cesses that require less skill and are less costly, it is still preferred in some manual operations where close control of heat input is required.

In the atomic-hydrogen process, an arc is established between two tungsten electrodes in a stream of hydrogen gas using alternating current. As the gas passes through the arc, molecular hydrogen is dissociated into atomic hydrogen under the intense heat. When the stream of hydrogen atoms strikes the workpiece, the environmental temperature is then at a level where recombining into molecules is possible. As a result of the recombining, the heat of dissociation absorbed in the arc is liberated, supplying the heat needed for fusing the base metal and any filler metal that may be introduced.

The atomic-hydrogen process depends on an arc, but is really a heating torch. The arc supplies the heat through the intermediate of the molecular-dissociation, atom-recombination mechanism. The hydrogen gas, however, does more than provide the mechanism for heat transfer. Before entering the arc, it acts as a shield and a coolant to keep the tungsten electrodes from overheating. At the weld puddle, the gas acts as a shield. Since hydrogen is a powerful reducing agent, any rust in the weld area is reduced to iron, and no oxide can form or exist in the hydrogen atmosphere. Weld metal, however, can absorb hydrogen, with unfavorable metallurgical effects. For this reason, the process gives difficulties with steels containing sulfur or selenium, since hydrogen reacts with these elements to form hydrogen sulfide or hydrogen selenide gases. These are almost insoluble in molten metal and either bubble out of the weld pool vigorously or become entrapped in the solidifying metal, resulting in porosity.

14.7 ARC-WELDING CONSUMABLES

Arc-welding consumables are the materials used up during welding, such as electrodes, filler rods, fluxes, and externally applied shielding gases. With the exception of the gases, all the commonly used consumables are covered by AWS specifications.

Twenty specifications in the AWS A5.x series prescribed the requirements for welding electrodes, rods, and fluxes.

14.7.1 Electrodes, Rods, and Fluxes

The first specification for mild-steel-covered electrodes, A5.1, was written in 1940. As the welding industry expanded and the number of types of electrodes for welding steel increased, it became necessary to devise a system of electrode classification to avoid confusion. The system used applies to both the mild-steel A5.1 and the low-alloy steel A5.5 specifications.

Classifications of *mild and low-alloy steel electrodes* are based on an *E* prefix and a four- or five-digit number. The first two digits (or three, in a five-digit number) indicate the minimum required tensile strength in thousands of pounds per square inch. For example, 60 = 60 kpsi, 70 = 70 kpsi, and 100 = 100 kpsi. The next to the last digit indicates the welding position in which the electrode is capable of making satisfactory welds: 1 = all positions—flat, horizontal, vertical, and overhead; 2 = flat and horizontal fillet welding (see Table 14.1). The last digit indicates the type of current to be used and the type of covering on the electrode (see Table 14.2).

Originally a color identification system was developed by the National Electrical Manufacturers Association (NEMA) in conjunction with the AWS to identify the electrode's classification. This was a system of color markings applied in a specific relationship on the electrode, as in Fig. 14.13*a*. The colors and their significance are

TABLE 14.1 AWS A5.1-69 and A5.5-69 Designations for Manual Electrodes

a. The prefix *E* designates arc-welding electrode.

b. The first two digits of four-digit numbers and the first three digits of five-digit numbers indicate minimum tensile strength:

E 60XX	60 000 psi minimum tensile strength
E 70XX	70 000 psi minimum tensile strength
E110XX	110 000 psi minimum tensile strength

c. The next-to-last digit indicates position:

EXX1X	All positions
EXX2X	Flat position and horizontal fillets

d. The suffix (for example, EXXXX-*A1*) indicates the approximate alloy in the weld deposit:

-A1	0.5% Mo
-B1	0.5% Cr, 0.5% Mo
-B2	1.25% Cr, 0.5% Mo
-B3	2.25% Cr, 1% Mo
-B4	2% Cr, 0.5% Mo
-B5	0.5% Cr, 1% Mo
-C1	2.5% Ni
-C2	3.25% Ni
-C3	1% Ni, 0.35% Mo, 0.15% Cr
-D1 and D2	0.25 to 0.45% Mo, 1.75% Mn
-G	0.5% min Ni, 0.3% min Cr, 0.2% min Mo, 0.1% min V, 1% min Mn (only one element required)

listed in Tables 14.3 and 14.4. The NEMA specification also included the choice of imprinting the classification number on the electrode, as in Fig. 14.13*b*.

Starting in 1964, new and revised AWS specifications for covered electrodes required that the classification number be imprinted on the covering, as in Fig. 14.13*b*. However, some electrodes can be manufactured faster than the imprinting equipment can mark them, and some sizes are too small to be legibly marked with an imprint. Although AWS specifies an imprint, the color code is accepted on electrodes if imprinting is not practical.

Bare mild-steel electrodes (electrode wires) for submerged-arc welding are classified on the basis of chemical composition, as shown in Table 14.5. In this classifying system, the letter *E* indicates an electrode as in the other classifying systems, but

TABLE 14.2 AWS A5.1-69 Electrode Designations for Covered Arc-Welding Electrodes

Designation	Current	Covering type
EXX10	dc+ only	Organic
EXX11	ac or dc+	Organic
EXX12	ac or dc−	Rutile
EXX13	ac or dc±	Rutile
EXX14	ac or dc±	Rutile, iron-powder (approx. 30%)
EXX15	dc+ only	Low-hydrogen
EXX16	ac or dc+	Low-hydrogen
EXX18	ac or dc+	Low-hydrogen, iron-powder (approx. 25%)
EXX20	ac or dc±	High iron-oxide
EXX24	ac or dc±	Rutile, iron-powder (approx. 50%)
EXX27	ac or dc±	Mineral, iron-powder (approx. 50%)
EXX28	ac or dc+	Low-hydrogen, iron-powder (approx. 50%)

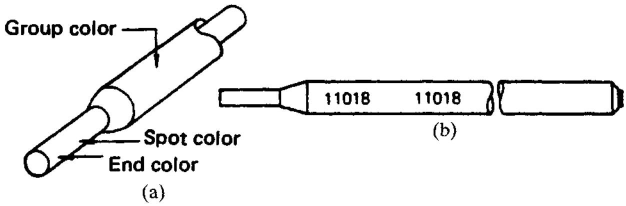


FIGURE 14.13 (*a*) National Electrical Manufacturers Association color-code method to identify an electrode's classification. (*b*) American Welding Society imprint method. *(The Lincoln Electric Company.)*

here the similarity stops. The next letter, *L, M,* or *H,* indicates low, medium, or high manganese, respectively. The following number or numbers indicate the approximate carbon content in hundredths of one percent. If there is a suffix *K,* this indicates a silicon-killed steel.

Fluxes for submerged-arc welding are classified on the basis of the mechanical properties of the weld deposit made with a particular electrode. The classification designation given to a flux consists of a prefix *F* (indicating a flux) followed by a two-digit number representative of the tensile-strength and impact requirements for test welds made in accordance with the specification. This is then followed by a

TABLE 14.3 Color Identification for Covered Mild-Steel and Low-Alloy Steel Electrodes

Spot color	End color			
	No color	Blue	Black	Orange
Group color—No color				
XX10, XX11, XX14, XX24, XX27, XX28, and all 60 XX				
No color	E6010	E7010G	....	EST
White	E6012	E7010-Ai	....	EC1
Brown	E6013	....	E7014	
Green	E6020			
Blue	E6011	E7011G		
Yellow	....	E7011-A1	E7024	
Black	....	....	E7028	
Silver	E6027			
Group color—Silver				
All XX13 and XX20 except E6013 and E6020				
Brown				
White				
Green	....	E7020G		
Yellow	....	E7020-A1		

TABLE 14.4 Color Identification for Covered Low-Hydrogen Low-Alloy Electrodes

Spot color	End color									
	No color	Blue	Black	White	Gray	Brown	Violet	Green	Red	Orange
Group color—Green										
XX15, XX16, and XX18, except E6015 and E6016										
Red	E7015G	E7015	....	....	E8015G	E9015G	....	E10015G	....	E12015G
White	....	E7015-A1	E90150-B3L	....	....	E9015-D1				
Brown										
Green	....	....	E8015-B2L	....	....	E9015-B3				
Bronze	....	....	E8015-B4L	....	....	E8015-B4				
Orange	E7016G	E7016	E7018	E8016-C3	....	E9016G	....	E10016G	....	E12016G
Yellow	....	E7016-A1	E7018-A1	E8016G	....	E9016-D1	....	E10015-D2	E11016G	
Black	....	....	E8018-C3	E8016-B1	E8018-B1	....	E9018-B3			
Blue	E7018G	....	E8018G	E8016-C1	E8018-C1	E9016-B3	E9018G	E10018G	E11018G	E12018G
Violet	....	....	....	E8016-C2	E8018-C2	E8016-B4	E9018-D1	E10018-D2		
Gray	....	....	E8018-B4	E8016-B2	E8018-B2	....		E10016-D2		
Silver	....	....	Mil-12018							

TABLE 14.5 AWS A5.17-69 Chemical-Composition Requirements for Submerged-Arc Electrodes

AWS classification	Chemical composition, percent						
	Carbon	Manganese	Silicon	Sulfur	Phosphorus	Copper†	Total other elements
Low manganese classes:							
EL8	0.10	0.30–0.55	0.05	0.035	0.03	0.15	0.50
EL8K	0.10	0.30–0.55	0.10–0.20	0.035	0.03	0.15	0.50
EL12	0.07–0.15	0.35–0.60	0.05	0.035	0.03	0.15	0.50
Medium manganese classes:							
EM5K‡	0.06	0.90–1.40	0.40–0.70	0.035	0.03	0.15	0.50
EM12	0.07–0.15	0.85–1.25	0.05	0.035	0.03	0.15	0.50
EM12K	0.07–0.15	0.85–1.25	0.15–0.35	0.035	0.03	0.15	0.50
EM13K	0.07–0.19	0.90–1.40	0.45–0.70	0.035	0.03	0.15	0.50
EM15K	0.12–0.20	0.85–1.25	0.15–0.35	0.035	0.03	0.15	0.50
High manganese class:							
EH14	0.10–0.18	1.75–2.25	0.05	0.035	0.03	0.15	0.50

†The copper limit is independent of any copper or other suitable coating which may be applied to the electrode.

‡This electrode contains 0.05 to 0.15 percent titanium, 0.02 to 0.12 percent zirconium, and 0.05 to 0.15 percent aluminum, which is exclusive of the "Total other elements" requirement.

Note: Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "Total other elements" in the last column of the table. Single values shown are maximum percentages.

set of letters and numbers corresponding to the classification of the electrode used with the flux.

Gas-shielded flux-cored electrodes are available for welding the low-alloy high-tensile steels. *Self-shielded flux-cored electrodes* are available for all-position welding, as in building construction. Fabricators using or anticipating using the flux-cored arc-welding processes should keep in touch with the electrode manufacturers for new or improved electrodes not included in present specifications.

Mild-steel electrodes for gas metal-arc welding of mild and low-alloy steels are classified on the basis of their chemical compositions and the as-welded mechanical properties of the weld metal. Tables 14.6 and 14.7 are illustrative.

AWS specifications for electrodes also cover those used for welding the stainless steels, aluminum and aluminum alloys, and copper and copper alloys, as well as for weld surfacing.

Shielding gases are consumables used with the MIG and TIG welding processes. The AWS does not write specifications for gases. There are federal specifications, but the welding industry usually relies on *welding grade* to describe the required purity.

The primary purpose of a shielding gas is to protect the molten weld metal from contamination by the oxygen and nitrogen in air. The factors, in addition to cost, that affect the suitability of a gas include the influence of the gas on the arcing and metal-transfer characteristics during welding, weld penetration, width of fusion and surface shape, welding speed, and the tendency to undercut. Among the inert gases—helium, argon, neon, krypton, and xenon—the only ones plentiful enough for practical use in welding are helium and argon. These gases provide satisfactory shielding for the more reactive metals, such as aluminum, magnesium, beryllium, columbium, tantalum, titanium, and zirconium.

Although *pure* inert gases protect metal at any temperature from reaction with constituents of the air, they are not suitable for all welding applications. Controlled quantities of reactive gases mixed with inert gases improve the arc action and metal-transfer characteristics when welding steels, but such mixtures are not used for reactive metals.

Oxygen, nitrogen, and carbon dioxide are reactive gases. With the exception of carbon dioxide, these gases are not generally used alone for arc shielding. Carbon dioxide can be used alone or mixed with an inert gas for welding many carbon and low-alloy steels. Oxygen is used in small quantities with one of the inert gases—usually argon. Nitrogen is occasionally used alone, but it is usually mixed with argon as a shielding gas to weld copper. The most extensive use of nitrogen is in Europe, where helium is relatively unavailable.

14.8 DESIGN OF WELDED JOINTS

While designers need some basic knowledge of welding processes, equipment, materials, and techniques, their main interest is in how to transfer forces through welded joints most effectively and efficiently. Proper joint design is the key to good weld design.

The loads in a welded-steel design are transferred from one member to another through welds placed in weld joints. Both the type of joint and the type of weld are specified by the designer.

Figure 14.14 shows the joint and weld types. Specifying a joint does not by itself describe the type of weld to be used. Thus 10 types of welds are shown for making a

TABLE 14.6 AWS A5.18-69 Mechanical Property Requirements for Gas Metal-Arc Welding Weld Metal[†]

Electrode group	AWS classification	Shielding gas[a]	Current and polarity[b]	Tensile strength[d] min., kpsi	Yield strength[e] min., kpsi	Elongation in 2 in[d] min., %
A. Mild steel	E70S-1	AO	dc, reverse	72	60	22
	E70S-2 E70S-3	AO and CO_2^c				
	E70S-4 E70S-5 E70S-6	CO_2				
	E70s-g	Not specified				
B. Low-alloy steel	E70S-1b E70S-GB	CO_2 Not specified	dc, reverse Not specified	72 72	60 60	17 22
C. Emissive	E70U-1	AO and A[c]	dc, straight	72	60	22

†As-welded mechanical properties determined from an all-weld-metal tension-test specimen.
[a]Shielding gases are AO, argon plus 1 to 5 percent oxygen; CO_2, carbon dioxide; A, argon.
[b]*Reverse polarity* means electrode is positive; *straight polarity* means electrode is negative.
[c]Where two gases are listed as interchangeable (that is, AO and CO_2 and AO and A) for classification of a specific electrode, the classification may be conducted using either gas.
[d]For each increase of one percentage point in elongation over the minimum, the yield strength or tensile strength, or both, may decrease 1 kpsi to a minimum of 70 kpsi for the tensile strength and 58 kpsi for the yield strength, except for group C electrodes.
[e]0.2 percent offset value.

TABLE 14.7 AWS A5.18-69 Chemical-Composition Requirements for Gas Metal-Arc Welding Electrode

AWS classification	Chemical composition, percent											
	Carbon	Manganese	Silicon	Phosphorus	Sulfur	Nickel†	Chromium†	Molybdenum†	Vanadium†	Titanium	Zirconium	Aluminum
Group A: Mild-steel electroces												
E70S-1	0.07–0.19	0.90–1.40	0.30–0.50	0.025	0.035							
E70S-2	0.06	0.90–1.40	0.40–0.70	0.025	0.035					0.05–0.15	0.02–0.12	0.05–0.15
E70S-3	0.06–0.15	0.90–1.40	0.45–0.70	0.025	0.035							
E70S-4	0.07–0.15	0.90–1.40	0.65–0.85	0.025	0.035							
E70S-5	0.07–0.19	0.90–1.40	0.30–0.60	0.025	0.035							0.50–0.90
E70S-6	0.07–0.15	1.40–1.85	0.80–1.15	0.025	0.035							
E70S-G	No chemical requirements‡											
Group B: Low-alloy steel electrodes												
E70S-1B	0.07–0.12	1.60–2.10	0.50–0.80	0.025	0.035	0.15		0.40–0.60				
E70S-GB	No chemical requirements											
Group C: Emissive electrode												
E70U-1	0.07–0.15	0.80–1.40	0.15–0.35	0.025	0.035							

†For groups A and C these elements may be present but are not intentionally added.

‡For this classification there are no chemical requirements for the elements listed with the exception that there shall be no intentional addition of Ni, Cr, Mo or V.

Note: Single values shown are maximums.

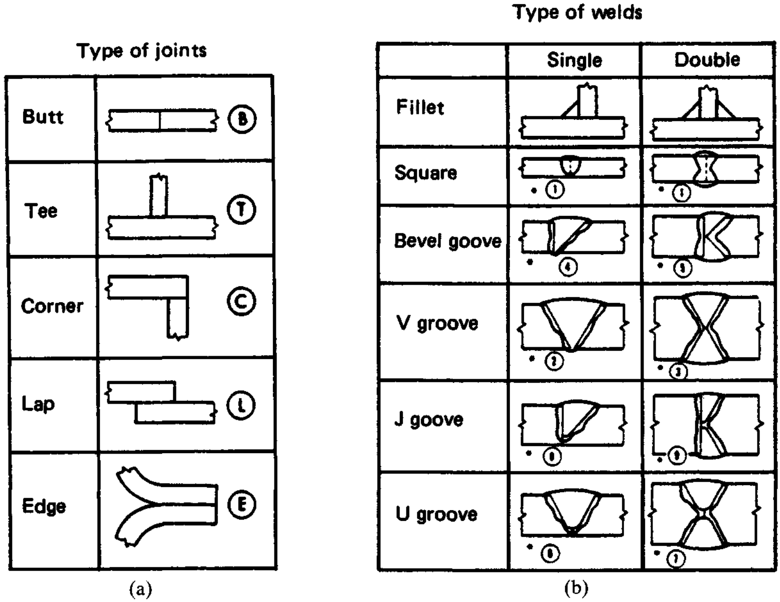


FIGURE 14.14 (*a*) Joint design; (*b*) weld grooves. *(The Lincoln Electric Company.)*

butt joint. Although all but two welds are illustrated with butt joints here, some may be used with other types of joints. Thus a single-bevel weld may also be used in a T or corner joint (Fig. 14.15), and a single-V weld may be used in a corner, T, or butt joint.

14.8.1 Fillet-Welded Joints

The fillet weld, requiring no groove preparation, is one of the most commonly used welds. Corner welds are also widely used in machine design. Various corner arrangements are illustrated in Fig. 14.16. The corner-to-corner joint, as in Fig. 14.16*a*, is difficult to assemble because neither plate can be supported by the other. A small electrode with low welding current must be used so that the first welding pass does not burn through. The joint requires a large amount of metal. The corner joint shown in Fig. 14.16*b* is easy to assemble, does not easily burn through, and requires just half

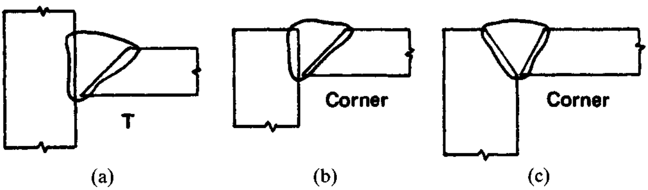


FIGURE 14.15 (*a*) Single-bevel weld used in T joint and (*b*) corner joint; (*c*) single-V weld in corner joint. *(The Lincoln Electric Company.)*

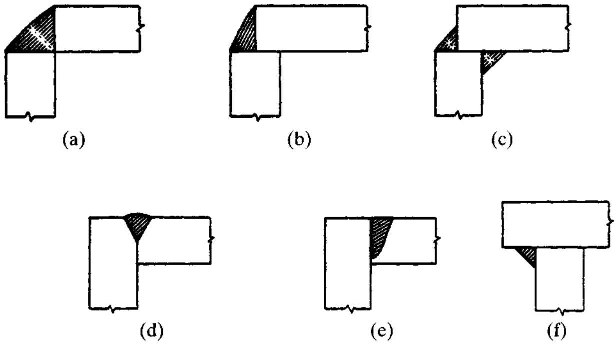


FIGURE 14.16 Various corner joints. *(The Lincoln Electric Company.)*

the amount of the weld metal as the joint in Fig. 14.16*a*. However, by using half the weld size but placing two welds, one outside and the other inside, as in Fig. 14.16*c*, it is possible to obtain the same total throat as with the first weld, but only half the weld metal need be used.

With thick plates, a partial-penetration groove joint, as in Fig. 14.16*d*, is often used. This requires beveling. For a deeper joint, a J preparation, as in Fig. 14.16*e*, may be used in preference to a bevel. The fillet weld in Fig. 14.16*f* is out of sight and makes a neat and economical corner.

The size of the weld should always be designed with reference to the size of the thinner member. The joint cannot be made any stronger by using the thicker member for the weld size, and much more weld metal will be required, as illustrated in Fig. 14.17.

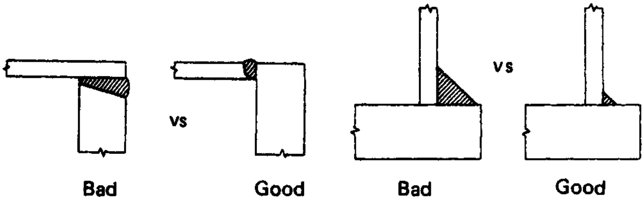


FIGURE 14.17 Size of weld should be determined with reference to thinner member. *(The Lincoln Electric Company.)*

In the United States, a fillet weld is measured by the leg size of the largest right triangle that may be inscribed within the cross-sectional area (Fig. 14.18). The throat, a better index to strength, is the shortest distance between the root of the joint and the face of the diagrammatical weld. As Fig. 14.18 shows, the leg size used may be shorter than the actual leg of the weld. With convex fillets, the actual throat may be longer than the throat of the inscribed triangle.

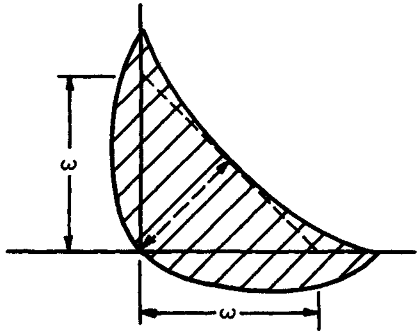


FIGURE 14.18 Leg size ω of a fillet weld. *(The Lincoln Electric Company.)*

14.8.2 Groove and Fillet Combinations

A combination of a partial-penetration groove weld and a fillet weld (Fig. 14.19) is used for many joints. The AWS prequalified single-bevel groove T joint is reinforced with a fillet weld.

The designer is frequently faced with the question of whether to use fillet or groove welds (Fig. 14.20). Here cost becomes a major consideration. The fillet welds in Fig. 14.20*a* are easy to apply and require no special plate preparation. They can be made using large-diameter electrodes with high welding currents, and as a consequence, the deposition rate is high. The cost of the welds increases as the square of the leg size.

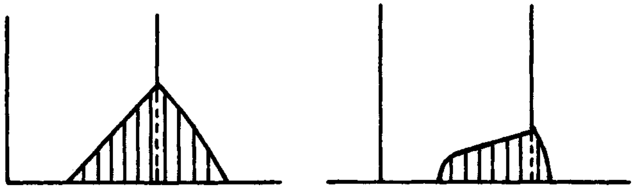


FIGURE 14.19 Combined groove- and fillet-welded joints. *(The Lincoln Electric Company.)*

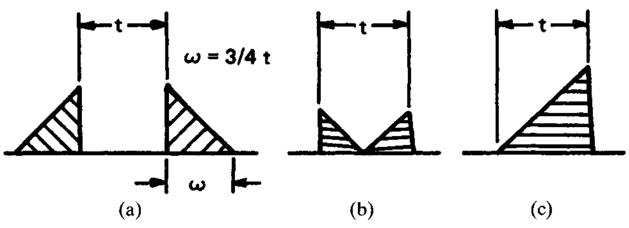


FIGURE 14.20 Comparison of fillet welds and groove welds. *(The Lincoln Electric Company.)*

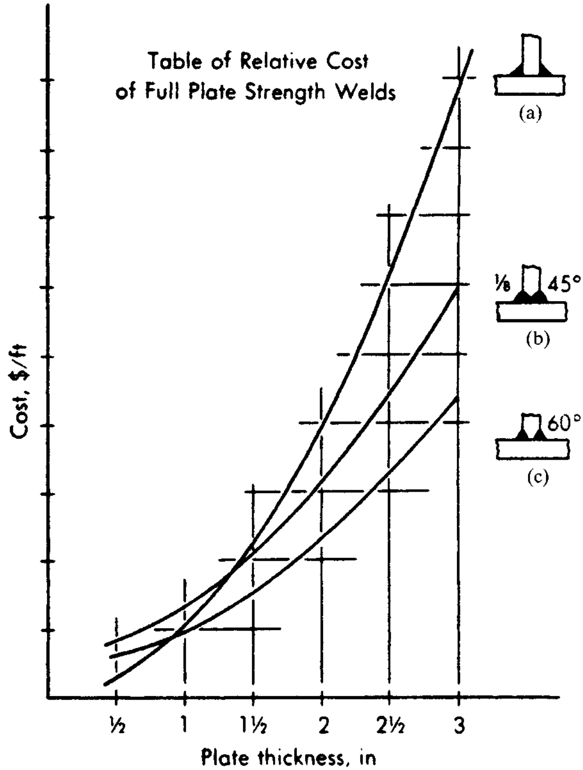


FIGURE 14.21 Relative cost of welds having the full strength of the plate. *(The Lincoln Electric Company.)*

In comparison, the double-bevel groove weld in Fig. 14.20*b* has about one-half the weld area of the fillet welds. However, it requires extra preparation and the use of smaller-diameter electrodes with lower welding currents to place the initial pass without burning through. As plate thickness increases, this initial low-deposition region becomes a less important factor and the higher cost factor decreases in significance. The construction of a curve based on the best possible determination of the actual cost of welding, cutting, and assembling, such as that illustrated in Fig. 14.21, is a possible technique for deciding at what point in plate thickness the double-bevel groove weld becomes less costly. The point of intersection of the fillet-weld curve with the groove-weld curve is the point of interest. The accuracy of this device is dependent on the accuracy of the cost data used in constructing the curves.

Referring to Fig. 14.20*c*, it will be noted that the single-bevel groove weld requires about the same amount of weld metal as the fillet welds deposited in Fig. 14.20*a*. Thus there is no apparent economic advantage. There are some disadvantages, though. The single-bevel joint requires bevel preparation and initially a lower deposition rate at the root of the joint. From a design standpoint, however, it offers a direct transfer of force through the joint, which means that it is probably better under fatigue loading. Although the illustrated full-strength fillet weld, having leg

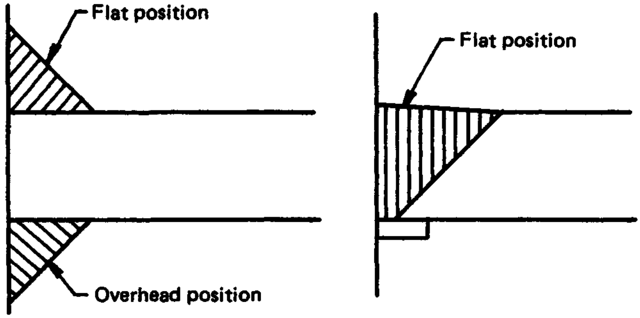


FIGURE 14.22 In the flat position, a single-bevel groove joint is less expensive than fillet welds in making a T joint. *(The Lincoln Electric Company.)*

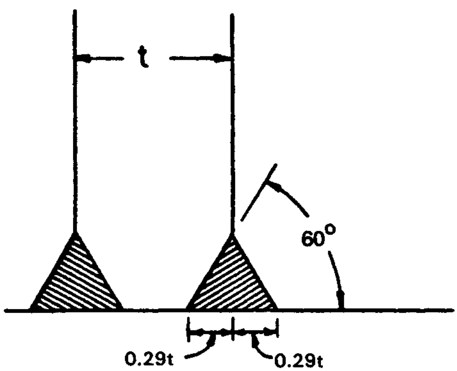


FIGURE 14.23 Partial-penetration double-bevel groove joint. *(The Lincoln Electric Company.)*

sizes equal to three-quarters the plate thickness, would be sufficient, some codes have lower allowable limits for welds, and many require a leg size equal to the plate thickness. In this case, the cost of the fillet-welded joint may exceed the cost of the single-bevel groove-welded joint in thicker plates. Also, if the joint is so positioned that the weld can be made in the flat position, a single-bevel groove weld would be less expensive than fillet welds. As can be seen in Fig. 14.22, one of the fillets would have to be made in the overhead position—a costly operation.

The partial-penetration double-bevel groove joint shown in Fig. 14.23 has been suggested as a full-strength weld. The plate is beveled to 60 degrees on both sides to give a penetration of at least 29 percent of the thickness of the plate (0.29*t*). After the groove is filled, it is reinforced with a fillet weld of equal cross-sectional area and shape. This partial-penetration double-bevel groove joint uses 57.8 percent of the weld metal used by the full-strength fillet weld. It requires joint preparation, but the 60-degree angle allows the use of large electrodes and high welding current.

Full-strength welds are not always required in the design, and economies can often be achieved by using partial-strength welds where these are applicable and

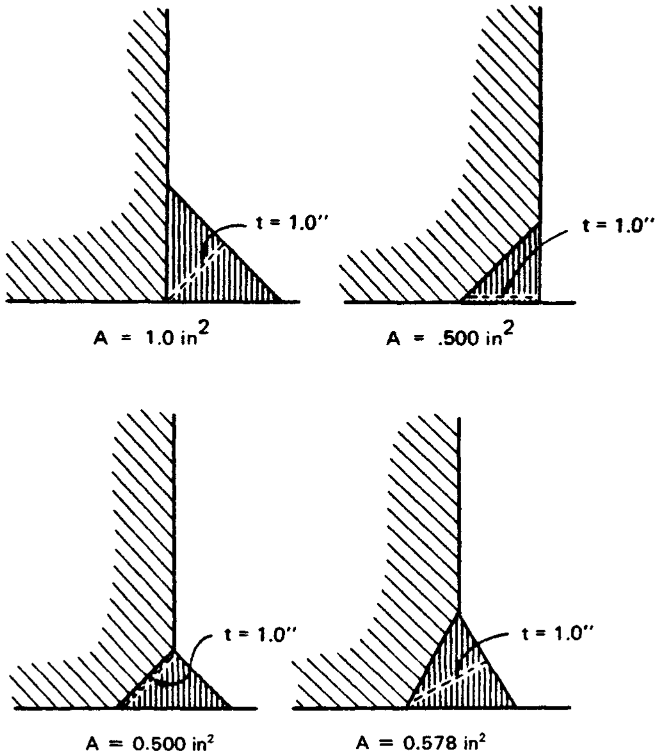


FIGURE 14.24 Comparison of weld joints having equal throats. *(The Lincoln Electric Company.)*

permissible. Referring to Fig. 14.24, it can be seen that on the basis of an unreinforced 1-in throat, a 45-degree partial-penetration single-bevel groove weld requires just one-half the weld area needed for a fillet weld. Such a weld may not be as economical as the same-strength fillet weld, however, because of the cost of edge preparation and the need to use a smaller electrode and lower current on the initial pass.

If the single-bevel groove joint were reinforced with an equal-leg fillet weld, the cross-sectional area for the same throat size would still be one-half the area of the

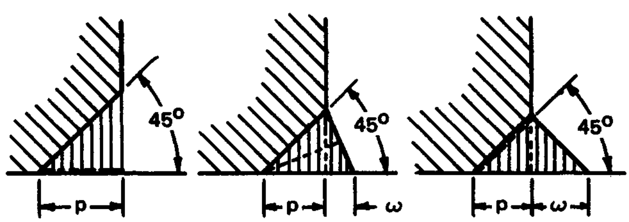


FIGURE 14.25 Comparison of weld joints with and without reinforcing fillet welds. *(The Lincoln Electric Company.)*

fillet, and less beveling would be required. The single-bevel 60-degree groove joint with an equal fillet-weld reinforcement for the same throat size would have an area 57.8 percent of that of the simple fillet weld. This joint has the benefit of smaller cross-sectional area—yet the 60-degree included angle allows the use of higher welding current and larger electrodes. The only disadvantage is the extra cost of preparation.

From this discussion it is apparent that the simple fillet-welded joint is the easiest to make, but it may require excessive weld metal for larger sizes. The single-bevel 45-degree included-angle joint is a good choice for larger weld sizes. However, one would miss opportunities by selecting the two extreme conditions of these two joints. The joints between these two should be considered. Referring to Fig. 14.25, one may start with the single-bevel 45-degree joint without the reinforcing fillet weld, gradually add a reinforcement, and finally increase the lower leg of the fillet reinforcement until a full 45-degree fillet weld is reached. In this figure, p = depth of preparation and ω = leg of reinforcing fillet.

When a partial-penetration groove weld is reinforced with a fillet weld, the minimum throat is used for design purposes, just as the minimum throat of a fillet or partial-penetration groove weld is used. However, as Fig. 14.26 shows, the allowable load for this combination weld is not the sum of the allowable limits for each portion of the combination weld. This would result in a total throat much larger than the actual throat.

Figure 14.27*a* shows the effect of using the incorrect throat in determining the allowable unit force on a combination weld. The allowable[†] for each weld was added separately. In Fig. 14.27*b*, weld size is correctly figured on the minimum throat.

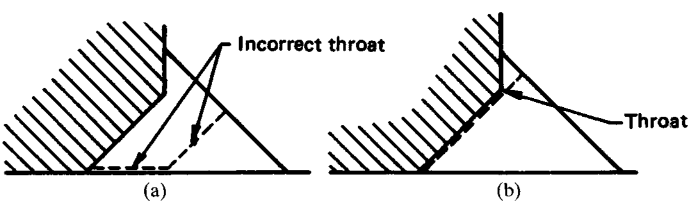


FIGURE 14.26 Determining minimum throat. (*a*) Incorrect result; (*b*) correct result. *(The Lincoln Electric Company.)*

14.8.3 Sizing of Fillets

Table 14.8 gives the sizing of fillet welds for rigidity at various strengths and plate thicknesses, where the strength of the weld metal matches the plate.

In machine design work, where the primary design requirement is rigidity, members are often made with extra-heavy sections, so that movement under load will be within very close tolerances. Because of the heavy construction, stresses are very low. Often the allowable stress in tension for mild steel is given as 20 kpsi, yet the welded machine base or frame may have a working stress of only 2 to 4 kpsi. The question arises as to how to determine the weld sizes for these types of rigidity designs.

[†] The term *allowable* is often used in the welding industry to indicate allowable load, allowable stress, or unit allowable load—EDS.

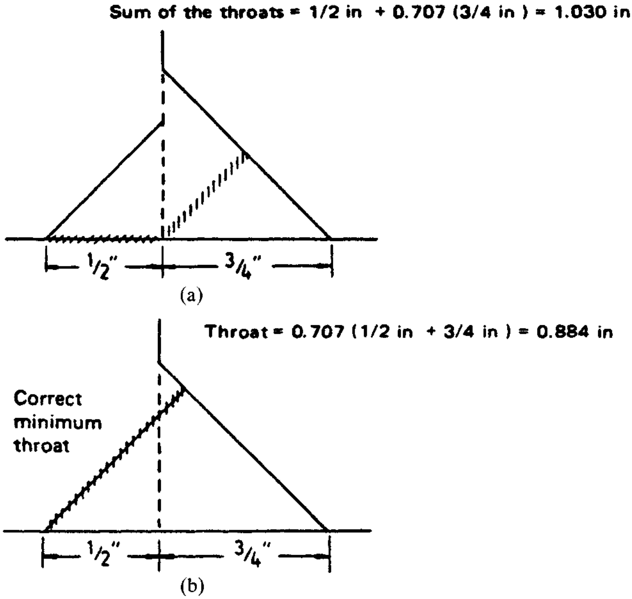


FIGURE 14.27 Examples showing the effect of correct and incorrect throat dimension in determining the allowable load on a combination weld. (*a*) The weld allowable load would be incorrectly figured by adding each weld throat separately; (*b*) weld allowable load is correctly figured using the minimum throat. *(The Lincoln Electric Company.)*

It is not very practical to first calculate the stresses resulting in a weldment when the unit is loaded within a predetermined dimensional tolerance and then use these stresses to determine the forces that must be transferred through the connecting welds. A very practical method, however, is to design the weld for the thinner plate, making it sufficient to carry one-third to one-half the carrying capacity of the plate. This means that if the plate were stressed to one-third to one-half its usual value, the weld would be sufficient. Most rigidity designs are stressed much below these values; however, any reduction in weld size below one-third the full-strength value would give a weld too small an appearance for general acceptance.

14.8.4 Groove Joints

Figure 14.28*a* indicates that the *root opening R* is the separation between the members to be joined. A root opening is used for electrode accessibility to the base or root of the joint. The smaller the angle of the bevel, the larger the root opening must be to get good fusion at the root. If the root opening is too small, root fusion is more difficult to obtain, and smaller electrodes must be used, thus slowing down the welding process. If the root opening is too large, weld quality does not suffer, but more weld metal is required; this increases welding cost and will tend to increase distortion.

TABLE 14.8 Rule-of-Thumb Fillet-Weld Sizes for Use in Cases Where the Strength of the Weld Metal Matches the Strength of the Plate

Plate thickness t, in	Strength design, full-strength weld, $\omega = 0.75t$	Rigidity design: 50% of full-strength weld, $\omega = 0.375t$	Rigidity design: 33% of full-strength weld, $\omega = 0.25t$
< 1/4	1/8	1/8†	1/8†
1/4	3/16	3/16†	3/16†
5/16	1/4	3/16†	3/16†
3/8	5/16	3/16†	3/16†
7/16	3/8	3/16	3/16†
1/2	3/8	3/16	3/16†
9/16	7/16	1/4	1/4†
5/8	1/2	1/4	1/4†
3/4	9/16	5/16	1/4†
7/8	5/8	3/8	5/16†
1	3/4	3/8	5/16†
1 1/8	7/8	7/16	5/16
1 1/4	1	1/2	5/16
1 3/8	1	1/2	3/8
1 1/2	1 1/8	9/16	3/8
1 5/8	1 1/4	5/8	7/16
1 3/4	1 3/8	3/4	7/16
2	1 1/2	3/4	1/2
2 1/8	1 5/8	7/8	9/16
2 1/4	1 3/4	7/8	9/16
2 3/8	1 3/4	1	5/8
2 1/2	1 7/8	1	5/8
2 5/8	2	1	3/4
2 3/4	2	1	3/4
3	2 1/4	1 1/8	3/4

†These values have been adjusted to comply with AWS recommended minimums.
SOURCE: The Lincoln Electric Company, Cleveland, Ohio.

Figure 14.28*b* indicates how the root opening must be increased as the included angle of the bevel is decreased. Backup strips are used on larger root openings. All three preparations are acceptable; all are conducive to good welding procedure and good weld quality. Selection, therefore, is usually based on cost.

Root openings and joint preparation will directly affect weld cost (mass of weld metal required), and the choice should be made with this in mind. Joint preparation involves the work required on plate edges prior to welding and includes beveling and providing a root face.

Using a double-groove joint in preference to a single-groove joint (Fig. 14.29) cuts in half the amount of welding. This reduces distortion and makes possible alternating the weld passes on each side of the joint, again reducing distortion.

In Fig. 14.30*a*, if the bevel or gap is too small, the weld will bridge the gap, leaving slag at the root. Excessive back-gouging is then required. Figure 14.30*b* shows how

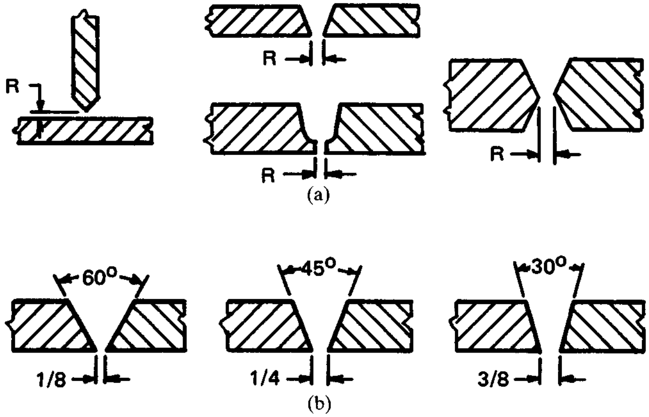


FIGURE 14.28 (*a*) Root opening is designated as *R;* (*b*) size of root opening depends on bevel angle. *(The Lincoln Electric Company.)*

proper joint preparation and procedure will produce good root fusion and will minimize back-gouging. In Fig. 14.30*c,* a large root opening will result in burnthrough. Spacer strip may be used, in which case the joint must be back-gouged.

Backup strips are commonly used when all welding must be done from one side or when the root opening is excessive. Backup strips, shown in Fig. 14.31*a* through *c,* are generally left in place and become an integral part of the joint. Spacer strips may be used, especially in the case of double-V joints, to prevent burnthrough. The spacer in Fig. 14.31*d* used to prevent burnthrough will be gouged out before welding the second side.

14.8.5 Backup Strips

Backup strip material should conform to the base metal. Feather edges of the plate are recommended when using a backup strip.

Short, intermittent tack welds should be used to hold the backup strip in place, and these should preferably be staggered to reduce any initial restraint on the joint. They should not be directly opposite one another (Fig. 14.32).

The backup strip should be in intimate contact with both plate edges to avoid trapped slag at the root, as shown in Fig. 14.33. On a butt joint, a nominal weld reinforcement (approximately $\frac{1}{16}$ in above flush) is all that is necessary, as shown in Fig.

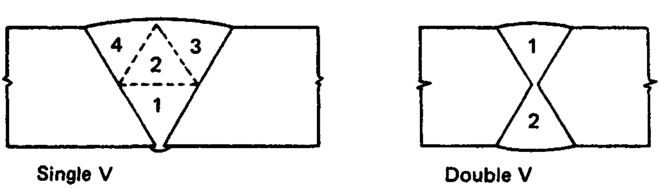


FIGURE 14.29 Using a double-groove joint in place of a single-groove joint reduces the amount of welding. *(The Lincoln Electric Company.)*

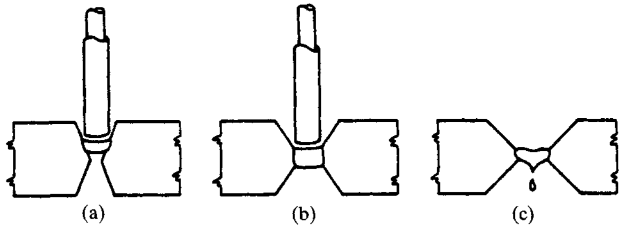


FIGURE 14.30 (*a*) If the gap is too small, the weld will bridge the gap, leaving slag at the root; (*b*) a proper joint preparation; (*c*) a root opening that is too large will result in burnthrough. *(The Lincoln Electric Company.)*

14.34*a*. Additional buildup, as shown in Fig. 14.34*b*, serves no useful purpose and will increase the weld cost. Care should be taken to keep both the width and the height of the reinforcement to a minimum.

14.8.6 Edge Preparation

The main purpose of a root face (Fig. 14.35*a*) is to provide an additional thickness of metal, as opposed to a feather edge, in order to minimize any burnthrough tendency. A feather-edge preparation is more prone to burnthrough than a joint with a root face, especially if the gap gets a little too large (Fig. 14.35*b*).

A root face is not as easily obtained as a feather edge. A feather edge is generally a matter of one cut with a torch, whereas a root face will usually require two cuts or possibly a torch cut plus machining.

A root face usually requires back-gouging if a 100 percent weld is required. A root face is not recommended when welding into a backup strip, since a gas pocket would be formed.

Plate edges are beveled to permit accessibility to all parts of the joint and to ensure good fusion throughout the entire weld cross section. Accessibility can be gained by compromising between maximum bevel and minimum root opening (Fig. 14.36).

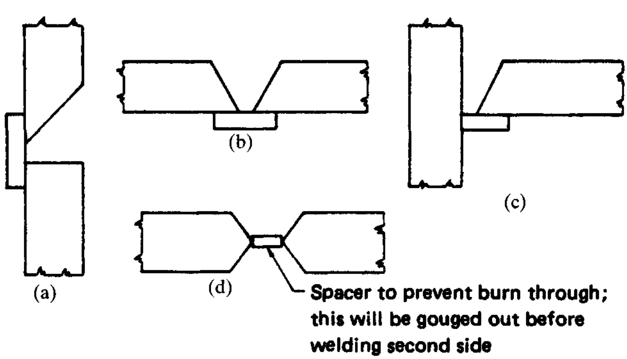


FIGURE 14.31 The backup strips shown in (*a*), (*b*), and (*c*) are used when all welding is done from one side or when the root opening is excessive; a spacer to prevent burnthrough as shown in (*d*) will be gouged out before welding the second side. *(The Lincoln Electric Company.)*

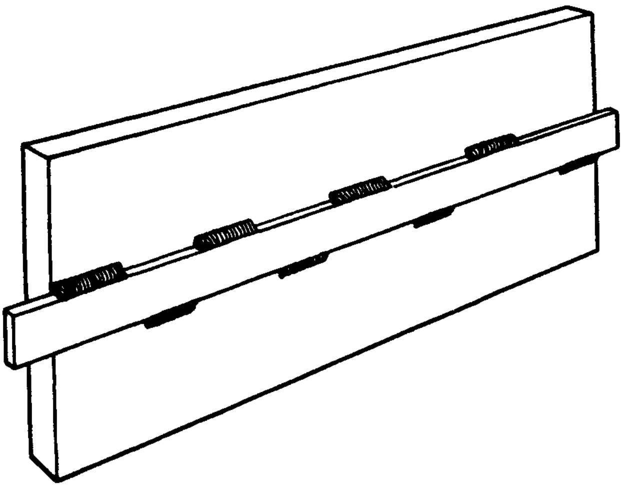


FIGURE 14.32 Short, intermittent tack welds should be used to hold the backup strip in place. *(The Lincoln Electric Company.)*

Degree of bevel may be dictated by the importance of maintaining proper electrode angle in confined quarters (Fig. 14.37). For the joint illustrated, the minimum recommended bevel is 45 degrees.

J and U preparations are excellent to work with, but economically they may have little to offer because preparation requires machining as opposed to simple torch cutting. Also, a J or U groove requires a root face (Fig. 14.38) and thus back-gouging.

To consistently obtain complete fusion when welding a plate, back-gouging is required on virtually all joints except bevel joints with a feather edge. This may be done by any convenient means: grinding, chipping, or gouging. The latter method is generally the most economical and leaves an ideal contour for subsequent beads.

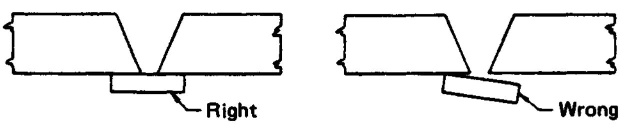


FIGURE 14.33 The backup strip should be in intimate contact with both edges of the plate. *(The Lincoln Electric Company.)*

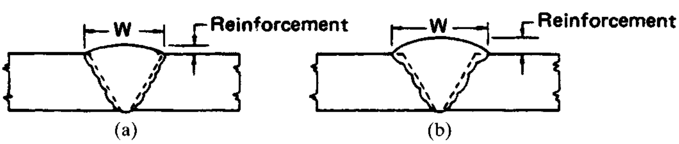


FIGURE 14.34 (*a*) A minimum reinforcement on a butt joint is preferred; (*b*) too much reinforcement. *(The Lincoln Electric Company.)*

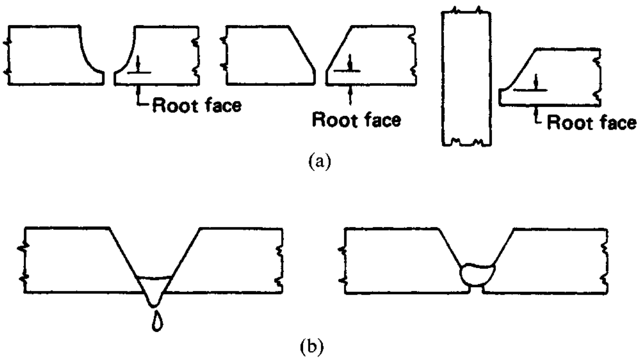


FIGURE 14.35 (*a*) A root face minimizes the tendency to burnthrough; (*b*) a feather edge is more prone to burnthrough than a joint with a root face. *(The Lincoln Electric Company.)*

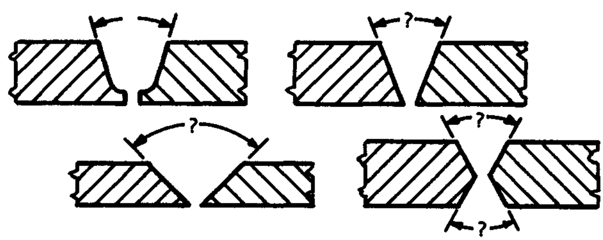


FIGURE 14.36 Accessibility is gained by compromising between bevel and root opening. *(The Lincoln Electric Company.)*

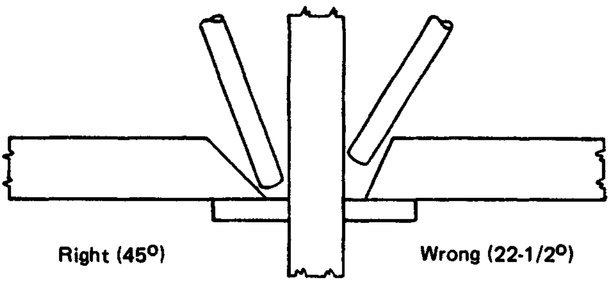


FIGURE 14.37 Degree of bevel may be dictated by the need for maintaining proper electrode angle. *(The Lincoln Electric Company.)*

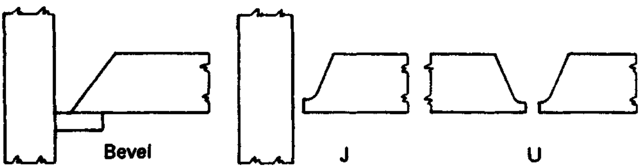


FIGURE 14.38 A bevel preparation with a backup strip may be more economical than a J or U groove. *(The Lincoln Electric Company.)*

Without back-gouging, penetration is incomplete (Fig. 14.39*a*). Proper back-chipping should be deep enough to expose sound weld metal, and the contour should permit the electrode complete accessibility (Fig. 14.39*b*).

14.9 CODES AND SPECIFICATIONS FOR WELDS

Welds are designed and executed in accordance with codes, standards, and specifications intended to enhance the integrity of the product and its safe performance in use. Codes and specifications are generally written by industrial groups, trade or professional organizations, or government bureaus, and each code or specification deals with applications pertaining specifically to the interest of the authoring body. Large manufacturing organizations may prepare their own specifications to meet their specific needs.

Among the major national organizations that write codes that involve arc welding are the American Welding Society (AWS), the American Institute of Steel Construction (AISC), the American Society for Testing Materials (ASTM), the American Society of Mechanical Engineers (ASME), and the American Petroleum Institute (API).

Among government agencies, the Interstate Commerce Commission (ICC) has rules for the fabrication of over-the-road vehicles and for containers used in interstate commerce. The various branches of the military services also prepare specifi-

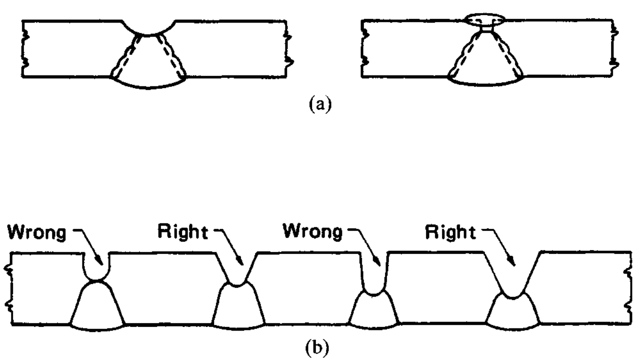


FIGURE 14.39 (*a*) Without back-gouging, penetration is incomplete; (*b*) proper back-gouging should be deep enough to expose sound weld metal. *(The Lincoln Electric Company.)*

cations. Some specifications—for example, those of the Society of Automotive Engineers (SAE)—actually are not standards, but are merely guides to recommended practices. Other specifications rigidly call out the design and fabrication procedures to be followed and are legally binding. In any event, neither the design nor the fabrication of a welded structure should be undertaken without full knowledge of all codes and requirements that must be met.

Meeting the requirements of a code does not protect anyone against liability concerning the performance of the welds or structure. Nor, in general, does any code-writing body approve, endorse, guarantee, or in any way attest to the correctness of the procedures, designs, or materials selected for code application.

The strength values permitted by governing codes are called *allowables*. Thus there are specified allowables for shear stress and unit force on various sizes of fillet welds, and there are fatigue allowables for various welds in reference to the geometry of the joint. Most weldments used in machinery are made in accordance with AWS and AISC specifications, with ASME and API rules applicable where pressure vessels and piping are involved.

14.9.1 Allowable Shear and Unit Forces

The basic formula for allowable shear stress τ for weld metal in a fillet or partial-penetration bevel-groove weld has been established by the AWS and AISC as

$$\tau = 0.30S_t \tag{14.1}$$

where S_t = minimum tensile strength. Table 14.9 shows the values for various weld-metal strength levels obtained by this formula and the more common fillet-weld sizes. These values are for equal-leg fillet welds where the effective throat t_e = 0.707ω, where ω is the leg size. With Table 14.9 one can calculate the allowable unit force f per linear inch for a weld size made with a particular electrode type. For example, calculating the allowable unit force f per inch for a ½-in fillet weld made with an E70 electrode gives

$$\begin{aligned} f = 0.707\omega\tau &= 0.707\omega\tau(0.30S_t) \\ &= 0.707(\tfrac{1}{2})(0.30)(70)(10)^3 \\ &= 7420 \text{ lb per linear inch} \end{aligned}$$

An AISC provision gives limited credit for penetration beyond the root of a fillet weld made with the submerged-arc process. Since penetration increases the effective throat thickness of the weld, as shown in Fig. 14.40, the provision permits an increase in this value when calculating weld strength. For fillet welds ⅜ in and smaller, the effective throat t_e is now equal to the leg size of the weld ω. Thus,

$$t_e = \omega \qquad \omega \le \tfrac{3}{8} \text{ in} \tag{14.2}$$

For submerged-arc fillet welds larger than ⅜ in, the effective throat of the weld is obtained by adding 0.11 to 0.707ω. Thus,

$$t_e = 0.707\omega + 0.11 \qquad \omega > \tfrac{3}{8} \text{ in} \tag{14.3}$$

TABLE 14.9 Allowable Unit Load for Various Sizes of Fillet Welds

Tensile strength of weld metal, kpsi						
S_t =	60	70	80	90	100	110
Allowable shear stress on throat of fillet weld or partial-penetration groove weld, kpsi						
τ =	18.0	21.0	24.0	27.0	30.0	33.0
Allowable unit force on fillet weld kip/linear in						
f =	12.73	14.85	16.97	19.09	21.21	23.33
Leg size ω, in	**Allowable unit force for various sizes of fillet welds, kip/linear in**					
1	12.73	14.85	16.97	19.09	21.21	23.33
$\frac{7}{8}$	11.14	12.99	14.85	16.70	18.57	20.41
$\frac{3}{4}$	9.55	11.14	12.73	14.32	15.92	17.50
$\frac{5}{8}$	7.96	9.28	10.61	11.93	13.27	14.58
$\frac{1}{2}$	6.37	7.42	8.48	9.54	10.61	11.67
$\frac{7}{16}$	5.57	6.50	7.42	8.35	9.28	10.21
$\frac{3}{8}$	4.77	5.57	6.36	7.16	7.95	8.75
$\frac{5}{16}$	3.98	4.64	5.30	5.97	6.63	7.29
$\frac{1}{4}$	3.18	3.71	4.24	4.77	5.30	5.83
$\frac{3}{16}$	2.39	2.78	3.18	3.58	3.98	4.38
$\frac{1}{8}$	1.59	1.86	2.12	2.39	2.65	2.92
$\frac{1}{16}$	0.795	0.930	1.06	1.19	1.33	1.46

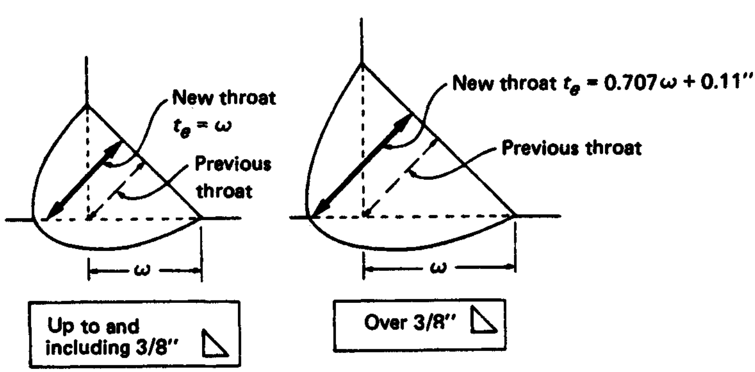


FIGURE 14.40 The AISC gives credit for penetration beyond the root of fillets made with the submerged-arc process. *(The Lincoln Electric Company.)*

where t_e is in inches. Note that allowance for penetration applies only to fillet welds made by the submerged-arc welding process. Electrode polarity will provide this penetration.

14.9.2 Minimum Fillet-Weld Size

The minimum sizes of fillet welds for specific material thicknesses are shown in Table 14.10. In the AISC Specifications and the AWS Structural Welding Code, this table has been expanded to include material less than ¼ in thick and ⅛-in fillets. Where materials of different thicknesses are being joined, the minimum fillet weld size is governed by the thicker material, but this size does not have to exceed the thickness of the thinner material unless required by the calculated stress.

TABLE 14.10 Minimum Fillet-Weld Size ω in Inches

Material thickness of thicker part joined	Minimum fillet size
To ¼ inclusive	⅛
Over ¼ to ½	3/16
Over ½ to ¾	¼
Over ¾ to 1½	5/16
Over 1½ to 2¼	⅜
Over 2¼ to 6	½
Over 6	⅝

SOURCE: AISC Specifications, Sec. 1.17.5.

14.9.3 Allowables for Weld Metal—A Handy Reference

Table 14.11 summarizes the AWS Structural Welding Code and AISC allowables for weld metal. It is intended to provide a ready reference for picking the proper strength levels for the various types of steels. Once this selection has been made, the allowables can be quickly found for the various types of welds that may be required for the specific assembly.

14.9.4 AISC Fatigue Allowables

The AISC Specifications include fatigue allowables, which also are accepted by the AWS Building Code, Sec. 8. Therefore, designers have something other than the AWS Building Code, Sec. 10, Bridges, with its automatic 10 percent lower allowable design stress, on which to base fatigue considerations.

Although developed for structures, these allowables are adaptable to the fatigue problems of machine-tool makers, equipment manufacturers, and others who fabricate with welded steel. They cover a wide range of welded joints and members and not only provide values for various types of welds, but also take into consideration the strength of members attached by welds.

The conventional method of handling fatigue is based on a maximum fatigue stress. The AISC-suggested method is based on the range of stress. Either may be used in design; they will give comparable values. The AISC method is generally quicker.

Under the new approach, the allowables for members are designed *M* and for welds *W*. A tensile load is *T*, a compressive load *C*, a reversal *R*, and shear *S*. In the chart used for determining values for allowable range of stress (Fig. 14.41), there are four groups representing life. These are

1. 20 000 to 100 000 cycles
2. Over 100 000 to 500 000 cycles
3. Over 500 000 to 2 000 000 cycles
4. Over 2 000 000 cycles

And there are eight different categories representing type of joint and detail of member. The chart provides the allowable range in stress σ_{sr} or τ_{sr}, which value may be used in the conventional fatigue formulas. These formulas are

$$\sigma_{max} = \frac{\sigma_{sr}}{1 - K} \quad \text{or} \quad \sigma_{max} = \frac{\tau_{sr}}{1 - K} \tag{14.4}$$

where

$$K = \frac{\text{min. stress}}{\text{max. stress}} = \frac{\text{min. force}}{\text{max. force}}$$

$$= \frac{\text{min. moment}}{\text{max. moment}} = \frac{\text{min. shear}}{\text{max. shear}} \tag{14.5}$$

Of course, the maximum allowable fatigue value used should not exceed the allowable for steady loading.

An alternative use of the allowable range of stress—taken from the table—is to divide it into the range of applied load. This will provide the required property of the section—area or section modulus. The section, as determined, must additionally be large enough to support the total load (dead and live load) at steady allowable stresses.

Reference to the chart of joint types and conditions and the table of allowable range of stress for the different categories (Fig. 14.41) will help make clear their use. Such reference also points up some of the new ideas introduced.

One new concept is that the fatigue allowable of a member, for example, a welded plate girder as shown by (2) in the chart (Fig. 14.41), is now determined by the allowable of the plate when connected by the fillet welds parallel to the direction of the applied stress. M and W are equal, and the applicable category is B, rather than the allowable of plate without welds, category A.

If stiffeners are used on the girder, as in (4), the fatigue allowable of the web or flange is determined by the allowable in the member at the termination of the weld or adjacent to the weld, category C or D, depending on the shear value in the web.

The fatigue allowable of a flange plate at the termination of a cover plate, either square or tapered end, is represented by (5). The applicable category is E. The same category also applies to a plate or cover plate adjacent to the termination of an intermittent fillet weld, as in (6) and (39).

Groove welds in butt joints of plate loaded transversely to the weld are shown in (8) to (14). In (15), the groove weld is parallel to the load. In (10), (13), (14), (15), and

TABLE 14.11 Permissible Stress of Weld†

<table>
<tr><th>Type of Weld Stress</th><th>Permissible Stress</th><th>Required Strength Level (1)(2)</th></tr>
<tr><td colspan="3">COMPLETE PENETRATION GROOVE WELDS</td></tr>
<tr><td>Tension normal to the effective throat.</td><td>Same as base metal.</td><td>Matching weld metal must be used. See Table below.</td></tr>
<tr><td>Compression normal to the effective throat.</td><td>Same as base metal.</td><td>Weld metal with a strength level equal to or one classification (10 ksi) less than matching weld metal may be used.</td></tr>
<tr><td>Tension or compression parallel to the axis of the weld.</td><td>Same as base metal.</td><td rowspan="2">Weld metal with a strength level equal to or less than matching weld metal may be used.</td></tr>
<tr><td>Shear on the effective throat.</td><td>.30 x Nominal Tensile strength of weld metal (ksi) except stress on base metal shall not exceed .40 x yield stress of base metal.</td></tr>
<tr><td colspan="3">PARTIAL PENETRATION GROOVE WELDS</td></tr>
<tr><td>Compression normal to effective throat.</td><td>Designed not to bear – .50 x Nominal Tensile strength of weld metal (ksi) except stress on base metal shall not exceed .60 x yield stress of base metal.

Designed to bear. Same as base metal.</td><td rowspan="4">Weld metal with a strength level equal to or less than matching weld metal may be used.</td></tr>
<tr><td>Tension or compression parallel to axis of the weld. (3)</td><td>Same as base metal.</td></tr>
<tr><td>Shear parallel to axis of weld.</td><td>.30 x Nominal Tensile strength of weld metal (ksi) except stress on base metal shall not exceed .40 x yield stress of base metal.</td></tr>
<tr><td>Tension normal to effective throat. (4)</td><td>.30 x Nominal Tensile strength of weld metal (ksi) except stress on base metal shall not exceed .60 x yield stress of base metal.</td></tr>
</table>

FILLET WELDS (3)		
Stress on effective throat, regarless of direction of application of load.	.30 x Nominal Tensile strength of weld metal (ksi) except stress on base metal shall not exceed .40 x yield stress of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.
Tension or compression parallel to axis of weld.	Same as base metal.	
PLUG AND SLOT WELDS		
Shear parallel to faying surfaces.	.30 x Nominal Tensile strength of weld metal (ksi) except stress on base metal shall not exceed .40 x yield stress of base metal.	Weld metal with a strength level equal to or less than matching weld metal may be used.

(1) For matching weld metal, see AISC Table 1.17.2 or AWS Table 4.1.1 or table below.
(2) Weld metal, one strength level (10 KSI) stronger than matching weld metal may be used when using alloy weld metal on A242 or A588 steel to match corrosion resistance or coloring characteristics (Note 3 of Table 4.1.4 or AWS D1.1).
(3) Fillet welds and partial penetration groove welds joining the component elements of built up members (ex. flange to web welds) may be designed without regard to the axial tensile or compressive stress applied to them.
(4) Cannot be used in tension normal to their axis under fatigue loading (AWS 2.5). AWS Bridge prohibits their use on any butt joint (9.12.1.1), or any splice in a tension or compression member (9.17), or splice in beams or girders (9.21), however, are allowed on corner joints parallel to axial force of components of built up members (9.12.1.2 (2). Cannot be used in girder splices (AISC 1.10.8).

MATCHING WELD METAL AND BASE METAL

Weld Metal	60 or 70	70	80	100	110
Type of Steel	A36; A53, Gr. B; A106, Gr. B; A131, Gr. A, B, C, CS, D, E; A139, Gr. B; A381, Gr. Y35; A500, Gr. A, B; A501; A516, Gr. 55, 60; A524, Gr. I, II; A529; A570, Gr. D, E; A573, Gr. 65; A709, Gr. 36; API 5L, Gr. B; API 5LX, Gr. 42; ABS, Gr. A, B, D, CS, DS, E	A131, Gr. AH32, DH32, EH32, AH36, DH36, EH36; A242; A441; A516, Gr. 65; 70; A537, Class 17; A572, Gr. 42, 45, 50, 55; A588 (4 in and under); A595, Gr. A, B, C; A606; A607, Gr. 45, 50, 55; A618; A633, Gr. A, B, C, D (2-1/2 in and under); A709, Gr. 50, 50W; API 2H; ABS Gr. AH32, DH32, EH32, AH36, DH36, EH36.	A572, Gr. 60, 65; A537, Class 2; A63, Gr. E	A514 [over 2-1/2 in (63 mm)] ; A709, Gr. 100, 100W [2-1/2 to 4 in (63 to 102 mm)]	A514 [2-1/2 in (63 mm) and under] ; A517; A709, Gr. 100, 100W [2-1/2 in (63 mm) and under]

†This table summarizes the AISC Specifications and the AWS Structural Welding Code ("Specification for the Design, Fabrication and Erection of Structural Steel for Buildings," American Institute of Steel Construction; AWS D.1-82, American Welding Society).

SOURCE: The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

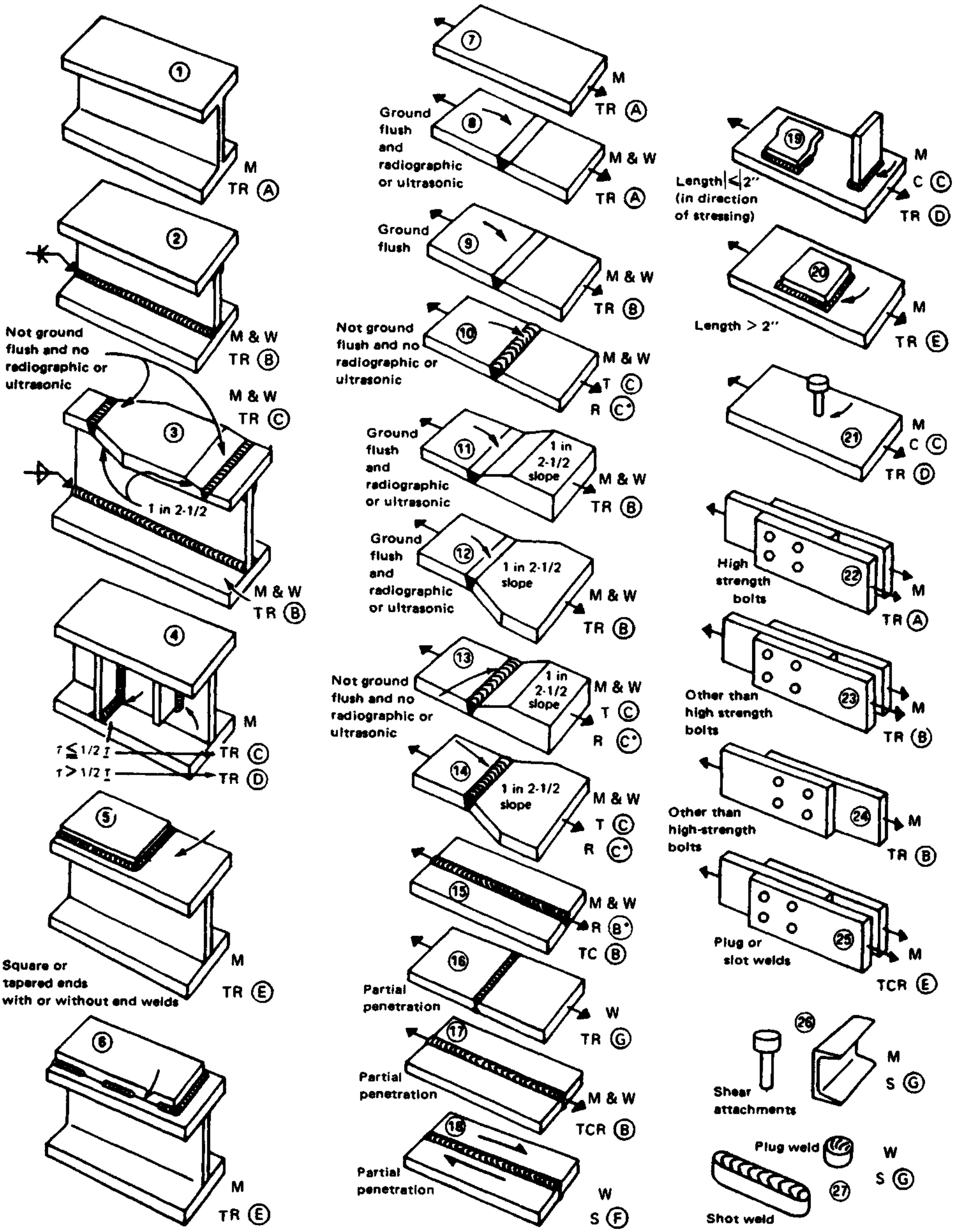
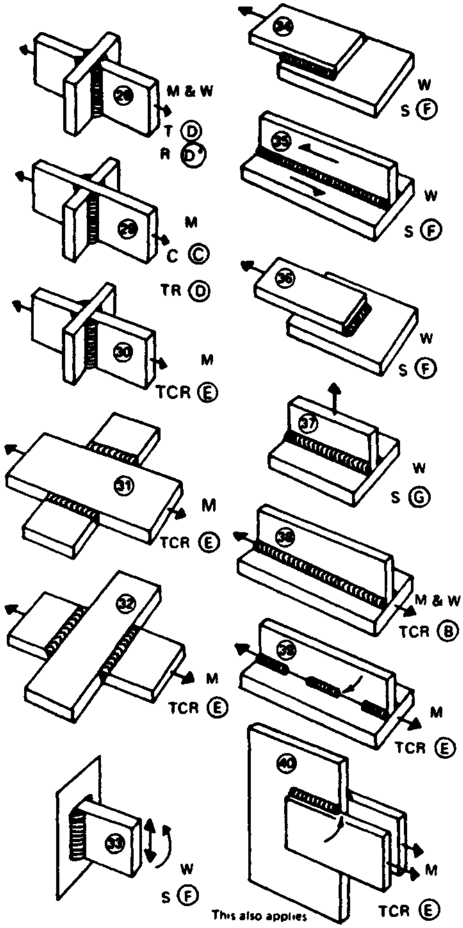


FIGURE 14.41 The AISC allowable range of stress σ_{sr} or τ_{sr}. *(The Lincoln Electric Company.)*



Curved arrow indicates region of application of fatigue allowables

Straight arrows indicate applied forces

Grind in the direction of stressing only

When slope is mentioned (ex. 1 in 2-1/2 this is always the maximum value. Less slope is permissible.

	20 000 to 100 000 ~	100 000 to 500 000 ~	500 000 to 2 000 000 ~	over 2 000 000 ~
Ⓐ A514	45	35	25	25
Ⓐ	40	32	24	24
Ⓑ	33	25	17	15
Ⓒ	28	21	14	12
Ⓓ	24	17	10	9
Ⓔ	17	12	7	6
Ⓕ	17	14	11	9
Ⓖ	15	12	9	8

But shall not exceed steady allowables

Allowable fatigue stress

$$\sigma_{max} = \frac{\sigma_{sr}}{1 - K}$$

For those categories marked with an asterisk (*) in the case of a reversal use

$$* \quad \sigma_{max} = \frac{\sigma_{sr}}{1 - 0.6K}$$

σ_{max} or τ_{max} = maximum allowable fatigue stress

σ_{sr} or τ_{sr} = allowable range of stress, from table

$$K = \frac{\sigma_{min}}{\sigma_{max}} = \frac{M_{min}}{M_{max}} = \frac{F_{min}}{F_{max}} = \frac{\tau_{min}}{\tau_{max}} = \frac{V_{min}}{V_{max}}$$

S = shear
T = tension
C = compression
R = reversal
M = stress in metal
W = stress in weld
$\underline{\tau}$ = allowable steady shear stress

FIGURE 14.41 (*Continued*) The AISC allowable range of stress σ_{sr} or τ_{sr}. *(The Lincoln Electric Company.)*

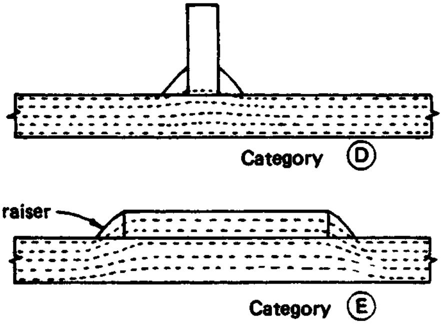


FIGURE 14.42 Note the decreased fatigue strength of the lower joint because of the stress raiser. *(The Lincoln Electric Company.)*

(28), an asterisk appears beside the category for reversal R of load. This means that a modified formula should be used for determining maximum fatigue stress:

$$\sigma_{\max} = \frac{\sigma_{sr}}{1 - 0.6K} \tag{14.6}$$

Using 0.6K provides a slight increase in fatigue allowable in the region of a complete reversal by changing the slope of the fatigue curve. The same butt joints used in a girder (3) do not show this increase in strength, and thus no asterisk appears beside R.

This approach gives, for the first time, fatigue allowables for partial-penetration groove welds, (16) to (18). Note by (19) and (20) that the fatigue allowable for a member with a transverse attachment is higher when the attachment is less than 2 in long, measured parallel to the axis of the load. Although there may be a similar geometric notch effect or abrupt change in section in both, it is the stress raiser that is

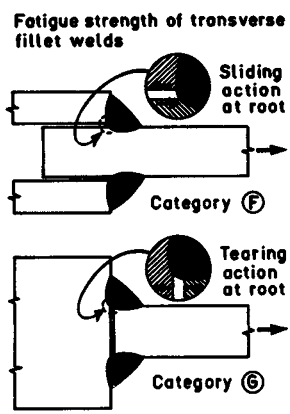


FIGURE 14.43 There is a greater tearing action at the root in category G, warranting a lower fatigue allowable. *(The Lincoln Electric Company.)*

important. The transverse bar in (19) is so short as far as the axis of the member and load are concerned that very little of the force is able to swing up and into the bar and then back down again. Consequently, the stress raiser is not severe. The longer bar attachment in (20), however, is sufficiently long to provide a path for the force through it and the connecting welds. Because of this force transfer through the welds, there will be a higher stress raiser and, as a result, a reduction of the fatigue strength of the member. The difference is illustrated in Fig. 14.42.

Item (30) of the chart, which falls into category E, should not be confused with (37), category G. Both depict transverse fillet welds, but (30) provides a fatigue allowable for the member adjacent to the fillet weld, whereas (37) provides a fatigue shear allowable for the throat of the fillet weld.

Knowing that the steady strength of a transverse fillet is about a third stronger than that of a parallel fillet, one might question why the fatigue allowable for a parallel fillet, (34) and (35), category F, is the same as that for a transverse fillet (36) and higher than that for a transverse fillet (37), category G. The fatigue strength of the transverse fillet (36) is actually higher than that of a parallel fillet (34), but they both fall into the range covered by category F. However, there is a difference in the two transverse fillet welds in (36) and (37). In (36) there may be a slight stress raiser because of the pinching together of forces as they pass through the weld. But in (37) there is a greater tearing action at the root of the weld, thus producing a lower fatigue strength and warranting a lower fatigue allowable. This is illustrated by Fig. 14.43.