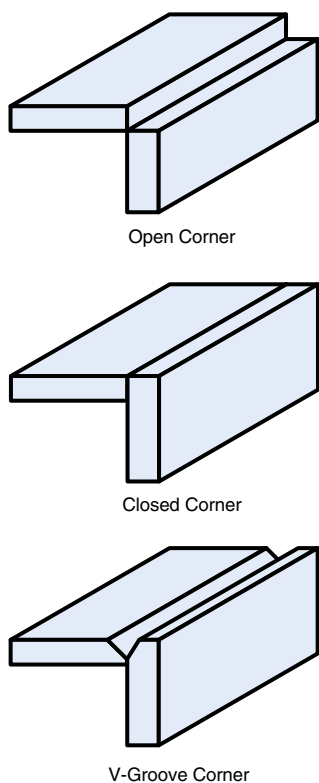


Figure 7.7 Corner joints.

T-Joints

A T-joint occurs when the surfaces of two members come together at approximately right angles, or 90°, and take the shape of a “T”. See Figure 7.8. On this particular type of joint, a fillet weld is used.

T-joints possess good mechanical strength, especially when welded from both sides. They generally require little or no joint preparation and are easily welded when the correct parameters are used. The edges of the T-joint may be left square if only a fillet weld is required. For groove welding they may be altered by thermal cutting/gouging, machining or grinding.

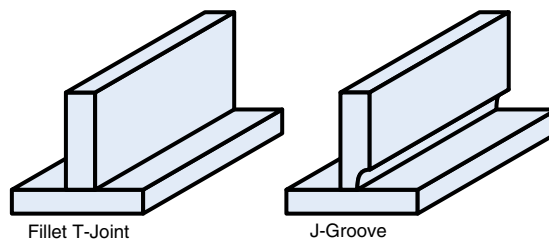


Figure 7.8 T-Joints

Fillet Welds

Fillet welds are approximately triangular in cross sectional shape and are made on members whose surfaces or edges are approximately 90° to each other. Fillet welds can be as strong, or stronger than the base metal if the weld is the correct size and the proper welding techniques are used. When discussing the size of fillet welds, weld contour must first be determined. Contour is the shape of the face of the weld. Figure 7.9 shows a cross section profile of the three types of fillet weld contours: flat, convex, and concave.

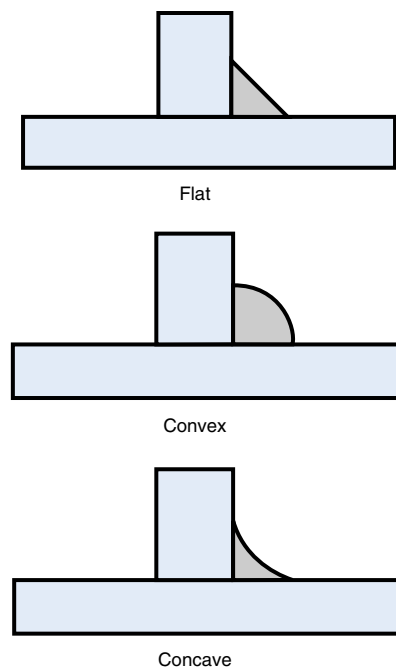
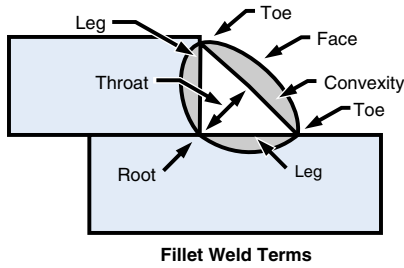


Figure 7.9 Fillet face contours.

Fillet Weld Size

It is important when discussing weld size and joint design to be familiar with the various parts of a weld. Figure 7.10 indicates the parts of a fillet weld.



Fillet Weld Terms

Figure 7.10 Convex fillet weld.

The size of a convex fillet weld is generally the length of the leg referenced. Figure 7.11 shows a convex fillet weld and the associated terms.

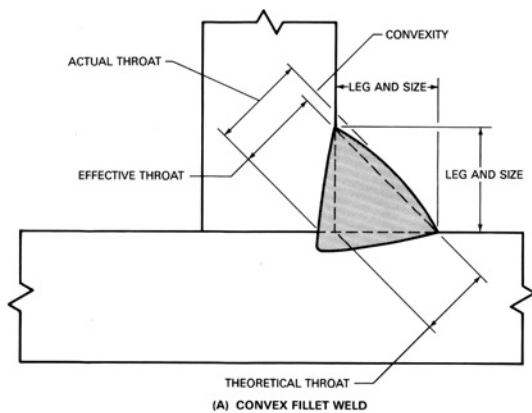


Figure 7.11 Convex fillet weld.

For concave fillet welding, the size and leg are two different dimensions. The leg is the dimension from the weld toe to the start of the joint root, however, the actual size of a convex fillet weld as shown in Figure 7.12, is measured as the largest triangle that can be inscribed within the weld profile. A special fillet weld gauge is used to measure concave fillet welds. If the weld is flat, the concave or convex fillet weld gauge can be used.

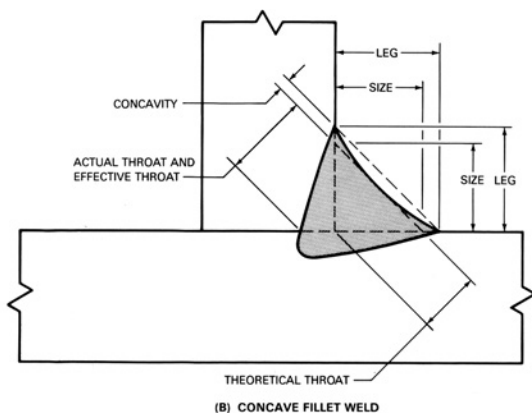


Figure 7.12 Concave fillet weld.

Fillet welds can also be measured in a slightly more complex way—by determining throat size. Three different throat sizes may be referred to when discussing the size of fillet welds, as seen in Figure 7.11 and 7.12.

Design engineers sometimes refer to the theoretical throat of a weld. As Figure 7.11 and 7.12 show, the theoretical throat extends from the point where the two base metal members join (beginning of the joint root), to the top of the weld minus any convexity on the convex fillet weld and on the concave fillet weld, to the top of the largest triangle that can be inscribed in the weld. The theoretical measurement looks at the weld as if it were an actual triangle and the penetration is not figured into the theoretical throat size.

The effective throat of a fillet weld is measured from the depth of the joint root penetration. This is an important consideration as the penetration is now considered part of this dimension. However, no credit is given for the convexity. **(The convexity by many is considered reinforcement, which would indicate more strength. The exception is a fillet weld where too much convexity is detrimental to the overall joint strength. Excess convexity increases stresses at the weld toes and can lead to cracking.)** On convex and concave fillet welds, effective throat is measured to the top of the largest triangle that can be drawn in the weld. This measurement can be used to indicate the size of the weld. The outward appearance of the weld may look too small but if the penetration can be assured, the weld will be of sufficient strength.

The actual throat of a fillet weld is the same as the effective throat on a concave fillet weld. But as can be seen on Figure 7.11, there is a difference. This throat dimension can also be used to indicate size and strength. If anything other than the theoretical throat is used to size a fillet weld, the welding procedure would have to be carefully written and in-process inspection would be required to assure that the joint is being properly penetrated. The overall reduction in fillet weld size, increased speed of welding, reduced heat input and reduction of internal stresses and distortion may make the effort worthwhile.

The general rule for fillet weld size is **the leg should be the same size as the thickness of the metals**. If 1/4" thick plate is being welded, a 1/4" leg fillet is needed to properly join the members. The old saying, "If a little is good, a lot is better," may be true in some cases but not with fillet welds.

Consider again the 1/4" thick plate. If a lot of weld would be better, think of 1/2" legs on the fillet. This would result in what is termed over-welding. This weld is not just twice as large as required, but its volume is three times that required. This wastes weld metal, the welder's time, causes more distortion and may even weaken the structure because of residual stress. Figure 7.13 shows correct and incorrect fillet welds.

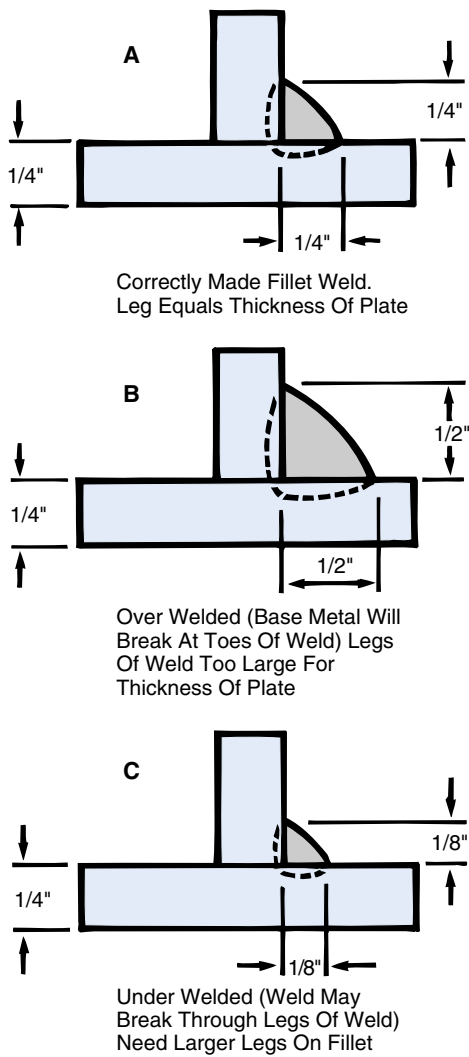


Figure 7.13 Correct/incorrect fillets.

A weld or weld joint is no stronger than its weakest point. Even though B of Figure 7.13 would appear to be much stronger, it will not support more stress than A. It may even support less stress due to the additional residual stresses built up in the joint that is over-welded.

When metals of different thicknesses are to be joined, such as welding a 1/4" thick plate onto a 1/2" thick plate in the form of a T-joint, the rule for fillet weld size is **size of fillet weld leg should equal the thickness of the metal being welded**. Since there are two different thicknesses, the best weld results will be obtained by making an unequal leg fillet weld. Figure 7.14 shows correct and incorrect examples.

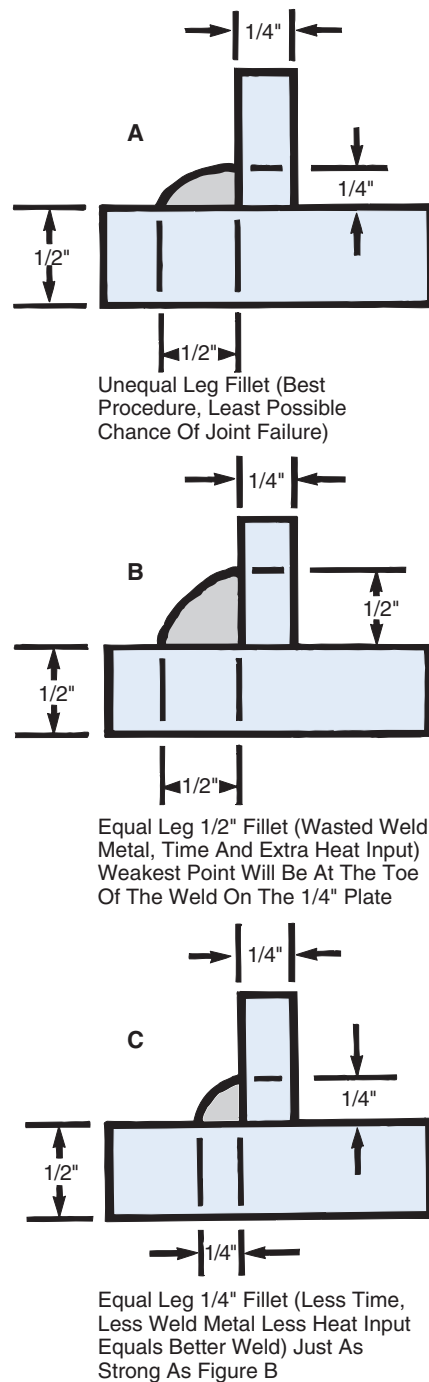


Figure 7.14 Unequal leg fillet.

The correct, unequal leg fillet weld has a 1/4" weld leg on the 1/4" plate and a 1/2" weld leg on the 1/2" plate. This would be the best way to handle this weldment. However, consider the results of making the weld with an equal leg fillet. There would then be two choices: a 1/2" fillet or a 1/4" fillet. In this instance, the 1/4" fillet would be the more practical, since a weldment is no stronger than its weakest point. The extra welds in the 1/2" fillet will also require more time, electrode wire, and induce more heat into the metal, causing more residual stress.

Groove Welds

The groove name is taken from the profile of the groove. A groove weld is made in square, V, bevel, U, J, flare-V or flare-bevel type grooves between workpieces. These are the most common type grooves to be encountered with the TIG process. Review Figure 7.4 for typical grooves found on butt type joints.

Square-Groove

A square-groove weld can be made with either a closed or an open groove. Usually if the base metal is thin (such as thin sheet metal gauge thicknesses), a square groove weld can be used. Remember the higher a gauge number, the thinner the material. In the base metal thickness range of 1/8" to 1/4", it is good to weld both sides of an open-square-groove-weld to provide proper penetration into the groove. Usually, open-square-groove-welds will not be made with groove openings of more than about 5/32". In some cases where welding is done from only one side of the joint, a temporary or permanent backup bar or strip can be used. On critical welds, a consumable insert can be used. These backings or inserts can ensure proper joint penetration, help avoid excessive melt-through, or provide a flush backing to the weld.

V-Groove

V-groove weld designs require careful preparation, yet they are quite popular. V-groove welds are usually made on medium to thicker metals, and are used quite often for pipe welding. They can provide excellent weld quality if properly completed. V-groove weld designs may or may not use permanent or temporary backups or consumable inserts, depending upon the joint design and type of joint penetration needed. Usually if backups are used, root openings can be somewhat wider.

The groove angle for a groove weld must be large enough for the torch to fit into the groove. The groove angle depends upon metal thickness, desired electrode extension and torch nozzle size. Usually V-groove welds are made on material over 1/8" to 1/4" in thickness. Adjusting the root face thickness can help control penetration.

Usually, the root pass of a weld without backing is done with some melt-through. Proper penetration and fusion of the root pass is necessary to avoid weld defects.

V-groove welds are often made on material up to about 3/8" thickness, while double V-groove welds are normally made on thicker materials up to roughly 3/4" in thickness. Double V-groove welds on thicker materials can use less deposited weld metal and limit distortion in the weld, especially if a small root face of about 1/8" is used on each member. Usually the weld passes on such a joint would be made alternating from one side of the joint to the other, helping avoid distortion.

Bevel-Groove

The bevel-groove weld also requires preparation, but in this case only one member need be beveled. The single bevel-groove can be used on material up to about 3/8", while double bevel-grooves are used on thicker material up to about 3/4". In most cases, up to 1/8" root openings are used on single and double bevels. Backing may or may not be used on single bevel-grooves, depending upon joint penetration requirements. A bevel-groove is sometimes used when welding in the horizontal position. Root faces up to about 1/8" are normally used for either single or double bevel-grooves.

U- and J-Grooves

On thicker materials, U- or J-grooves can provide good penetration. They do not use as much deposited weld metal as a V-groove or bevel-groove joint design. With thicker materials, the U- and J-grooves can be used with a smaller groove angle and still maintain proper fusion. A normal groove angle for either a U- or J-groove is about 20° to 25°. This would also apply to the double U- and double J-grooves.

One disadvantage of U- and J-groove design is the preparation of the base material. Air carbon arc, plasma gouging or special mechanical cutting tools are required for preparation of the J- or U-type design. V- or bevel-grooves are easier to prepare.

Flare-V and Flare-Bevel

Flared-groove welds are named after the shape of the base members to be welded. One or both of the members have a type of rounded edge, which already forms a groove for welding. They take their shape from the curved, bent or circular material the joint is being constructed from. Usually no preparation is needed for flare type groove welds.

Groove Weld Size

When a weld is called for on a joint, the size of the weld is important for the joint to carry the load applied to it. In order to understand groove weld size, it is important to understand some of the terms applied to typical groove—such as a V-groove joint. One must have an understanding of groove angle, bevel angle, root face and root opening. These are shown in Figure 7.15.

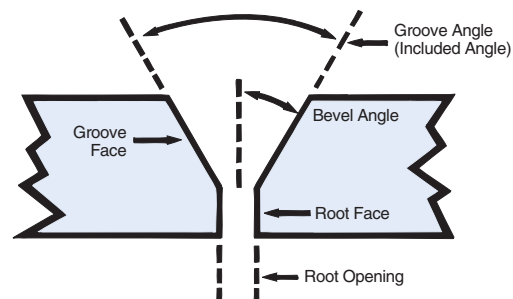


Figure 7.15 V-Groove butt joint with terms.

If a groove weld is indicated and no weld size is specified, a full size weld completely penetrating the joint should be used. If the weld size can be made smaller, indications of this should be shown on the drawing and welding symbol. Smaller weld size is referred to as a partial penetration joint and is acceptable if it will carry the applied load.

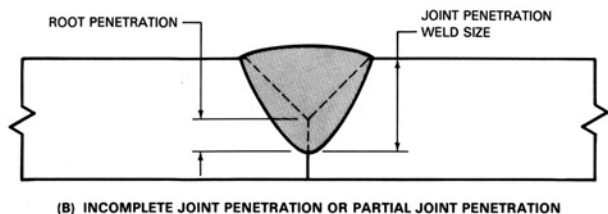


Figure 7.16 V-Groove butt joint with partial joint penetration and terms.

The groove weld size relates to how deep the weld fuses into the joint. The groove should be completely filled, excess fill called weld reinforcement should be minimal. Any extra reinforcement decreases the strength of the joint by creating extra stresses at the weld toes. In most cases, the weld size does not take any weld reinforcement into its measurement. Figure 7.17 shows a complete joint penetration groove weld.

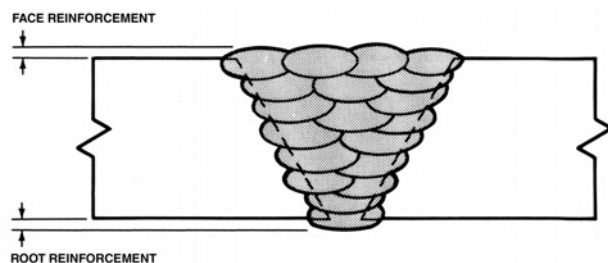


Figure 7.17 V-Groove butt joint multi-pass weld with complete joint penetration with face and root reinforcement shown.

By reducing the bevel angle and thus the groove angle, the amount of weld metal required to fill the groove is reduced. Figure 7.18 shows the great reduction in weld volume by decreasing the groove angle from 60° to 45°.

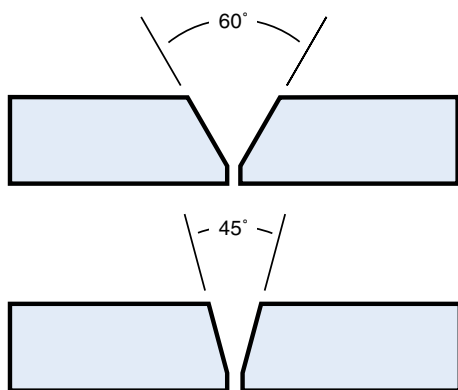


Figure 7.18 Compare joint designs.

A smaller groove angle can reduce the cost of filler metal needed to fill the joint and thus help to reduce time and labor costs. The amount of heat input to the joint is reduced, which will reduce distortion and residual stresses that could cause the weld to crack. Less scrap is produced, as less metal is removed to produce the smaller beveled angle. When changing the groove angle, the weld size must be maintained.

Joint design for various types of groove welds can be expensive, since some groove weld joints require more preparation than others. Therefore, it is helpful to know when preparation is necessary and when it can be avoided.

Weld Length

Fillet and groove welds are usually made the full length of the joint. In some cases, fillet welded joints can achieve their full strength by only welding a portion of the joint. The effective length of a fillet weld is measured as the overall length of the full-size fillet weld. The start and stop of the weld must be allowed for in the length measurement. The TIG process is very capable of making excellent starts and with crater filling to the welds full cross section. However, the weld starts and stops are not square so allowance is made when measuring the length to account for the start and stop radius.

If a specific weld length is specified, it will be shown on the print. In some cases, the fillet weld will be made at intermittent intervals. The spaces between the welds are determined by the center-to-center distance of the welds, which is called the pitch. If intermittent fillet welds are called for, the print will indicate their length and pitch.

Multiplying the weld length with the weld size equals the weld area. $\text{Area} = \text{weld size} \times \text{weld length}$. It is important to understand that this will determine how much stress the joint can take. The design engineer is aware of the base material properties and the loads it will see in service and applies the formula. $\text{Stress} = \text{Load} / \text{Weld Area}$. Safety margins are built in and the designer applies the weld size and length to the print. Much weld efficiencies are lost due to over welding; follow the specifications on the print and do not over weld.

Weld Positions

When discussing groove welds a “G” is used to signify a groove weld, and a number is assigned to signify welding position. Plate weld designations are as:

- 1G — flat position, groove weld
- 2G — horizontal position, groove weld
- 3G — vertical position, groove weld
- 4G — overhead position, groove weld

Pipe welds as:

- 1G — flat position groove weld, pipe rotated
- 2G — horizontal groove weld, pipe axis is vertical
- 5G — multiple positions (overhead, vertical and flat) groove weld, pipe axis is horizontal and is not rotated
- 6G and 6GR — multiple positions groove weld, pipe axis is 45° from horizontal and is not rotated

Figure 7.19 represents a graphic view of these groove weld positions on plate and pipe.

When discussing fillet welds an “F” is used to signify a fillet weld, and a number is assigned to signify the welding position. Plate positions are designated as:

- 1F — flat position, fillet weld
- 2F — horizontal position, fillet weld
- 3F — vertical position, fillet weld
- 4F — overhead position, fillet weld

Pipe positions as:

- 1F — flat position, fillet weld pipe axis is 45° from the horizontal and the pipe is rotated
- 2F — horizontal position, fillet weld pipe axis is vertical
- 2FR — horizontal position, fillet weld pipe axis is horizontal and the pipe is rotated
- 4F — overhead position, fillet weld pipe axis is vertical
- 5F — multiple positions (overhead, vertical and horizontal), fillet weld pipe axis is horizontal and is not rotated
- 6F — multiple positions, fillet weld pipe axis is 45° from horizontal and is not rotated

Figure 7.20 represents a graphic view of these fillet weld positions on plate and pipe.

If possible, it is best to make both fillet and groove welds in the flat (1) position. This allows for proper penetration, proper wetting action and avoidance of undercut. Positioners are often used to keep welds in the flat position for the highest weld productivity. However, there are times when this is not possible and the weld must be made in the position encountered. The TIG process is very applicable to welding in all positions, as the filler metal is deposited directly in the weld pool and does not transfer across the arc as it does in other arc welding processes. Proper welding techniques must still be observed to weld in the various positions.

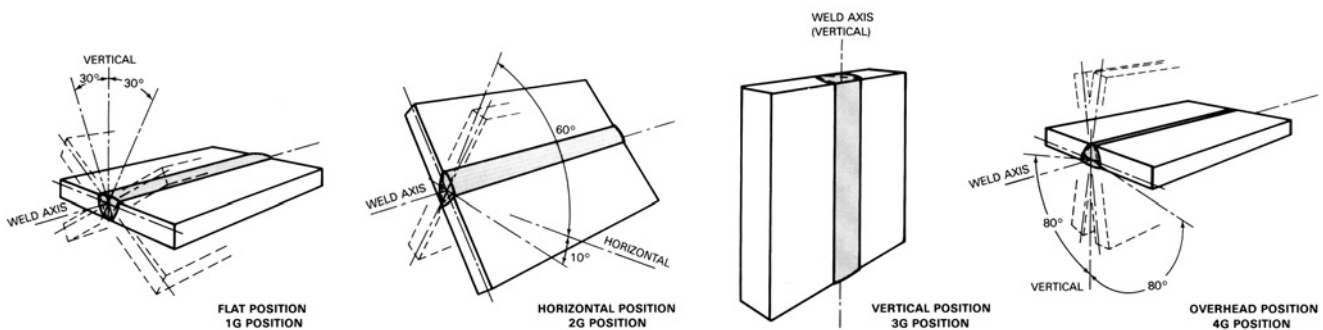


Figure 7.19 Groove weld positions.

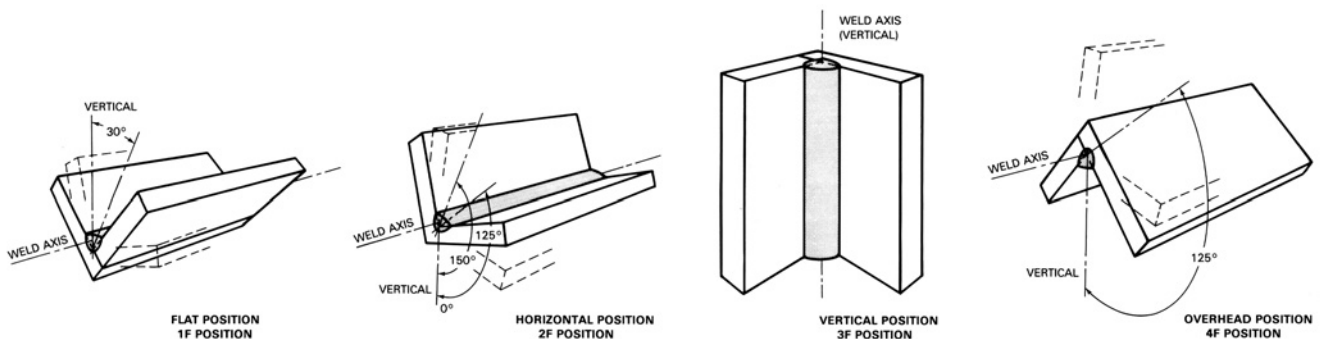


Figure 7.20 Fillet weld positions.