
Fundamentals of Arc Welding

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FUNDAMENTALS OF ARC WELDING

Welding is the process of joining two pieces of metal by intense heating with or without the application of pressure or by the application of pressure alone (without heating) and with or without the use of filler material. It is distinguished from other forms of mechanical connections, such as riveting or bolting, which involves friction or mechanical interlocking.

Welding offers many advantages over riveting or bolting:

1. Welded structures are more rigid compared to structures with riveted and bolted connections;
2. Welding gives the appearance of a one-piece construction as against the cluttered surface of bolted or riveted connections;
3. Welded structures allow the elimination of a large percentage of the gusset and splice plates necessary for riveted or bolted structures.
4. Welding saves up to 15% of the steel weight and economies are achieved due to elimination of operations like drilling and punching, It also saves time in detailing and fabrication;
5. The strength of the welded joint equals or exceeds the strength of the original base metal, thereby placing no restriction on the joints;
6. Weld connections offer the designer more freedom for innovation in his design, make changes and to correct mistakes during erection;
7. Welding is practicable for almost all types/shapes of joints; for example, connection of a steel pipe column to other members;
8. Welding offers air tight and water tight joining of plates and hence ideal for oil storage tanks, ships etc.

Some disadvantages:

1. Skilled manpower is needed for operation and inspection of welded connections;
2. Welded joints are highly prone to cracking under fatigue loading - non-destructive evaluation may have to be carried out to detect defects in welds;
3. Costly equipment is essential to make welded connections;

4. Proper welding can not be done in the field environment;
5. Large residual stresses and distortion are developed in welded connections.

In the earlier days, combination of bolting, riveting and welding was not practiced. Structures were completely welded, bolted or riveted. Today, combination of bolting, riveting and welding is commonly used in steel structures but generally combination techniques are not used in one and the same joint. The present trend is to use welding for workshop connections or splices, and high strength bolts for field joints.

There are over 50 different welding processes, but gas and arc welding is most commonly employed in industrial manufacturing.

Gas welding is a non-pressure process using heat from a gas flame. In gas welding a mixture of oxygen and some combustible gas such as MAPP (methylacetylene-propadiene) or acetylene is burned at the tip of a torch. The flame produced is applied directly to the metal edges to be joined and to a filler metal, which is melted to the joint. Gas welding has the advantage of involving equipment that is portable and does not require an electric power source. It is widely used in maintenance and repair work because of the ease in transporting oxygen and fuel cylinders. But, the process is slow compared to other means of welding.

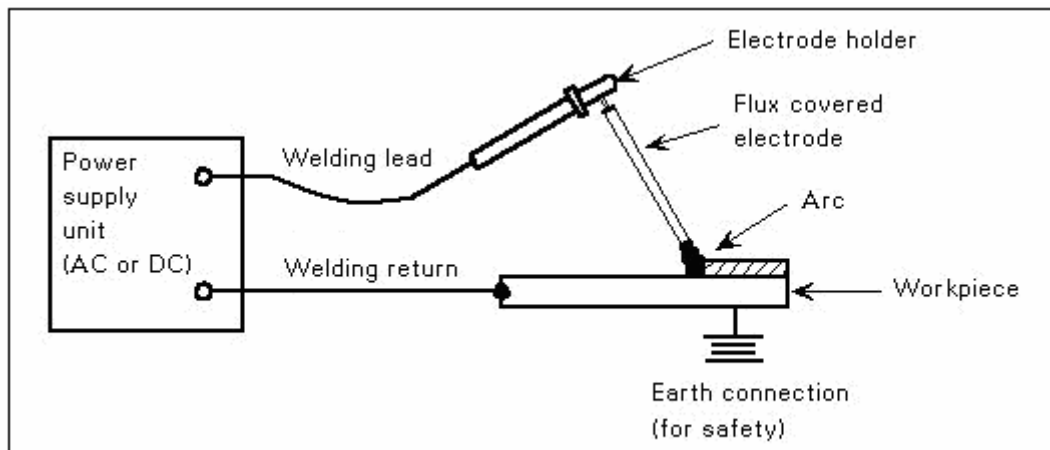
Electric arc welding is by far the most popular fusion process for joining metals in commercial welding practices. In this process, the workpieces are heated to the fusion temperature by an electric arc, causing two parts to be melted and intermixed. Upon cooling and solidification, a metallurgical bond is created. Since the joining is an intermixture of metals, the final weldment potentially has the same strength properties as the metal of the parts.

Almost all structural welding is arc welding. This course is particularly concerned with the arc welding processes commonly used in structural work.

SECTION 1

BASIC ARC WELDING PROCESSES

In arc welding, the intense heat needed to melt metal is produced by an electric arc. The arc is a continuous spark formed between the actual work and an electrode (stick or wire) when a large current at a low voltage is discharged between the electrode and the base metal through an ionized column of gas. The resistance of the air or gas between the electrode and the objects being welded, changes the electric energy into heat. A temperature of 3300°C to 5500°C is produced in the arc.



ARC WELDING CIRCUIT

The welding rod is connected to one terminal of the current source that is manually or mechanically guided along the joint. The electrode can either be a rod with the purpose of simply carrying the current between the tip and the work. Filler metal is melted into the space between the joint from a separate rod or wire.

Two types of filler metals commonly used in welding are welding rods and welding electrodes.

The term **welding rod** refers to a form of filler metal that does not conduct an electric current during the welding process. The only purpose of a welding rod is to supply filler metal to the joint. This type of filler metal is often used for gas welding.

In electric-arc welding, the term **electrode** refers to the component that conducts the current from the electrode holder to the metal being welded. Electrodes are classified into two groups: consumable and non-consumable.

- Consumable electrodes progressively melt away due to the heat of an electric arc held between it and the work. It not only provides a path for the current but they also supply filler metal to the joint. An example is the electrode used in shielded metal-arc welding.
- Non-consumable electrodes are only used as a conductor for the electrical current, such as in gas tungsten arc welding. The filler metal for gas tungsten arc welding is a hand fed consumable welding rod.

Electrode size is nominated by diameter of core wire and is determined by the amperage and the heat input into the job. Electrodes are available from 2mm to 6mm diameter. Within limits, larger electrodes permit more economical welding on heavy jobs, but with correct techniques the maintenance welder need rarely exceed 4mm to achieve sound welds. Similarly, a suitable 2.5mm electrode with appropriate technique can weld down to 1.5mm material, although on the flat a 2mm size may be desirable. The specification covering the requirements for welding electrodes is American Welding Society (AWS) **AWS A - 5.1** and the code that covers the welding of steel structures is **AWS D1.1**.

Power Source

Arc welding may be done with alternating current (AC) or direct current (DC) with the electrode either positive or negative. Each current type has its advantages and limitations, and these must be considered when selecting the type of current for a specific application. Factors which need to be considered are as follows:

- Voltage Drop - Voltage drop in the welding cables is lower with AC. This makes AC more suitable if the welding is to be done at long distances from the power supply. However, long cables, which carry AC should not be coiled because the inductive losses encountered in such cases can be substantial.
- Low Current - With small diameter electrodes and low welding currents, DC provides better operating characteristics and a more stable arc.

- Arc Starting - Striking the arc is generally easier with DC, particularly if small diameter electrodes are used. With AC, the welding current passes through zero each half cycle, and this presents problems for arc starting and arc stability.
- Arc Length - Welding with a short arc length (low arc voltage) is easier with DC than with AC. This is an important consideration, except for the heavy iron powder electrodes. With those electrodes, the deep crucible formed by the heavy covering automatically maintains the proper arc length when the electrode tip is dragged on the surface of the joint.
- Arc Blow - Alternating current rarely presents a problem with arc blow because the magnetic field is constantly reversing (120 times per second). Arc blow can be a significant problem with DC welding of ferritic steel because of unbalanced magnetic fields around the arc.
- Welding Position - Direct current is somewhat better than AC for vertical and overhead welds because lower amperage can be used. With suitable electrodes, however, satisfactory welds can be made in all positions with AC.
- Metal Thickness - Both sheet metal and heavy sections can be welded using DC. The welding of sheet metal with AC is less desirable than with DC. Arc conditions at low current levels required for thin materials are less stable on AC power than on DC power.

Review of a welding application will generally indicate whether alternating or direct current is most suitable. Power sources are available as DC, AC, or combination AC/DC units. The power source for the SMAW process must be a constant-current type rather than a constant voltage type, because it is difficult for a welder to hold the constant arc length required with constant-voltage power sources. If DC is chosen, the polarity also becomes an important factor. For example, the effects of polarity in GTAW are directly opposite the effects of polarity in SMAW; in SMAW, the distribution of heat between the electrode and work, which determines the penetration and weld bead width, is controlled mainly by the ingredients in the flux coating on the electrode. In GTAW where no flux coating exists; heat distribution between the electrode and the work is controlled solely by the polarity.

From welding point of view the **voltage** is only really important in as much as sufficient "pressure" is required to make the current flow through a circuit. The arc must be ignited. This is caused by supplying an initial voltage high enough to cause a discharge. In any circuit of a given resistance, it is the current which primarily determines the amount of heat generated. The **current** controls heat input. The minimum value is fixed by the need to fuse the plate and to keep the arc stable; the specified minimum, however, this may be higher to avoid cracks. The maximum current depends on operating conditions. Usually, as high a current as possible is used to achieve faster welding, and hence lower costs. *The use of maximum current may be restricted by position; in the overhead position, for example, currents above 160 amps cannot be used.*

The current is also chosen to match the electrode diameter. The upper limit is usually determined by the ability of the electrode to run out its full length without deterioration of its running characteristics or weld metal properties. On lighter material, currents may be reduced to reduce penetration or overheating of the base material.

It is very important that, while we can use small cables on the high voltage-low amperage (primary) side of our AC arc welder, we must have low resistance heavy conductors for the high amperage low voltage (secondary) welding circuit or else the leads will overheat. Similarly a secondary lead which is too long or too small will cause such a drop in voltage that it can no longer maintain a stable current across the arc between the electrode and the work.

ARC WELDING PROCESSES

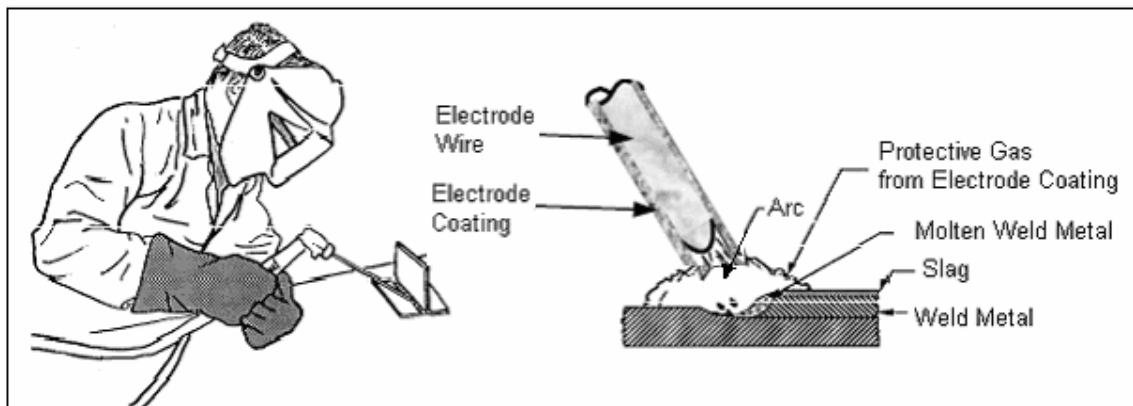
Different processes of arc welding are explained in the following paragraphs:

SHIELDED METAL ARC WELDING (SMAW)

Shielded Metal Arc Welding (SMAW) is the most extensively used manual welding method for general welding applications. It is frequently referred to as stick or covered electrode welding. SMAW uses a consumable electrode which is coated with a flux that melts during the welding operation. The coating forms the gas and slag to shield the arc and molten weld pool and therefore the process is called shielded arc welding. The flux also provides method of adding scavengers, deoxidizers and alloying elements to the

weld metal. Depending upon the type of electrode being used, the covering performs one or more of the following functions:

- Provides a gas to shield the arc and prevent excessive atmospheric contamination of the molten filler metal as it travels across the arc.
- Provides scavengers, deoxidizers, and fluxing agents to cleanse the weld and prevent excessive grain growth in the weld metal.
- Establishes the electrical characteristics of the electrode.
- Provides a slag blanket to protect the hot weld metal from the air and enhance the mechanical properties, bead shape, and surface cleanliness of the weld metal.
- Provides a means of adding alloying elements to change the mechanical properties of the weld metal.



SHIELDED METAL ARC WELDING (SMAW)

In SMAW process, pressure is not used and filler metal is obtained from the electrode.

Type of operation: manual

Heat source: Arc

Shielding: Principally Flux: some gas generated by flux

Power source: AC or DC

Voltage: 16 to 40V

Current Range: 25 to 350 A

Heat Input: 0.5 to 11 KJ/s

Mode of operation:

First electrode should be selected properly based on the base metal properties, type of equipment, welding position etc. After selecting electrode size, the parameters of welding machines are to be set and the edge made ready for welding. The Welder establishes an arc between the end of the electrode and the parent metal at the joint line (To start the arc, generally two different methods are employed. In the first method, generally practiced by beginners, known as scratch method the electrode is moved in an arc so that it will scratch the work metal and thus establish the current flow. In the other method known as tapping start, the electrode is held vertically above the point where the welding is to start and in a swift motion it is moved down to contact the metal and then lifted as much as the arc gap). The arc melts the parent metal and the electrode to form a weld pool which is protected by the molten flux layer and gas generated by the flux covering of the electrode. The welder moves the electrode towards the weld pool to keep the arc gap at a constant length and at the same time move it sideways in a weaving motion to maintain the bead width. Electrodes are generally 460 mm long. When the electrode has been melted to a length of about 50 mm, the arc is extinguished. The solidified slag or flux is removed from the surface and the weld is continued with a fresh electrode.

Typical Applications:

The SMAW process can be used for welding most structural and alloy steels. These include low-carbon or mild steels; low-alloy, heat-treatable steels; high-alloy steels such as stainless steels and other alloys. SMAW is used in fabrication of pressure vessel, ships, structural steel work, pipelines, construction and repair of machine parts and any other general purpose welding.

Advantages:

- This process is highly versatile and economical;
- Equipment is least expensive and portable;
- Job of any thickness can be welded;

- SMAW can be used in all positions--flat, vertical, horizontal, or overhead--and requires only the simplest equipment. Thus, SMAW lends itself very well to field work.

Disadvantages:

The main disadvantages are slow speed. Slag removal, unused electrode stubs, and spatter add to the cost of SMAW. Unused electrodes stubs and spatter account for about 40 percent of the consumed electrodes. Another cost is the entrapment of slag in the form of inclusions, which may have to be removed. It also takes a considerable amount of practice to get the rod angle, welding amperage, and tip to work distance just right to get quality welds.

Electrode Classification System:

The SMAW electrode classification code contains an E and three numbers that signify "Strength, position, type of covering and diameter".

Consider for example the tag E7018-1/8.

- The number 70 represents the minimum tensile strength of deposited metal in as-welded condition, which in this case is 70kPSI (70,000 PSI).
- The number 1 following the number 70 suggests that the weld can be done in all positions, horizontal, vertical and overhead. [Number 2 indicates the electrode is only suited to flat position welding and to horizontal position welding of fillet welds and number 4 indicates the electrode is suitable for vertical-down welding and for other positions as described in AWS A5.1].
- The 8 means low hydrogen flux covering. [The number "15" indicates that the covering of this electrode is a lime type, which contains a large proportion of calcium or alkaline earth materials. These electrodes are usable with dc reverse-polarity only. The designation "16" indicates electrodes that have a lime-or titania-type covering with a large proportion of titanium-bearing minerals. The coverings of these electrodes also contain readily ionizing elements, such as potassium, to stabilize the arc for ac welding].
- Finally, the 1/8 is the diameter of the electrode, 1/8 of an inch.

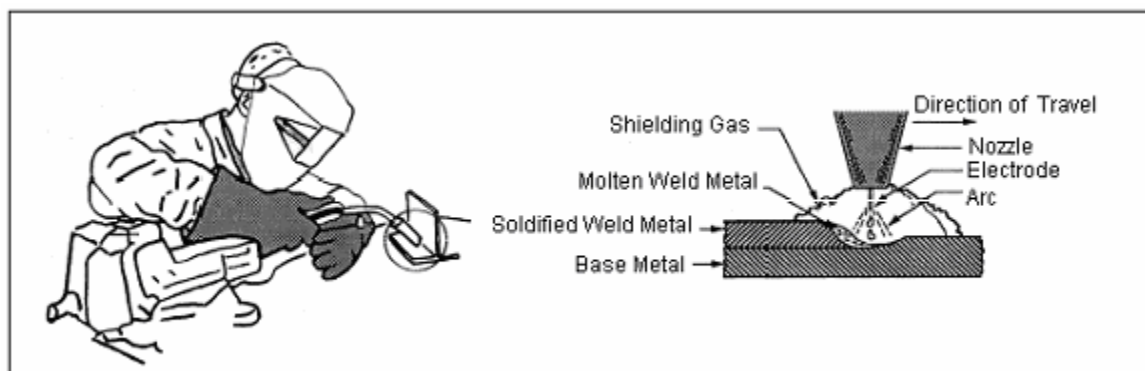
A welder must understand these numbers to know 'which is the proper rod to use for the specific job'. For other examples, refer to AWS Spec A5.1.

Weld Metal Mechanical Properties:

The AWS requires the deposited weld metal to have a minimum tensile strength of 60,000 to 100,000 psi (413,700 to 689,500 kPa) with minimum elongations of 20 to 35 percent.

GAS METAL ARC WELDING (GMAW)

In gas-metal arc welding (GMAW or MIG); a bare electrode is shielded from the air by inert gas (argon or carbon dioxide). The electrode is fed into the electric arc, and melts off in droplets to enter the liquid metal that forms the weld. Flux is not necessary to shield the pool; however, occasionally a flux - coated electrode is used to produce slag. The arc length is maintained by the power supply unit. This is sometimes also referred to as Metal Inert Gas (MIG) welding.



GAS METAL ARC WELDING (GMAW)

Type of operation: GMAW is basically a semi-automatic process, in which the arc length and the feeding of the wire into the arc are automatically controlled. Therefore operator's job is mainly to position the gun at a right angle and moving it at a controlled travel speed.

Basic equipment used consists of DC-power source, a wire feeder, a shielding gas supply, controls for governing wire drive, gas flow and cooling water and a welding gun.

In this process the electrode tip to the weld pool across the arc is either globular, spray type or short-circuiting type depending on the magnitude of welding current, current density, shielding gas and type of electrode.

Heat sources: arc

Shielding:

Different combinations of welding processes and materials require different combinations of welding gases. Most of the commonly used gases for GMAW consist of pure gases – argon and carbon dioxide OR mixtures - argon/CO₂, argon/O₂, argon/Helium.

- Pure argon and/or Argon/Helium mixture is the most popular shielding gas for welding Aluminum. [Pure Argon (100% Argon) provides good arc stability, improved cleaning action and better arc starting characteristics but has poor penetration].
- Pure CO₂ and/or Argon/CO₂ mixtures are used for welding Carbon Steel. [Pure CO₂ provide poor arc stability but is unable to produce spray transfer. It promotes globular transfer, which can cause a great deal of spatter. Ideally Argon/CO₂ is a better choice. Alternatively, Argon/O₂ mixtures exhibit a characteristic "nail-head" penetration profile with carbon steel, which is the most common application. Oxygen creates a very wide and fairly shallow penetration profile, with high heat input at the surface of the work but note that its concentrations are kept less than 10%. Oxygen also is used in tri-mixes with CO₂ and argon, where it provides the wetting and spray advantages].
- Mixtures of argon/O₂, Argon/Helium and/or Argon/Helium/CO₂ are used for Stainless Steel. [An important attribute in welding stainless steel alloys is to combine good levels of penetration with good arc stability; the ideal shielding gas would be 98% argon + 2% O₂].
- Pure helium is generally NOT used for GMAW. [The helium content gases are usually more expensive and have a lower density than argon. Helium mixtures are sometimes used, which may increase welding speeds in some circumstances].

Power Source: Normally DCEP (direct current electrode positive) and sometimes DCEN (direct current electrode negative) on thicker materials;

Current Range: 60 to 500 A

Heat Input: 1 to 25 KJ/s

Mode of operation:

An arc is established between the end of electrode and the parent metal at the joint line. The consumable electrode is in the form of a wire reel which is fed at a constant rate, through the feed rollers. The welding torch is connected to the gas supply cylinder which provides the necessary inert gas. The current from the welding machine is changed by the rate of feeding of the electrode wire. The arc length is controlled by a power supply unit and the welder is required to keep the nozzle at a fixed height above the weld pool (usually about 20 mm).

Typical Applications:

This process is versatile and can be used with a wide variety of metals and alloys, including aluminum, copper, magnesium, nickel, and many of their alloys, as well as iron and most of its alloys. GMAW welding provides a method of welding stainless steels at high speeds, because it is a semi-automatic process with high arc times and deposition rates. Flux or slag is totally absent. This minimizes cleaning and finishing time and gives consistent weld-metal chemistry. Though GMAW process is applicable to many Cu alloys, it is preferred for the welding of aluminum bronzes, silicon bronzes and copper nickels in section thicknesses greater than 3 mm. For lower thicknesses, the GTAW process is preferred. GMAW welding can be used for deoxidized coppers to get the same weld soundness and strength as is obtained with the TIG process.

The average deposition rate for GMAW application is 8 to 9 lbs per hour using a solid welding wire.

GMAW Welding Parameters

There are number of welding parameters which must be considered in GMAW, like

- Electrode size,
- Welding current,
- Arc voltage,

- Arc travel speed, and
- Electrode position

Electrode Size

The electrode size increases as the base metal thickness increases. However, the selection of electrode size is important and should be made with care, depending on the particular application. For a given current, a change to a smaller electrode size results in a faster droplet transfer rate and hence a higher melting rate due to an increase in the current density.

Welding Current

When the current is too low, the molten metal fails to wet the joint surface and causes lack of fusion. When the current is too high, it gives rise to spatter, porosity and poor weld bead profile. With increasing current, the melting rate of the electrode increases. For a given electrode size, increasing the amperage within the usable range results in (a) increased depth and width of weld penetration, (b) increased deposition rate, and (c) increased size of weld bead, provided all the other variables are kept constant.

Arc Voltage

This determines the type of metal transfer by influencing the rate of droplet transfer across the arc. The arc voltage to be used depends on base metal thickness, type of joint, electrode composition and size, shielding gas composition, welding position, type of weld and other factors.

Arc Travel Speed

Arc travel speed affects weld bead size and penetration. There is a certain value of travel speed at which the weld penetration is maximum. If this value is lowered, the weld pool becomes larger and shallower and the advancing arc impinges on this weld pool rather than on the base metal. The result is a shallower penetration and a wider weld bead. As the travel speed is increased, the heat input rate of the arc is decreased. The result is decreased penetration and narrower weld bead. When the travel speed is excessive, undercutting occurs along the edges of the weld bead, because the deposition of filler metal is not sufficient to fill the path melted by the arc.

Electrode Position

As with all arc welding processes, the position of the gun and the electrode with respect to the joint affects the weld bead shape and penetration in a much larger measure than arc voltage or arc travel speed. The gun angle is usually maintained within 10 to 20° on either side of the vertical.

Advantages:

The major advantages of gas metal-arc welding are:

- Works with most metals;
- High quality welds can be produced much faster than with SMAW or GTAW;
- Do not produce slag in the weld metal, since flux is not used;
- The gas shield protects the arc so that there is very little loss of alloying elements as the metal transfers across the arc. Only minor weld spatter is produced, and it is easily removed;
- Production is improved, as there is no need to deslag or change electrode. It is highly suitable for fillet - welded joints, such as beam to beam or stiffener to panel connections.

Disadvantages:

The major disadvantage of this process is that the equipment is complex and it may not be the process of choice if you are looking for something that offers portability and convenience. GMAW also requires additional equipment such as a hose, regulator, solenoid (electric valve) in the wire feeder and flowmeter. Equipment and consumables are expensive, require skilled workers.

Electrode Classification System:

The GMAW electrode classification of low alloy steel electrodes is similar to the classification of carbon steel electrodes. An example of a low alloy steel classification is E81T1-NI2

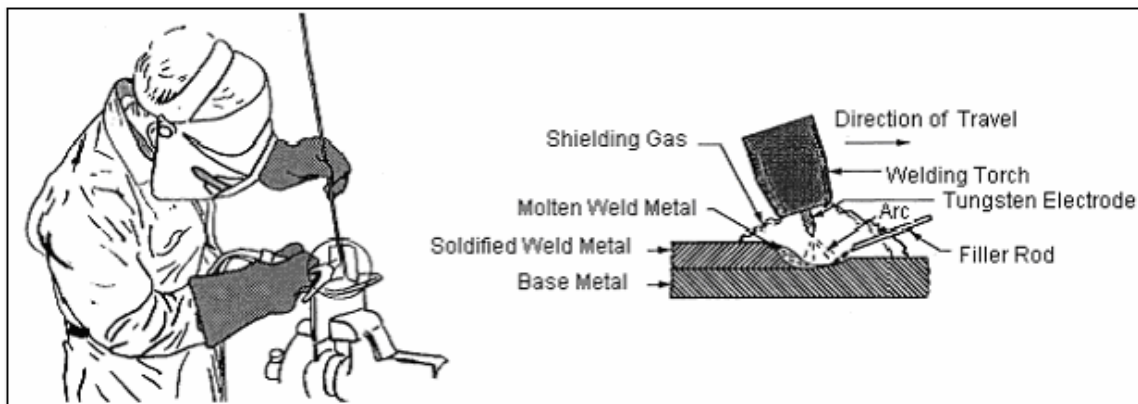
Where:

- The "E" indicates electrode.
- The second digit or "8" indicates the minimum tensile in strength in units of 10,000 psi. In this case it is 80,000 psi (552 MPa).

- The third digit or "1" indicates the welding position capabilities of the electrode. A "1" indicates all positions and a "0" flat and horizontal position only.
- The "T" indicates a tubular or flux-cored electrode used in flux cored arc welding.
- The fifth digit or "1" describes the usability and performance characteristics of the electrode. These digits are the same as used in carbon steel electrode classification but only EXXT1-X, EXXT4-X, EXXT5-X and EXXT8-X are used with low alloy steel flux-cored electrode classifications.
- The suffix or "Ni2" tells the chemical composition of the deposited weld metal.

GAS TUNGSTEN ARC WELDING (GTAW)

Gas tungsten arc welding (GTAW) [also known as tungsten inert gas (TIG) welding] is a process which produces coalescence of metals by heating them with an arc between a tungsten (non-consumable) electrode and the work piece. Shielding is obtained from a gas or gas mixture. GTAW is normally done with a pure tungsten or tungsten alloy rod, but multiple electrodes are sometimes used. The heated weld zone, molten metal, and tungsten electrode are shielded from the atmosphere by a covering of inert gas fed through the electrode holder. Filler metal may or may not be added. A weld is made by applying the arc so that the touching work-piece and filler metal are melted and joined as the weld metal solidifies. This process is similar to other arc welding processes in that the heat is generated by an arc between a non-consumable electrode and the work-piece, but the equipment and electrode type distinguish GTAW from other arc welding processes.



GAS TUNGSTEN ARC WELDING (GTAW)

Type of operation: manual, automatic

Heat source: arc

Shielding:

Most of the commonly used gases for GTAW consist of pure gases – argon and helium OR mixtures - argon/helium and argon/H₂.

- Pure argon is the most popular shielding gas for welding carbon steel, stainless steel and aluminum. [When welding with alternating current (AC), pure argon is the most popular gas used. Pure argon (100% Argon) will provide good arc stability, improved cleaning action, and better arc starting characteristics].
- Pure helium can be used for aluminum but in practice Argon/helium mixtures are commonly used for both stainless steel and aluminum because of their higher heat characteristics. [Helium / argon mixtures, usually 25% helium and 75% argon can help to increase travel speeds when AC - GTAW. Mixtures of more than 25% helium for AC – GTAW are used, but not often, as they can tend to produce instability, under certain circumstances, in the AC arc. Pure helium or high percentages of helium (He-90%, Ar-10%) shielding gas are used primarily to provide fast welding speeds and outstanding penetration. This configuration is used with direct current electrode negative (DCEN) and sometimes used to produce full penetration butt welds, welded from one side only, onto temporary baking with no V-groove preparation, just a square edged plate].
- Argon/H₂ mixture is used for stainless steel. [Hydrogen at concentrations of less than 10 percent is primarily used with austenitic stainless steels to promote oxide removal and increase heat input. Hydrogen is not suitable for ferritic or martensitic steels because of cracking issues].

Power Source: Both DC (DCEN or DCEP) and AC

Current Range: 10 to 300 A

Heat Input: 0.2 to 8 KJ/s

Mode of operation:

An arc is established between the end of a tungsten electrode (contains core tungsten or tungsten with 0.15 to 0.40 % zirconia, it may also contain 1 to 2 % thoria.). The electrode

is not melted and the welder keeps the arc gap constant. The current is controlled by the power supply unit. Filler metal, usually available in 1 m lengths of bare wire, is added to the leading edge of the pool as required. The molten metal is shielded by an inert gas supplied to the welding zone through the annular path surrounding the tungsten electrode which replaces the air in the arc area. Argon is the most commonly used shielding gas.

Process Variables

The primary variables in GTAW are arc voltage (arc length), welding current, travel speed, and shielding gas. The amount of energy produced by the arc is proportional to the current and voltage. The amount transferred per unit length of weld is inversely proportional to the travel speed. The arc in helium is more penetrating than that in argon. However, because all of these variables interact strongly, it is impossible to treat them as truly independent variables when establishing welding procedures for fabricating specific joints.

Arc Current - As a general statement, arc current controls the weld penetration, the effect being directly proportional, if not somewhat exponential. Arc current also affects the voltage, with the voltage at a fixed arc length increasing in proportion to the current. For this reason, to keep a fixed arc length, it is necessary to change the voltage setting when the current is adjusted.

Arc Voltage - The voltage measured between the tungsten electrode and the work is commonly referred to as the 'arc voltage'. Arc voltage is a strongly dependent variable, affected by the following:

- Arc current
- Shape of the tungsten electrode tip
- Distance between the tungsten electrode and the work
- Type of shielding gas

The arc voltage is changed by the effects of the other variables, and is used in describing welding procedures only because it is easy to measure. Since the other variables such as the shield gas, electrode, and current have been predetermined, arc voltage becomes a way to control the arc length, a critical variable that is difficult to monitor.

Arc Length - Arc length is important with this process because it affects the width of the weld pool; pool width is proportional to arc length. Therefore, in most applications other than those involving sheet, the desired arc length is as short as possible.

When arc voltage is being used to control arc length in critical applications, care must be taken to observe the other variables, which affect arc voltage. Among them are electrode and shielding gas contaminants, improperly fed filler wire, temperature changes in the electrode, and electrode erosion. Should any of these change enough to affect the arc voltage during mechanized welding, the arc length must be adjusted to restore the desired voltage.

Travel Speed - Travel speed affects both the width and penetration of a gas tungsten arc weld. However, its effect on width is more pronounced than that on penetration. Travel speed is important because of its effect on cost. In some applications, travel speed is defined as an objective, with the other variables selected to achieve the desired weld configuration at that speed. In other cases, travel might be a dependent variable, selected to obtain the weld quality and uniformity needed under the best conditions possible with the other combination of variables. Regardless of the objectives, travel speed generally is fixed in mechanized welding while other variables such as current or voltage are varied to maintain control of the weld.

Wire Feed - In manual welding, the way filler metal is added to the pool influences the number of passes required and the appearance of the finished weld.

In machine and automatic welding, wire feed speed determines the amount of filler deposited per unit length of weld. Decreasing wire feed speed will increase penetration and flatten bead contour. Feeding the wire too slowly can lead to undercut, centerline cracking, and lack of joint fill. Increased wire feed speed decreases weld penetration and produces a more convex weld.

Typical applications:

GTAW is used chiefly for thin and exotic metals including aluminum, magnesium, stainless steels, nimonic alloys, and copper and also for reactive metals like titanium and zirconium which dissolve oxygen and nitrogen and become embrittled, if exposed to air while melting. It is widely used in chemical plants, sheet work in aircraft engines and structures. It can be used on almost all metals, but it is generally not used for the very low melting metals such as solders, or lead, tin, or zinc alloys.

Advantages:

The major advantages of GTAW are:

- Produces superior quality welds, generally free of defects.
- Free of the spatter, which occurs with other arc welding processes.
- Works with most metals. It gives high- quality weld, welding can be done in all positions, chances of slag inclusion in bead are very less.
- Can be used with or without filler metal as required for the specific application.
- The process provides more precise control of the weld than any other arc welding process, because the arc heat and filler metal are independently controlled.
- Visibility is excellent because no smoke or fumes are produced during welding, and there is no slag or spatter that must be cleaned between passes or on a completed weld.
- The gas tungsten arc welding process is very good for joining thin base metals down to 30 gauges because of excellent control of heat input. This makes it a good process for computer housings, electronic components, and tubing.
- As in oxyacetylene gas welding, the heat source and the addition of filler metal can be separately controlled. Because the electrode is non-consumable, the process can be used to weld by fusion alone without the addition of filler metal.

Disadvantages:

GTAW is expensive because the arc travel speed and weld metal deposition rates are lower than with some other methods. Some limitations of the gas tungsten arc process are:

- The process is slower than other arc welding processes (SMAW or GMAW).
- Deposition rates are lower than other arc welding processes (SMAW or GMAW). The average deposition rate for GTAW application is only 2 to 3 lbs per hour.
- Transfer of molten tungsten from the electrode to the weld causes contamination. The resulting tungsten inclusion is hard and brittle.

- Inert gases for shielding and tungsten electrode costs add to the total cost of welding compared to other processes.
- It is less economical than the consumable electrode arc welding processes for thicker sections greater than 3/8 in. (10 mm).
- There is difficulty in shielding the weld zone properly in drafty environments.

Potential Problems:

Potential problems with the process include:

- Tungsten inclusions can occur if the electrode is allowed to contact the weld pool.
- Contamination of the weld metal can occur if proper shielding of the filler metal by the gas stream is not maintained.
- There is low tolerance for contaminants on filler or base metals.
- Possible contamination or porosity is caused by coolant leakage from water-cooled torches.
- Arc blow or arc deflection, as with other processes.

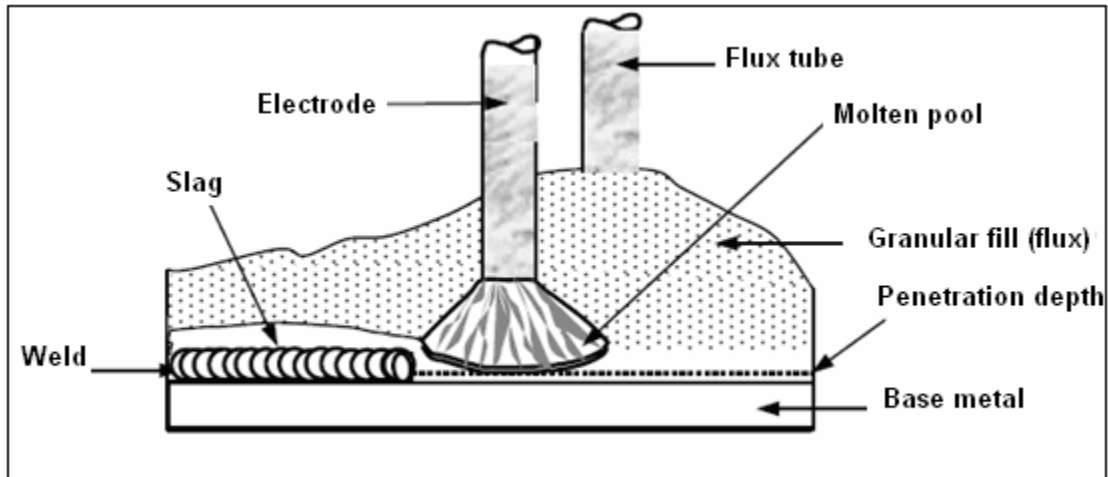
SUBMERGED ARC WELDING (SAW)

Submerged Arc Welding (SAW) produces coalescence of metals by heating them with an arc between a bare metal electrode and the work. The arc and molten metal are 'submerged' in a blanket of granular fusible flux on the work. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplemental source such as welding rod or metal granules.

In submerged arc welding, the arc is covered by a flux. This flux plays a main role in that

- The stability of the arc is dependent on the flux.
- Mechanical and chemical properties of the final weld deposit can be controlled by flux.
- The quality of the weld may be affected by the care and handling of the flux.

Submerged arc welding is a versatile production welding process capable of making welds with currents up to 2000A, AC or DC, using single or multiple wires or strips of filler metal. Both ac and dc power sources may be used on the same weld at the same time.



SUBMERGED ARC WELDING (SAW) PROCESS

Type of operation:

Submerged arc welding can be applied in three different modes: semi-automatic, automatic, and machine. Each method requires that the work be positioned so that the flux and the molten weld pool will remain in place until they have solidified. Many types of fixtures and positioning equipment are available or can be built to satisfy this requirement.

- **Semi-automatic Welding** - Semi-automatic welding is done with a hand-held welding gun, which delivers both flux and the electrode. A wire feeder drives the electrode. Flux may be supplied by a gravity hopper mounted on the gun or pressure fed through a hose. This method features manual guidance using relatively small diameter electrodes and moderate travel speeds. The travel may be manual or driven by a small gun-mounted driving motor.
- **Automatic Welding** - Automatic welding is done with equipment that performs the welding operation without requiring a welding operator to continually monitor and adjust the controls. Expensive self-regulating equipment can be justified in order to achieve high-production rates.

- **Machine Welding** - Machine welding employs equipment that performs the complete welding operation. However, it must be monitored by a welding operator to position the work, start and stop welding, adjust the controls, and set the speed of each weld.

Heat source: arc

Fluxes: Fluxes for submerged arc welding are granulated to controlled size and may be of the fused, agglomerated or sintered type. Originally a fused, crushed and graded flux was used. The advantages claimed for such a flux being that it was totally free of moisture and not hygroscopic. Both the chemical composition and the state of division of the flux have an important bearing on the way it behaves in welding.

Agglomerated fluxes are made by mixing the finely ground constituents with an aqueous solution of a binder such as sodium silicate. The aim is to produce particles a few mm in diameter made up of a mass of finer particles of the constituent minerals. After agglomeration the flux is dried at temperatures up to 800 °C. Sintered fluxes are made by heating pelletized powdered constituents to temperatures just below the melting point of some of the constituents. The temperatures reached during manufacture place limitations on the composition of fluxes. To fuse a flux, temperatures must be so high that carbonates and many other minerals are decomposed. As a result, basic fluxes incorporating carbonates must be made by one of the other processes such as agglomeration.

During welding some of the granulated flux is melted to cover both the weld pool and the metal particles being transferred from the electrode to the pool. In both these stages reactions occur between the metal and the flux involving particularly silicon and manganese, the elements which play a major role in controlling the strength and soundness of the deposit.

Power Source: The power source chosen for a submerged arc welding system plays a major operating role. Several types of power supply are suitable for submerged arc welding. A dc power supply may be a transformer-rectifier or a motor or engine generator, which will provide a constant voltage (CV), constant current (CC), or a selectable CV/CC output. AC power supplies are generally transformer types, and may provide either a CC output or a CV square wave output. Because SAW is generally a

high-current process with high-duty cycle, a power supply capable of providing high amperage at 100 percent duty cycle is recommended.

Mode of operation:

The submerged arc welding process utilizes the heat of an arc between a continuously fed electrode and the work. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred through the arc to the workpiece, where it becomes the deposited weld metal. Shielding is obtained from a blanket of granular flux, which is laid directly over the weld area. The flux close to the arc melts and intermixes with the molten weld metal, helping to purify and fortify it. The flux forms a glass-like slag that is lighter in weight than the deposited weld metal and floats on the surface as a protective cover. The weld is submerged under this layer of flux and slag, hence the name submerged arc welding. The flux and slag normally cover the arc so that it is not visible. The unmelted portion of the flux can be reused. The electrode is fed into the arc automatically from a coil. The arc is maintained automatically. Travel can be manual or by machine. The arc is initiated by a fuse type start or by a reversing or retracts system.

The most popular method of application is the machine method, where the operator monitors the welding operation. Second in popularity is the automatic method, where welding is a pushbutton operation. The process can be applied semi-automatically; however, this method of application is not too popular. The process cannot be applied manually because it is impossible for a welder to control an arc that is not visible.

Applications:

Submerged-arc welding has found its main application with mild and low-alloy steels, although the process has also been used for copper, aluminum- and titanium-base alloys with the development of suitable fluxes. It is a method used mainly for the downhand welding of thicknesses above 5 mm where the welds are long and straight. The welding head itself may be moved over the work on a self-propelled carriage or gantry or the work may be revolved beneath the stationary-welding head. The method is widely used for both butt welds and fillet welds in shipbuilding, pressure vessel, structural engineering, pipe welding and storage tank fabricating industries. For the last purpose special self-propelled machines with devices for supporting the flux are used for welding the girth seams in position on-site.

SAW is typically used for welding thick steel plates; metal thicknesses from 1/16 to 1/2 inches (1.6 to 12.7 mm) can be welded with no edge preparation and with edge preparation, welds can be made with a single pass on material from 1/4 to 1 inch (6.4 to 25.4 mm). Factors that determine whether to use submerged arc welding include:

- The chemical composition and mechanical properties required of the final deposit
- Thickness of base metal to be welded
- Joint accessibility
- Position in which the weld is to be made
- Frequency or volume of welding to be performed.

Advantages:

The major advantages of SAW are:

- High deposition;
- High quality of the weld metal;
- Extremely high deposition rate and speed;
- Smooth, uniform finished weld with no spatter;
- Little or no smoke;
- No arc flash, thus minimal need for protective clothing;
- High utilization of electrode wire;
- Easy automation for high-operator factor;
- Normally, no involvement of manipulative skills.

Disadvantages:

The major disadvantages of SAW are:

- The major limitation of submerged arc welding is its limitation of welding positions. The welding positions are limited because the large pool of molten metal and the slag are very fluid and will tend to run out of the joint. Under special controlled procedures, it is possible to weld in the horizontal position, sometimes called 3 o'clock welding. This requires special devices to hold the flux

up so that the molten slag and weld metal cannot run away. The process cannot be used in the vertical or overhead position.

- The high-heat input, slow-cooling cycle can be a problem when welding quenched and tempered steels. The heat input limitation of the steel in question must be strictly adhered to when using submerged arc welding. This may require the making of multipass welds where a single pass weld would be acceptable in mild steel.
- In semiautomatic submerged the arc is not visible, and therefore this device is difficult to use without aids to help the welder guide the welding head over the work and maintain a constant speed. It can be a disadvantage in reaching the root of a groove weld and properly filling or sizing.
- A metallurgical problem most associated with SAW is solidification cracking in the weld metal.

Which welding process is most appropriate! There are no hard-and-fast rules. Each welding process has its place though some are more suitable for certain metals, materials, thicknesses and environments. In general, the four most common arc welding processes are summarized below....

The Four Most Common Arc Welding Processes

Process	Electrodes	Shielding	Current Type	Operation	Operator skill required	Welding Position	Popularity
Shielded metal arc welding (SMAW)	Rigid metal	Stick coatings	AC, DC	Manual	High	All	Diminishing
Gas metal arc welding (GMAW or	Solid wire	Argon, CO ₂ gas	DC	Semi auto and Automatic	Low to High	All	Growing

Process	Electrodes	Shielding	Current Type	Operation	Operator skill required	Welding Position	Popularity
MIG)							
Gas tungsten arc welding (GTAW or TIG)	Tungsten	Argon gas, Helium, mixtures	AC, DC	Manual and Automatic	Low to High	All	Steady
Submerged arc welding (SAW)	Solid wire	Argon gas	AC, DC	Automatic	Low to Medium	Flat and Horizontal	Steady

Shielding Gas Mixtures

Many different gas mixtures are used in welding, depending on the process and material.

Shielding Gas or Mix	GMAW or MIG			GTAW or TIG		
	Carbon Steel	Stainless Steel	Aluminum	Carbon Steel	Stainless Steel	Aluminum
Ar			X	X	X	X
He					X	X
CO ₂	X					
Ar/CO ₂	X					
Ar/O ₂	X	X				
Ar/He		X	X		X	X
Ar/CO ₂ /O ₂	X					

Shielding Gas or Mix	GMAW or MIG			GTAW or TIG		
	Carbon Steel	Stainless Steel	Aluminum	Carbon Steel	Stainless Steel	Aluminum
Ar/H ₂					X	
Ar/He/CO ₂	X	X				
He/Ar/CO ₂		X				

No matter what welding process you use, there is some basic information you need to know. The remainder of this course provides general information on welding instructions, procedures, welding symbols, and weld various types of joints.

SECTION 2

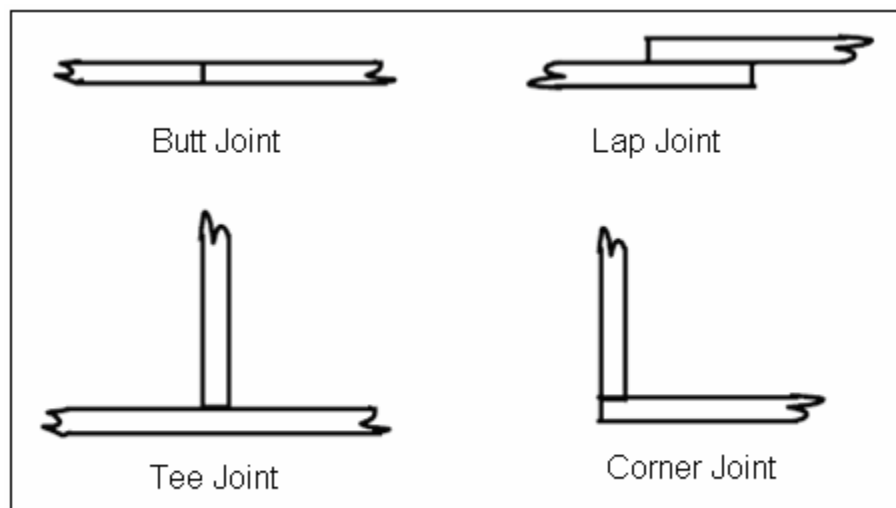
TYPES OF JOINTS & WELDS

To become a skilled welder, you first need to understand the technical vocabulary of welding. In this section we will introduce you to some of the basic terms of the welding language. Once you understand the language of welding, you will be prepared to interpret and communicate welding information accurately.

Types of Joints

A variety of joints is used in structural steel work and they can be classified into four basic configurations:

- Lap joint
- Tee joint
- Butt joint, and
- Corner joint



BASIC WELD JOINTS

For lap joints the ends of two members are overlapped, and for butt joints the two members are placed end to end in the same plane. The T- joints form a Tee and in Corner joints, the ends are joined like the letter L.

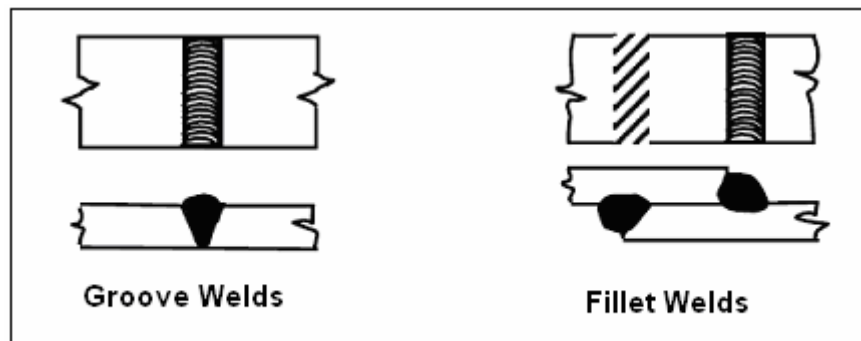
Lap joint is one of the strongest types of joints available; however, for maximum joint efficiency, you should overlap the metals a minimum of three times the thickness of the

thinnest member you are joining. Lap joints are commonly used with torch brazing and spot welding applications.

Types of Welds

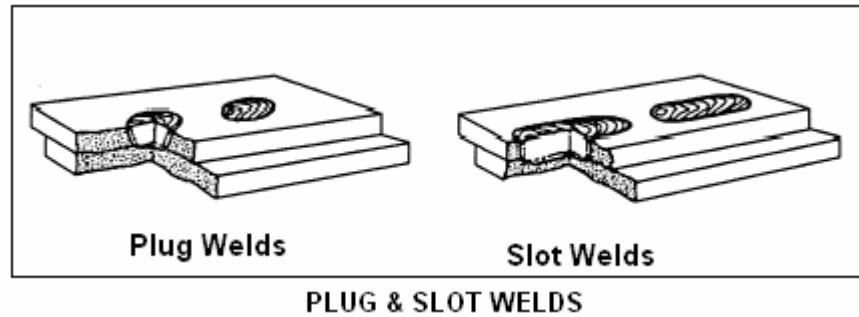
Most common joints are made up of **fillet weld** and the **groove weld**. Fillet welds are suitable for lap joints and tee joints; and groove welds for butt and corner joints. Groove welds can be of complete penetration or incomplete penetration depending upon whether the penetration is complete through the thickness or partial. Generally a description of welded joints requires an indication of the type of both the joint and the weld.

Though fillet welds are weaker than groove welds, about 80% of the connections are made with fillet welds. The reason for the wider use of fillet welds is that in the case of fillet welds, when members are lapped over each other, large tolerances are allowed in erection. For groove welds, the members to be connected have to fit perfectly when they are lined up for welding. Further groove welding requires the shaping of the surfaces to be joined and to ensure full penetration and a sound weld, a backup plate is temporarily provided.



GROOVE & FILLET WELDS

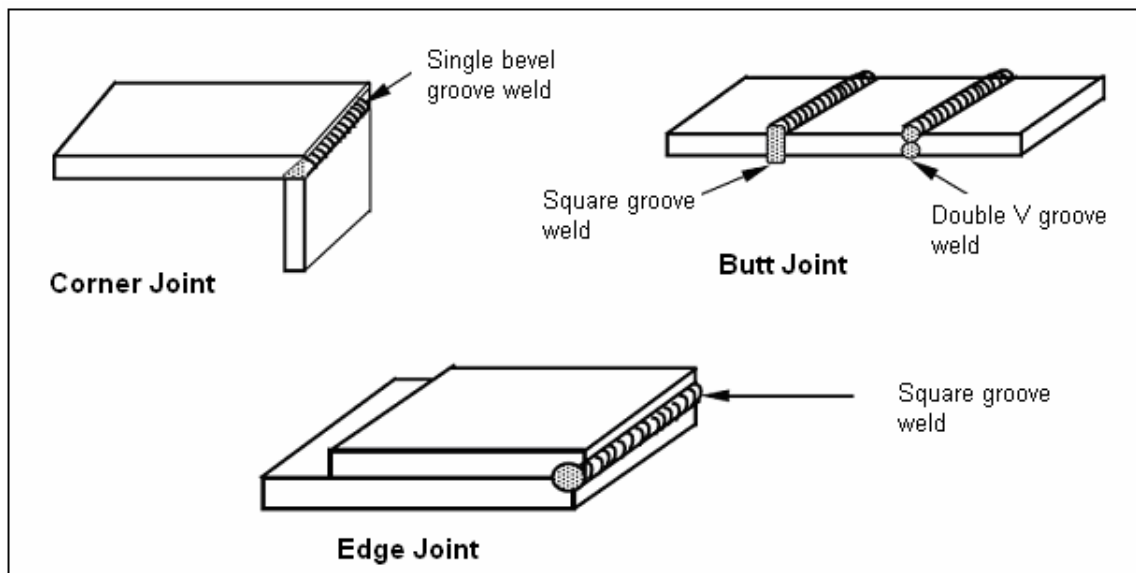
Plug and **slot welds** are welds made through holes or slots in one member of a lap joint. These welds are used to join that member to the surface of another member that has been exposed through the hole. The hole may or may not be completely filled with weld metal. These types of welds are often used to join face-hardened plates from the backer soft side, to install liner metals inside tanks, or to fill up holes in a plate.



Plug and slot welds are generally NOT used in structural steel work. In this course we will discuss groove and fillet welds in detail.

GROOVE WELDS

The main use of groove welds is to connect structural members, which are in the same plane. Groove welds are simply welds made in the groove between two members to be joined. The weld is adaptable to a variety of butt joints. There are many variations of groove welds and each is classified according to its particular shape (such as single or double bevel groove weld, square groove weld and V groove weld etc).



TYPICAL CONNECTIONS WITH GROOVE WELD

Groove welds have high strength, high resistance to impact and cyclic stress. They are most direct joints and introduce least eccentricity in the joint. But their major disadvantages are: high residual stresses, necessity of edge preparation and proper

aligning of the members in the field. Therefore, field butt joints are rarely used. To minimize weld distortions and residual stresses, the heat input is minimized and hence the welding volume is minimized. This reduction in the volume of weld also reduces cost. Hence for thicker plates, double groove welds are generally used.

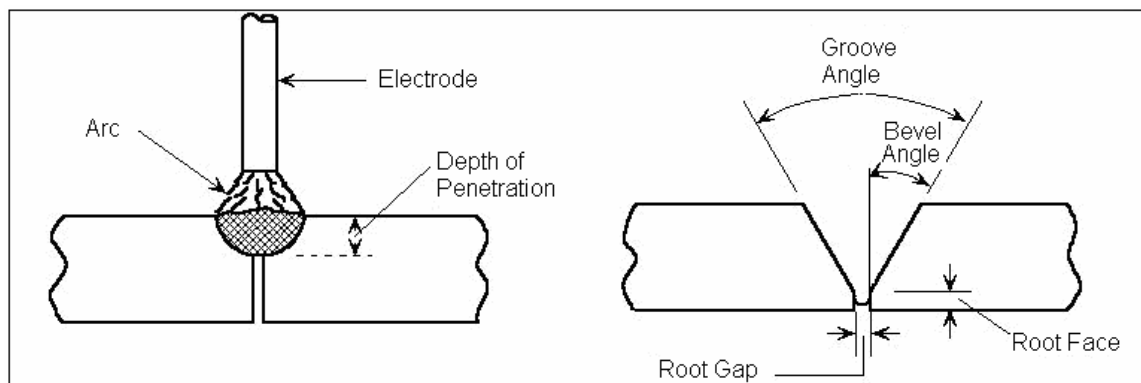
Groove Weld Terminology

For you to produce welds that meet the job requirements, it is important that you become familiar with the terms used to describe a weld.

Root - The root of the weld is the point where the faces of the metallic members meet. The root may be a point, a line, or an area, when viewed in cross section. For a butt weld, the root opening, R , is the separation of the pieces being joined and is provided for the electrode to access the base of a joint; the smaller the root opening the greater the angle of the bevel.

Groove Angle - The groove angle is the total angle of the groove between the parts to be joined. For example, if the edge of each of two plates were beveled to an angle of 30 degrees, the groove angle would be 60 degrees. This is often referred to as the “included angle” between the parts to be joined by a groove weld.

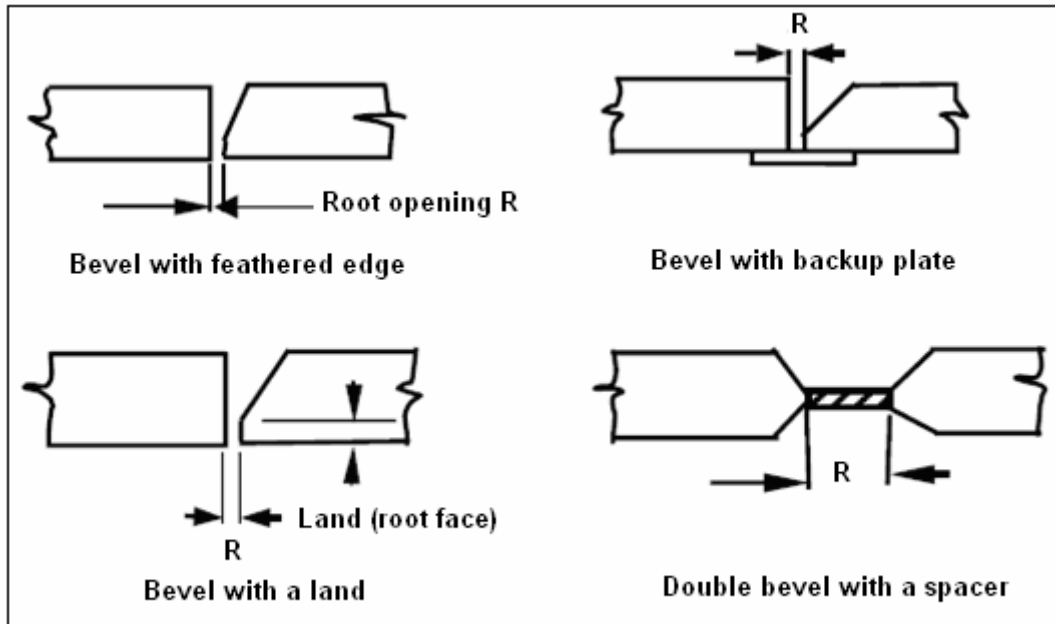
Bevel Angle - The bevel angle is the angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.



GROOVE WELD TERMINOLOGY

Joint penetration - It refers to the minimum depth that a groove weld extends from its face into a joint, exclusive of weld reinforcement.

Root Opening - The root opening refers to the separation between the parts to be joined at the root of the joint. The root opening is usually governed by the diameter of the thickness filler material. This, in turn, depends on the base metal and the welding position. Having an adequate root opening is essential for root penetration.

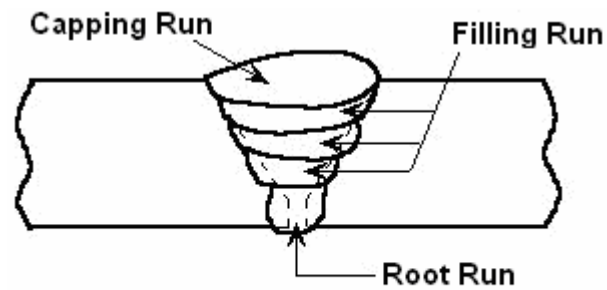


TYPICAL EDGE PREPARATION FOR BUTT WELD

For a butt weld, the root opening, R , is the separation of the pieces being joined and is provided for the electrode to access the base of a joint. The smaller the root opening, the greater shall be the angle of the bevel.

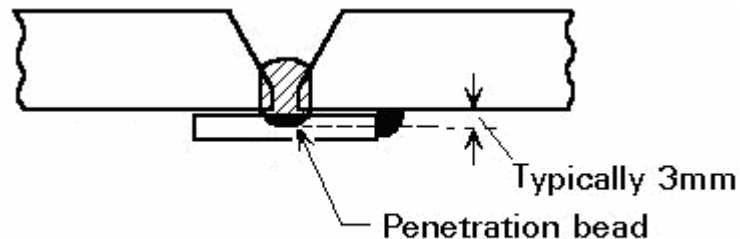
Depth of Penetration - The depth by which the arc melts into the plate is called the depth of penetration. As a very rough guide, the penetration is about 1 mm per 100A and in manual welding the current is usually 150 – 200 amperes. This means that the edges of the plate must be cut back along the joint line for continuity through the thickness to be achieved. This groove is filled with the molten metal from the electrode. The first run that is deposited in the bottom of a groove is termed as the **root run**.

Root run - The groove is filled with the molten metal from the electrode. The first run that is deposited in the bottom of a groove is termed as the root run.



PENETRATION IN ARC WELDING

For good penetration, the root faces must be melted. Simultaneously, the weld pool also must be controlled, preferably, by using a backing strip. Steel backing strip may be held in place by short lengths of fillet weld or removed after welding. Penetration bead must not be too wide, otherwise weld pool will collapse; typically 3mm is a good practice.

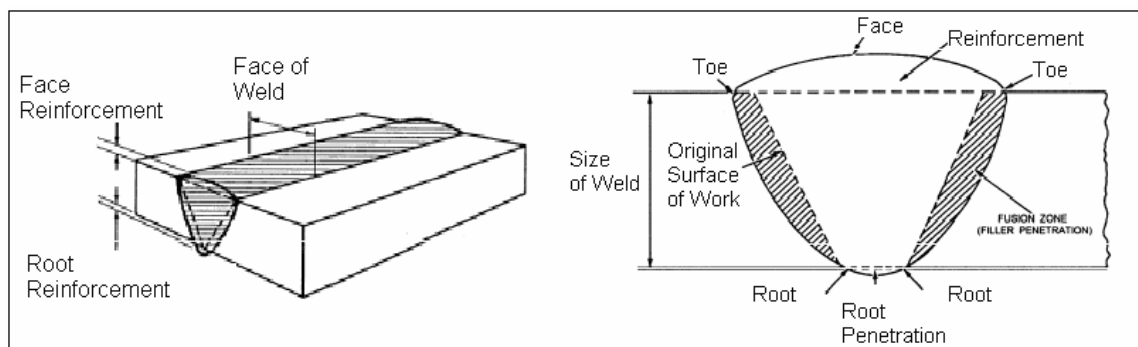


ROOT RUN TECHNIQUES

Face - The face is the exposed surface of a weld on the side from which the weld was made.

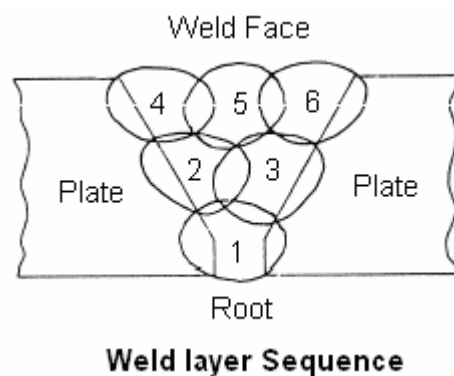
Toe - The toe is the junction between the face of the weld and the base metal.

Weld reinforcement is a term used to describe weld metal in excess of the metal necessary to fill a joint.



Bead - During the process of welding a deposit of metal is left on the material. This is called “Bead”. There are several types of beads; a weave, fillet and a straight bead are three of the basic beads.

Groove welds may be joined with one or more weld beads, depending on the thickness of the metal. If two or more beads are deposited in the groove, the weld is made with multiple-pass layers. As a rule, a multiple-pass layer is made with stringer beads in manual operations. Another term you should be familiar with, when making a multiple-pass weld, is the “buildup sequence”; it refers to the order in which the beads of a multiple-pass weld are deposited in the joint.

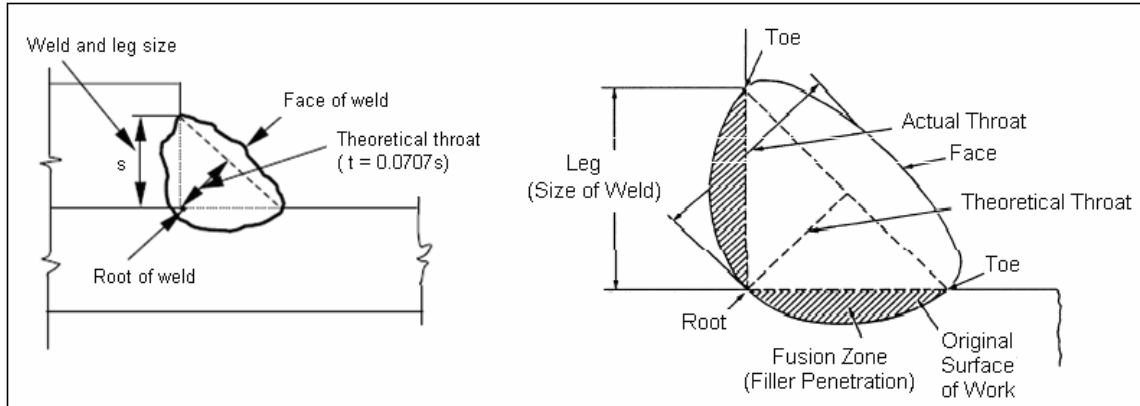


Often welding instructions specify an “inter-pass” temperature, which refers to the temperature below which the previously deposited weld metal must be before the next pass may be started. After the effects of heat on metal are discussed, later in the course, you will understand the significance of the buildup sequence and the importance of controlling the inter-pass temperature.

FILLET WELDS

Fillet weld is used to join two surfaces that are at approximately right angles to each other in a lap, tee, or corner joint. Owing to their economy, ease of fabrication and adaptability, fillet welds are widely used. They require less precision in the fitting up because the plates being joined can be moved about more than the groove welds. Another advantage of fillet welds is that special preparation of edges, as required by groove welds, is not required. In a fillet weld the stress condition in the weld is quite different from that of the connected parts.

A typical fillet weld is shown below:



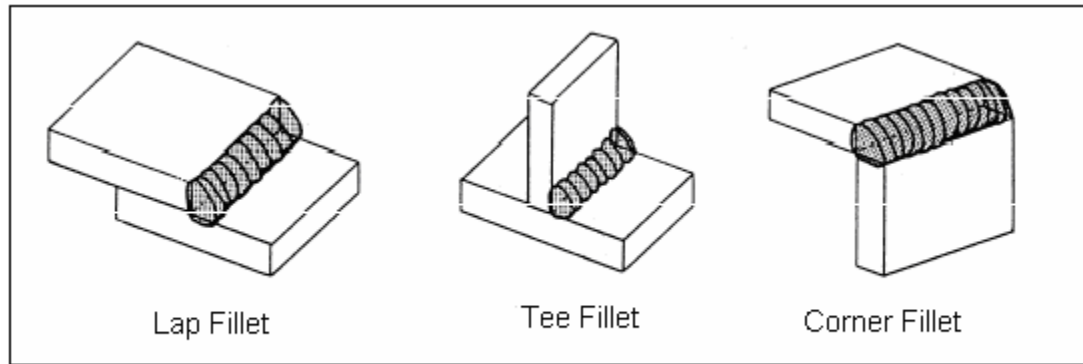
TYPICAL FILLET WELD

The terminology of fillet weld is similar to groove weld except that the terms “leg” and “throat” apply only to fillet welds. The root of a weld includes the points at which the back of the weld intersects the base metal surfaces. When we look at a triangular cross section of a fillet weld, the **leg** is the portion of the weld from the toe to the root. The **throat** is the distance from the root to a point on the face of the weld along a line perpendicular to the face of the weld. Theoretically, the face forms a straight line between the toes.

Note - In determining the size of a groove weld, such factors as the depth of the groove, root opening, and groove angle must be taken into consideration. The size of a fillet weld refers to the length of the legs of the weld. The two legs are assumed to be equal in size unless otherwise specified.

Fillet Weld Connections

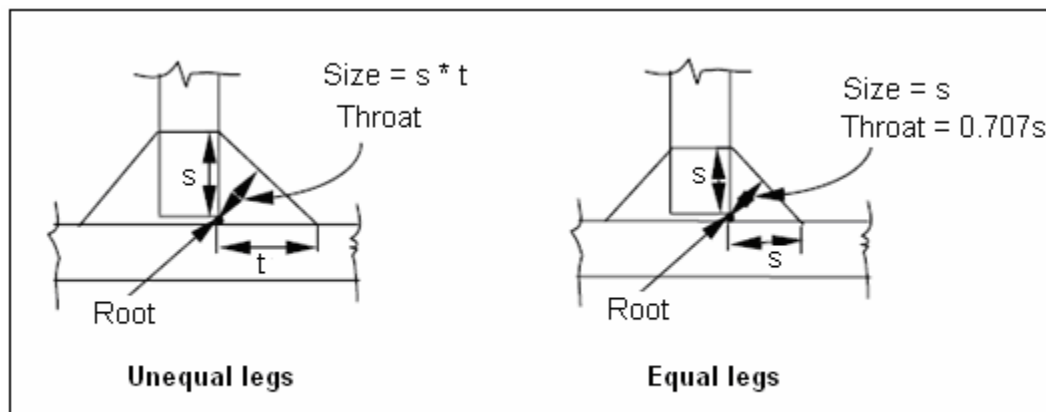
Across-sectional view of a **fillet weld** is triangular in shape. The typical fillet weld connections are shown in Fig. below:



TYPICAL FILLET WELD CONNECTIONS

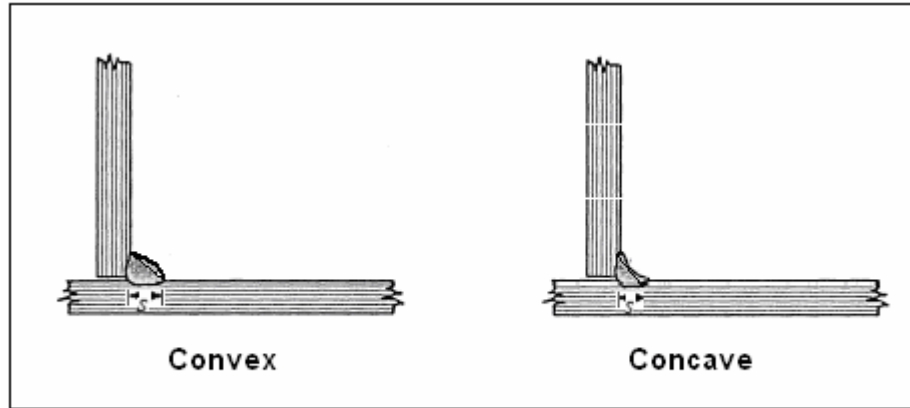
Size of Fillet Weld

The size of a fillet weld is defined by the length of the two sides of the largest right triangle, which can be inscribed within the weld cross section. A major share of welds of this type has equal legs i.e. they form right isosceles triangle shown in Fig. below. The critical dimension of a fillet weld is its throat, the shortest distance from the root to the hypotenuse of the defining triangle.



UNEQUAL & EQUAL LEGS FILLET WELDS

The root of the weld is the point where the faces of the metallic members meet. The theoretical throat of a weld is the shortest distance from the root to the hypotenuse of the triangle. The throat area equals the theoretical throat distance times the length of the weld. Though a fillet weld is specified by defining the two sides of the inscribed triangle, its actual cross section will be quite complex. A fillet weld must penetrate the base metal and the interface of the weld is either concave or convex.



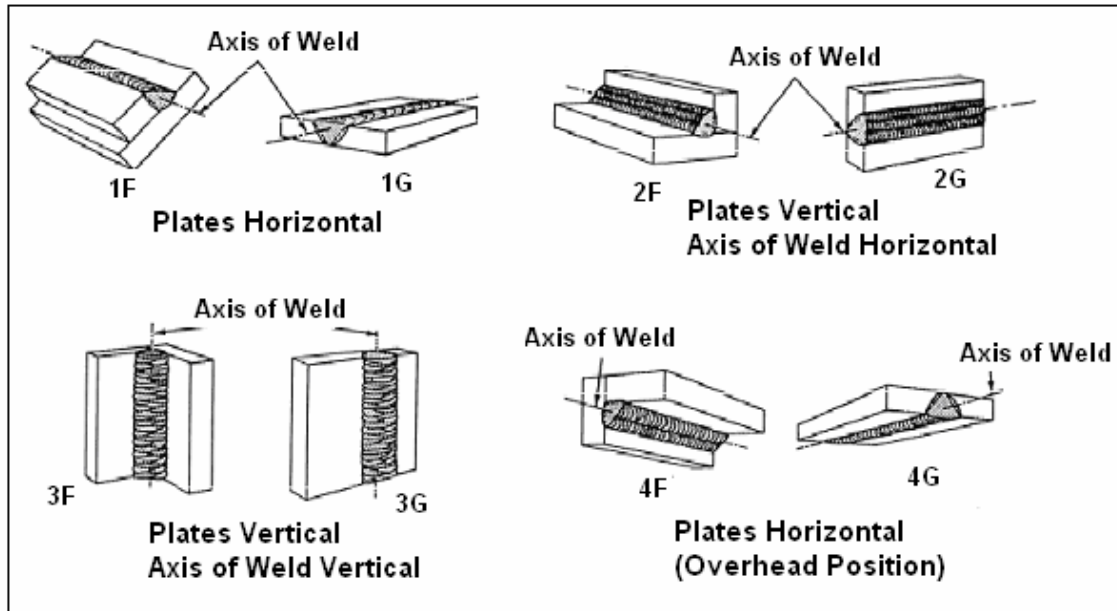
CROSS SECTION OF FILLET WELD

The concave shape of free surface provides a smoother transition between the connected parts and hence causes less stress concentration than a convex surface. But it is more vulnerable to shrinkage and cracking than the convex surface and has a much reduced throat area to transfer stresses. On the other hand, convex shapes provide extra weld metal or reinforcement for the throat. But while making a convex surface there is always the possibility of causing undercut at the edges, which undermines the strength of the joint. The stress concentration is higher in convex welds than in concave welds. *It is generally recommended that for statically loaded structures, a slightly convex shape is preferable, while for fatigue – prone structures, concave surface is desirable.*

Large welds are invariably made up of a number of layers or passes. For reasons of economy, it is desirable to choose weld sizes that can be made in a single pass. Large welds can be made in a single pass by an automatic machine, though manually, 8mm fillet is the largest single-pass layer.

Welding Classification based on Position

Welds are also classified according to their position into flat, horizontal, vertical and overhead. Flat welds are the most economical to make while overhead welds are the most difficult and expensive.

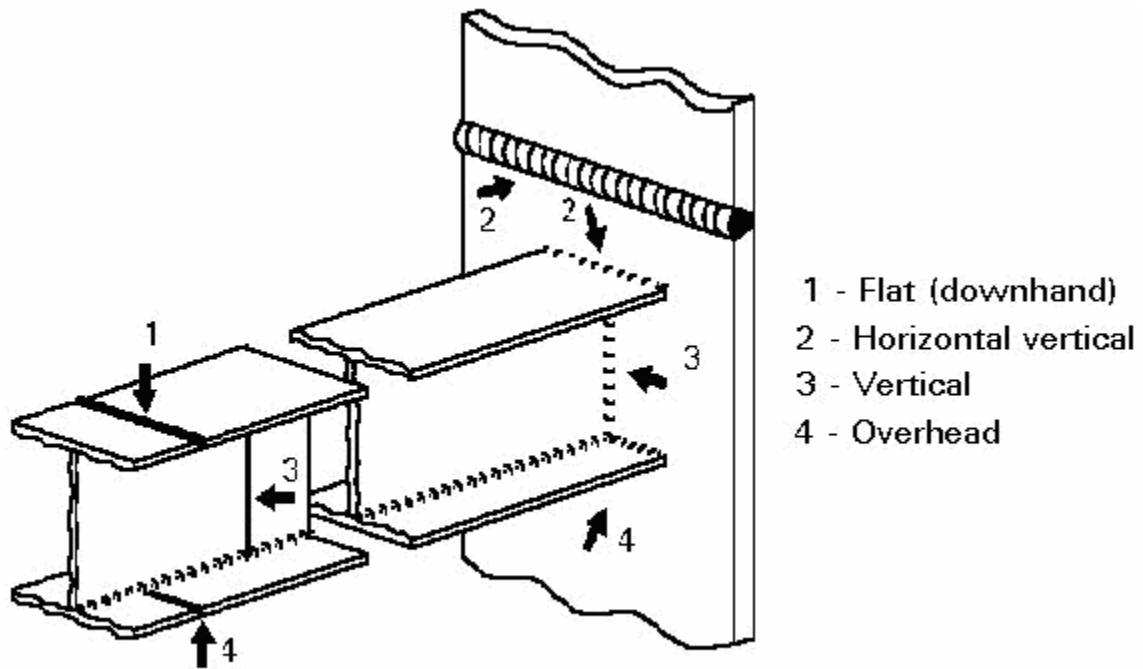


WELDING CLASSIFICATION BASED ON POSITION

The American Welding Society (AWS) identifies these positions by a number/letter designation; for instance, the 1G position in figure above refers to a groove weld that is to be made in the flat position. Here the 1 is used to indicate the flat position and the G indicates a groove weld. For a fillet weld made in the flat position, the number/letter designation is 1F (F for fillet). These number/letter designations refer to test positions. These are positions a welder would be required to use during a welding qualification test. As a steelworker, there is a good possibility that someday you will be required to certify or perform a welding qualification test; therefore, it is important that you have a good understanding and can apply the techniques for welding in each of the test positions.

Because of gravity, the position in which you are welding affects the flow of molten filler metal. Use the flat position, if at all possible, because gravity draws the molten metal downward into the joint making the welding faster and easier. Horizontal welding is a little more difficult, because the molten metal tends to sag or flow downhill onto the lower plate. Vertical welding is done in a vertical line, usually from bottom to top; however, on thin material downhill or downhand welding may be easier. The overhead position is the most difficult position. Because the weld metal flows downward, this position requires considerable practice on your part to produce good quality welds.

Example of structural steel welding positions is shown in figure - below:



STRUCTURAL STEEL WELDING POSITIONS

SECTION - 3

WELDABILITY OF STEELS

The term weldability is defined as the ability to obtain economic welds, which are good, crack - free and would meet all the requirements. Of great importance are the chemistry and the structure of the base metal and the weld metal. The most common materials used in industry are tabulated below:

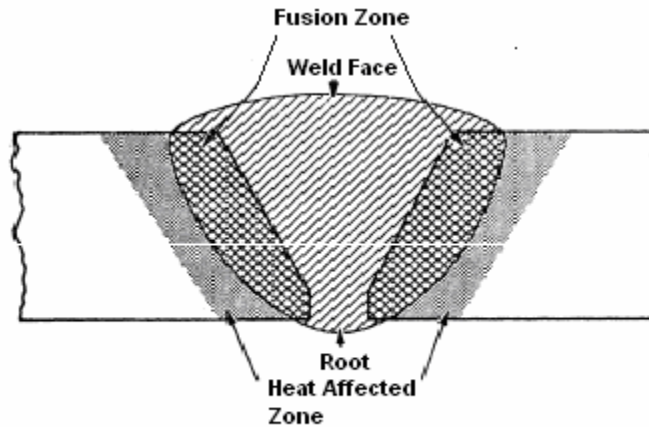
ASTM Materials Commonly Used

Material	Carbon Steel	Impact Tested CS	Stainless Steel
Plate	A516 Gr 55 to 70 A537 Cl 1 or 2	As CS with supplementary requirement S5	A240 304
Pipe	A106 Gr B	A333 Gr 6	A312 TP 304
Flanges	A105	A350 LF2	A182 F304
Forged Fittings	A234 WPB	A765 Gr 1 or 2	A403 WP304
Bolts	A194 B7	A320 L7	A320 B8M
Nuts	A194 2H	A194 Gr 4 (S4)	A194 M
Tubing	A179 , A214	A334 Gr 6	A213 TP304
Casting	A216 WCB	A352 LCB	A351 CF8

The following paragraphs will introduce you to some of the basic terms of the welding language.

Fusion Zone - The fusion zone is the region of the base metal that is actually melted. The depth of fusion is the distance that fusion extends into the base metal or previous welding pass.

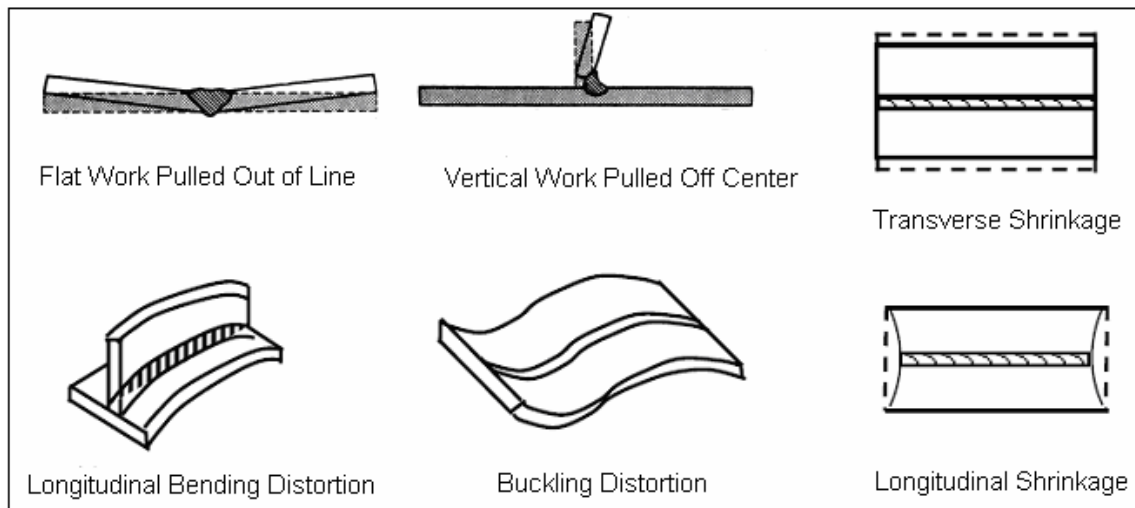
Heat Affected Zone (HAZ) - When the weld pool is cooling and solidifying, the majority of the heat flows through the parent metal alongside the joint. The structure of the steel in the area surrounding the weld, which has not melted will be altered by the intense heat of the weld. This is referred to as the heat-affected zone (HAZ) on the base metal.



ZONES IN A WELD

Distortion in Weldments

When a piece of metal is heated, the metal expands and upon cooling the metal contracts and tries to resume its original shape. But in welding process, expansion and contraction forces may not be uniform throughout all parts of the metal. This is due to the difference in the temperature of the weld metal and the base metal regions near the weld that leads to internal stresses causing bending, buckling and rotation. The displacement arising out of these forces are called distortion. Some of the distortions types are illustrated in Figure below:



WELD DISTORTION

All metals, when exposed to heat buildup during welding, expand in the direction of least resistance. Conversely, when the metal cools, it contracts by the same amount;

therefore, if you want to prevent or reduce the distortion of the weldment, you have to use some method to overcome the effects of heating and cooling.

OTHER COMMON DEFECTS IN WELDS

If good welding methods and procedures are not followed a number of defects may be developed causing discontinuities within the weld. Some of the important defects are described below:

Cracks - Cracks can occur in both the base metal and the weld metal as a result of welding. The cracks are mainly caused by three principle reasons:

- High carbon and alloy content of the base metal;
- Hydrogen and nitrogen absorption;
- Rapid cooling rate.

Aspects of base metal and weld metal composition are very important as is also the need for low hydrogen electrodes to be dry. The presence of iron sulphide in the weld metal is most likely to produce solidification cracks on contraction.

Insufficient throat thickness can lead to weld cracking in a shrinking weld and a restrained joint. Hydrogen cracking in the weld metal is likely when welding high strength low alloyed steels (HSLA). Carbon equivalent values help determine the risk of hydrogen cracking.

Undercut - Undercut is the term given to a sharp narrow groove along the toe of the weld due to the scouring action of the arc removing the metal and not replacing it with weld metal. It reduces cross sectional area (and strength) but more importantly it provides a notch into the heat affected area of the joint which will act as a stress raiser and possible point of crack initiation. This type of defect is formed due to the use of excessive current, incorrect electrode angles, too fast travel speed or an excessively long arc. The defect is detected easily by visual inspection and repaired easily by depositing additional weld material.

Lack of Fusion - In this defect, weld metal lies adjacent to un-fused base material or previous runs without admixture i.e. the two sections are not welded together. This is

usually associated with the opposite situation which causes undercut in that too much molten metal is flowing within the joint area without sufficient direct arc action on the base metal beneath. Incomplete fusion results if

- the mating surfaces are not properly cleaned of all coatings such as mill scales, slag, oxides etc;
- Current input is insufficient causing improper melting of base metal.

Slag Inclusions – Slag is formed in the welding process due to the chemical reaction of the melted electrode coating. It normally consists of metal oxides and other compounds. Since it has less density than the molten weld metal the slag usually floats on the surface. On cooling, this is removed by the welder. But, if the cooling is rapid, the slag may get trapped before it can rise to the surface. When several passes of weld are made to achieve the desired weld size, the slag that forms between each process must be removed completely. The main reason for slag inclusion is due to the failure to remove the slag fully between runs, excessive weaving and the use of too large an electrode in a narrow groove or too low amperage.

Incorrect Profile - Excessive concavity results in insufficient throat thickness in relation to the nominated weld size. Excessive convexity results in poor weld contour which in multilayer welds can give rise to slag inclusions while in the finished weld it provides a poor stress pattern and a local notch effect at the toe of the weld. Selection of correct size and type of electrode with correct current and electrode manipulation will not give these defects.

Inadequate Penetration - When the weld penetration is less than that specified it is termed as inadequate penetration. This type of defect, primarily occurring in groove welds, is due to insufficient groove angles, very large electrodes, inadequate weld current, larger welding rates, or insufficient gaps at the root of welds. The defect can be avoided by means of backup plates.

Porosity - Porosity is formed when a number of gas pockets or voids are trapped during the cooling process. Porous welds may arise as a result of coating breakdown due to excessively high current, longer arc length, excessive moisture pickup by the electrode

(particularly low hydrogen types), and impurities absorbed from the base metal. Using wet electrodes is bad practice.

FACTORS AFFECTING THE QUALITY OF WELDED CONNECTIONS

A good weld is obtained from a combination of many factors, from the design of the weld to the welding operation. Even a well-designed weld may not give a strong connection if it is not properly made. Some of those factors that affect the quality of the weld are explained in the following.

Proper Edge Preparation and Fit-up

Proper edge preparation and fit-up can restrict the effects of distortion and is essential to good quality welds. The choice of edge preparation plays an important role in reducing distortion, for example:

- Double V is better than single V
- Single U is better than single V

Additionally, you one should use **tack welds**, especially on long joints. A tack weld is a weld made to hold parts of an assembly in proper alignment temporarily until the final welds are made. Although the sizes of tack welds are not specified, they are normally between 1/2 inch to 3/4 inch in length, but never more than 1 inch in length. In determining the size and number of tack welds for a specific job, you should consider thicknesses of the metals being joined and the complexity of the object being assembled. As a rule of thumb, tack welds should be spaced at least 12 inches apart and run approximately twice as long as the thickness of the weld.

Control the Heat Input

In arc welding, energy is transferred from the welding electrode to the base metal by an electric arc. When the welder starts the arc, both the base metal and the filler metal are melted to create the weld. This melting is possible because a sufficient amount of power (energy transferred per unit time) and energy density is supplied to the electrode.

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because, like preheat and interpass temperature, it influences

the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and the HAZ.

Calculation:

Heat input is typically calculated as the ratio of the power (i.e., voltage x current) to the velocity of the heat source (i.e., the arc) as follows:

$$H = E * I / (1000 * S)$$

Where

- H = heat input (kJ/in or kJ/mm)
- E = arc voltage (volts)
- I = current (amps)
- S = travel speed (in/min or mm/sec)

You should understand that the faster a weld is made, the less heat is absorbed by the base metal. As you gain welding experience, it will become easier for you to weld a seam with the minimum amount of heat by simply speeding up the welding process. Regardless of your experience, it is often necessary to use a welding technique designed to control heat input.

Example - If the arc voltage is 20, the current is 300 amps and the welding speed is 2.5 mm/sec calculate the heat input for unit length.

Solution - Using equation, $H = E * I / (1000 * S)$

$$H = 20 * 300 / (1000 * 2.5) = 2.4 \text{ kJ/mm}$$

The heat input per unit length of the weld will be 2.400 kJ/ mm.

Preheating the Metal

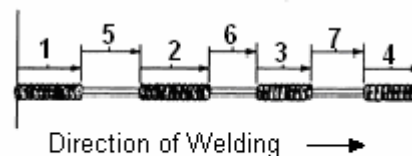
Sudden cooling of steel results in a hard and less ductile material called martensite. The main function of preheating is to reduce the weld metal cooling rate so that transformation to martensite is reduced below a certain critical level. *The slower cooling gives more time for hydrogen to diffuse out of the weld area and delays the development*

of maximum residual stresses. Gas torches, heat-treating furnaces or electric-resistance heaters are used in preheating the weld area.

The preheating is restricted to a narrow portion, where the joint is to be made. The region, which is heated, expands, whereas the rest of the metal resists the expansion. As a consequence compressive stresses are induced near the joint during the heating. After the welding operation is over, the region of intense heating starts cooling. The contraction, which should result, is prevented because the two separate pieces, which were originally free to expand, have now been joined and are not free to contract. Further, the temperature distribution of the weldment would be vastly different from that of the two separate pieces. The net result is that tensile stresses are developed near the weld and compressive stresses away from it.

Intermittent Welds

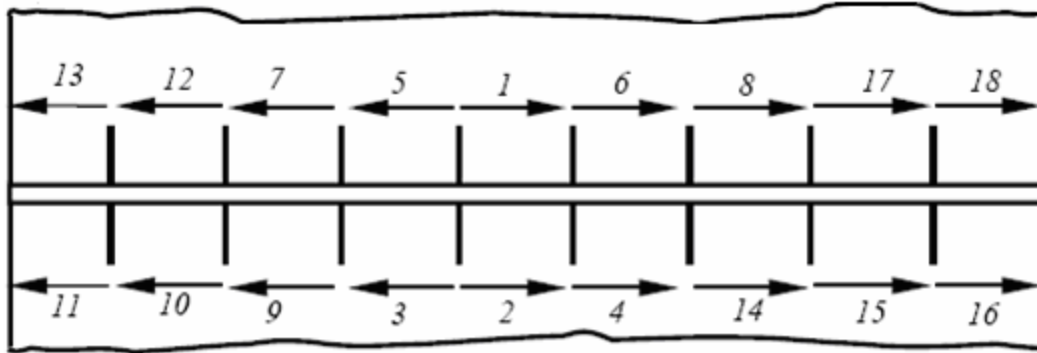
Because the mechanical properties of the base metal are affected by the welding heat, it is important to control the heat input. One technique often used to minimize heat input is the intermittent weld. An intermittent weld (sometimes called a skip weld) instead of one continuous weld reduces occurrence of distortion. In an intermittent weld, a short weld is made at the beginning of the joint; next, you skip to the center of the seam and weld a few inches and then weld at the other end of the joint. Finally, return to the end of the first weld and repeat the cycle until the weld is finished.



Intermittent Butt Weld

Welding Sequence

Sequence of welding plays a key role in obtaining a satisfactory welded fabrication. The smallest weld size that can fulfill the requirements is the hallmark of a good weld designer. *It is always advisable to weld away from a point of restraint; welding of a joint should start from the centerline and proceed towards the free end.* The principle of doubling-up method is employed for a single run fillet weld on either side of the vertical member.



**Sequence of Welding Fillet Welds on either side of a Vertical Member
(Doubling-up Method)**

Limit the Number of Weld Passes

You can keep distortion to a minimum by using as few weld passes as possible. You should limit the number of weld passes to the number necessary to meet the requirements of the job.



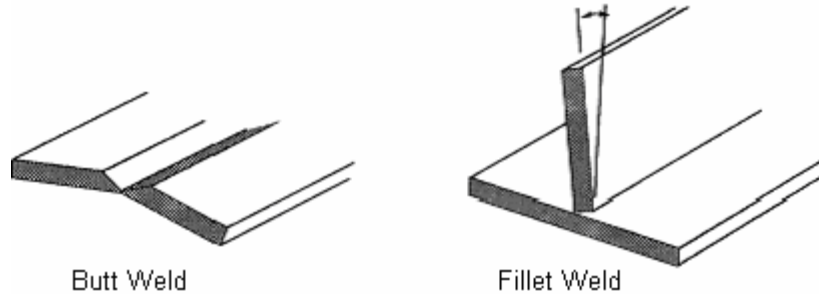
WELD PASSES

Use Jigs and Fixtures

Holding the metal in a fixed position prevents excessive movements. Use of jigs and fixtures to hold the metal rigidly in position during the welding operation can help prevent distortion.

Allow for Distortion

To reduce distortion, angle the parts to be welded slightly in the opposite direction in which the contraction takes place. When the metal cools, contraction forces pull the pieces back into position. Figure below shows how distortion can be overcome in both the butt and tee joints.



ALLOWING FOR DISTORTION

Using Proper Electrodes, Welding Apparatus and Procedures

Depending on the grade of steel and its thickness, appropriate electrode with suitable diameter has to be selected. The size of the electrode is chosen based on the size of the weld to be made and also on the output of the welding apparatus. It is important that the welding apparatus is capable of delivering enough current for the size of the electrode. Since the output of welding apparatus can be controlled within limits, an electrode of small size may also be used.

Correct Choice of Joint Design

The details of a joint, which includes both the geometry and the required dimensions, are called the joint design. Although welded joints are designed primarily to meet strength and safety requirements, there are other factors that must be considered. A few of these factors are as follows:

- Whether the load will be in tension or compression and whether bending, fatigue, or impact stresses will be applied
- How a load will be applied; that is, whether the load will be steady, sudden, or variable
- The direction of the load as applied to the joint
- The cost of preparing the joint

Another consideration that must be made is the ratio of the strength of the joint compared to the strength of the base metal. This ratio is called **joint efficiency**. An

efficient joint is one that is just as strong as the base metal. Understanding the correct joint design enables you to produce better welds. In general following guidelines apply:

Butt Joints

Square Butt Joint - The square butt joint is used primarily for metals that are 3/16 inch or less in thickness. The joint is reasonably strong, but its use is not recommended when the metals are subject to fatigue or impact loads.

Groove Butt Joint - When you are welding metals greater than 3/16 inch in thickness, it is often necessary to use a grooved butt joint. The purpose of grooving is to give the joint the required strength. When you are using a grooved joint, it is important that the groove angle is sufficient to allow the electrode into the joint; otherwise, the weld will lack penetration and may crack. However, you also should avoid excess beveling because this wastes both weld metal and time. Depending on the thickness of the base metal, the joint is either single-grooved (grooved on one side only) or double-grooved (grooved on both sides). As a welder, you primarily use the single-V and double-V grooved joints.

Single V Butt Joint - The single-V butt joint is for use on plates 1/4 inch through 3/4 inch in thickness. Each member should be beveled so the included angle for the joint is approximately 60 degrees for plate and 75 degrees for pipe. Preparation of the joint requires a special beveling machine (or cutting torch), which makes it more costly than a square butt joint. It also requires more filler material than the square joint; however, the joint is stronger than the square butt joint. But, as with the square joint, it is not recommended when subjected to bending at the root of the weld.

Double V Butt Joint - The double-V butt joint is an excellent joint for all load conditions. Its primary use is on metals thicker than 3/4 inch but can be used on thinner plate where strength is critical. Compared to the single-V joint, preparation time is greater, but you use less filler metal because of the narrower included angle. Because of the heat produced by welding, you should alternate weld deposits, welding first on one side and then on the other side. This practice produces a more symmetrical weld and minimizes warpage.

Tee Joints

Square Tee Joint - The square tee joint requires a fillet weld that can be made on one or both sides. It can be used for light or fairly thick materials. For maximum strength, considerable weld metal should be placed on each side of the vertical plate.

Single Bevel Tee Joint - The single-bevel tee joint can withstand more severe loadings than the square tee joint, because of better distribution of stresses. It is generally used on plates of 1/2 inch or less in thickness and where welding can only be done from one side.

Double Bevel Tee Joint - The double-bevel tee joint is for use where heavy loads are applied and the welding can be done on both sides of the vertical plate.

Lap Joints

Single Lap Fillet Joint - Metal up to ½ inch thickness and not subject to heavy loads can be welded using this joint.

Double Fillet Lap Joint – Use double fillet lap joints for metals subjected to heavy loads. When welded properly, the strength of this joint is very close to the strength of the base metal.

WELD TEST METHODS

There are several non-destructive examination (NDE) techniques to check the quality of welds. They are explained in the following.

Visual inspection by a competent person will give a good indication of the quality of welds; but may not be able to gauge the sub surface condition of the welds. An experienced welder, by visual inspection, would be able to know whether satisfactory fusion and penetration are obtained. He will be able to recognize good welds by their shape, size and general appearance. In a good weld, the metal should be nearly its original color after it has cooled. In case of over heating, it will give a rusty appearance. Methods of determining the internal soundness of a weld are described below:

1. **Liquid Penetrants** - In this method, a type of dye is spread over the weld surface. This dye penetrates into the surface cracks of the weld. After the penetration of the dye, any excess material is removed and a powdery developer is sprayed to draw

the dye out of the cracks. Then, the outline of the cracks can be seen with naked eye. In some cases, fluorescent dyes are used for improved visibility of the cracks.

2. **Magnetic Particles** - The weld that is inspected is 'magnetized' electrically. Cracks, which are present at or near the surface, would cause North and South poles to form on each side of the cracks. Dry iron filings are then kept on the weld. They form patterns when they cling to cracks. From the patterns, the location of cracks, their size and shapes are established.
3. **Ultrasonic Testing** - By means of the ultrasonic equipment, sound waves are sent through one side of the material and they are reflected from the opposite side. These reflections are indicated in a cathode ray tube. Any defect in the weld will alter the time of the sound transmission. By the help of the picture in the tube, flaws can be detected and their severity can be judged.
4. **Radiography** - This is an expensive method and can be used to check the welds in important structures. Portable X-ray machines along with radium or radioactive cobalt would give excellent pictures. This method is reliable for butt welds, but is not satisfactory for fillet welds due to difficulty in interpreting pictures. Another drawback of the method is the radioactive danger. Much care has to be taken while carrying out this inspection to protect the workers on the job.

A properly welded connection is usually much stronger (1.5 to 2 times) than the strength of the members being connected. The reasons for the extra strength are: electrode wire is made up of premium steel, the metal is melted electrically and the cooling rate is rapid. Due to these factors, the weld strength is always higher than required by the design.

Weld Defect Acceptance Levels

In general the following weld defects detected during inspection are acceptable for structures.

1. For joints welded from both the sides, incomplete penetration with thickness up to 5% of the parent metal thickness, but not exceeding 2 mm and the length more than 500 mm can be accepted. The aggregate length of flaw shall not be more than 200 mm per meter length of the joint. Incomplete penetration and cracks are not allowed at or near the end or beginning of a joint.

2. For joints welded from one side without backing strip, incomplete penetration with thickness up to 15% of parent metal thickness but not exceeding 3 mm at the root is allowed.
3. Slag inclusion located along the weld as a chain or unbroken line is allowed if their aggregate length does not exceed 200 mm per meter of weld length. Size of the slag may also be considered.
4. Total of isolated gas pores and slag inclusion shall not exceed five per square centimeter of the weld.
5. Total of incomplete penetration, slag inclusion on pores located separately or as a chain shall not exceed 10% of metal thickness but not greater than 2 mm when welding is done from both the sides and 15% of metal thickness, but not greater than 3 mm when welding is done from one side.
6. For metal thickness up to 10 mm, undercuts shall not be more than 0.5 mm. For metal thickness more than 10 mm, undercuts shall not be greater than 1 mm.
7. Incomplete weld, molten metal flow, pits and cracks shall not be allowed.

SECTION 5

WELDING PROCEDURES

There are essentially three steps to be followed to ensure good welding:

1. Establishing good welding procedures
2. Use of pre-qualified welders
3. Availability of competent inspectors in shop and field

The term **welding procedure** is used to describe the complete process involved in making a weld. It covers a record of all of the different elements, variables, and factors such as choice of electrode, edge preparation, welding sequence, joint details, preheat, welding parameters such as voltage, current, welding position, number of weld run to fill the groove and post weld treatments (e.g. grinding, heat treatment etc.) that are involved in producing a specific weld or weldment.

Welding procedures should be written whenever it is necessary to:

- Maintain dimensions by controlling distortion;
- Reduce residual or locked up stresses;
- Minimize detrimental metallurgical changes;
- Consistently build a weldment the same way;
- Comply with certain specifications and codes.

Elements of Weld Procedure

Some of the important elements of weld procedure are elaborated below.

1. **Environment:** Weld procedure must account for actual site conditions. In cold regions, it may be necessary to heat steel up to 20%. The humid weather or condensation might help formation of porosity. Electrodes must be kept in dry condition. In moist / humid environments the electrodes may be kept in a warm container to avoid moisture entrapment in the flux coating.
2. **Welding position:** Vertical welding is slower compared to welding in the flat position. Overhead welding causes weld splutter and require special skills. It is better avoided.

3. **Current:** The current controls the heat input. A minimum current is required for fusing the plate and to keep the arc stable. Generally a high current is used to obtain quicker welding so as to reduce cost. It may not be possible to use maximum current always, a specific example being welding in the overhead position. The current limit for overhead use is 160A. Usually high current results in low impact properties. Further very high value of current may cause cracks in the Heat-Affected Zone (HAZ).
4. **Shrinkage:** While cooling after the welding operation, the hot metal in the welded region contracts causing the joint to shrink. But this contraction is prevented by the adjacent colder metal. This causes stress, sometimes even beyond yield stress, and causes plastic deformation. This also might cause distortion of the member. By following proper edge preparation and weld procedure, this can be minimised. After the plastic deformation a residual stress pattern is formed in the joint. Tensile stresses are formed in the weld metal and HAZ zones, whereas compression in the adjacent steel.
5. **Pre heating:** Hydrogen induced cracking (cold cracking, delayed cracking) is a serious problem affecting weldability. The degree of cracking occur due to the combined effects of four factors:
 - Brittle microstructure
 - Presence of hydrogen in weld metal
 - Tensile stresses in the weld area
 - Temperature range (-100°C to 200°C)

Defining Essential Variables

Essential variables are those factors which must be recorded and if they are changed in any way, the procedure must be retested and requalified. Essential variables involved in the procedure usually include the following:

- The welding process and its variation
- The method of applying the process
- The base metal type, specification, or composition

- The base metal geometry, normally thickness
- The base metal need for preheat or postheat
- The welding position
- The filler metal and other materials consumed in making the weld
- The weld joint, that is, the joint type and the weld
- Electrical or operational parameters involved
- Welding technique.

Non essential Variables

Some specifications also include nonessential variables. Non essential variables are usually of less importance and may be changed within prescribed limits and the procedure need not be re-qualified. These are usually the following:

- The travel progression (uphill or downhill)
- The size of the electrode or filler wire
- Certain details of the weld joint design
- The use and type of weld backing
- The polarity of the welding current.

The procedure write-up must include each of the listed variables and describe in detail how it is to be done. The second portion of the welding procedure is the joint detail sketch and table or schedule of welding conditions.

Pre-qualification of Welding Procedures

Welding procedures are necessary to produce welds that will meet the requirements of commonly used codes. The American Welding Society (AWS) produces the *Structural Welding Code* that is used for the design and construction of steel structures (**AWS D1.1**). Another code that is used for the construction of steam boilers and pressure

vessels is published by the American Society of Mechanical Engineers (ASME). Using the appropriate welding code, along with the project drawings and specifications, the welding inspector develops a welding procedure specification that meets the requirements of the job. The different codes have somewhat different requirements for a welding procedure, but in general a welding procedure consists of three parts as follows:

- A detailed written explanation of how the weld is to be made
- A drawing or sketch showing the weld joint design and the conditions for making each pass or bead
- A record of the test results of the resulting weld.

If the weld meets the requirements of the code or specification and if the written procedure is properly executed and signed it becomes a **qualified welding procedure**.

Once a welding procedure has been developed, welders are then required to perform a Welding Performance Qualification test. After the test is complete, the weld specimens are tested according to the requirements of the welding procedure specification. *For most codes, if a welder continues to use a particular process and procedure, the welder's qualification remain in effect indefinitely.*

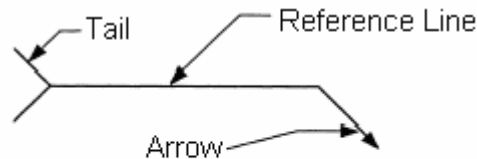
SECTION 6

READING WELDING DRAWINGS & SYMBOLS

Drawings or sketches are used to convey the ideas of an engineer to the craftsman working in the shop. As a welder, you must be able to work from a drawing in order to fabricate the structure or components exactly as the engineer has designed them. To read a drawing, you must know how engineers use lines, dimensions, symbols and notes to communicate their ideas on paper. In this section, we briefly discuss each of these drawing elements.

Welding Symbols

Welding information concerning type, size, position, welding process etc. is conveyed by standard symbols. Welding symbols have been standardized by the American Welding Society (AWS) in US and internationally by IS: 813-1986, "Scheme of Symbols for Welding".



STANDARD WELDING SYMBOL

A welding symbol may include the following elements:

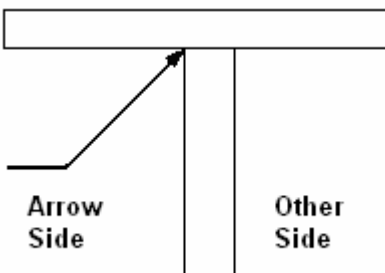
- Reference Line
- Arrow
- Basic Weld Symbol
- Dimensions & Other Data
- Supplementary Symbols
- Finish Symbols
- Tail
- Specifications, Process, Or Other References

Note - A standard welding symbol consists of a reference line, an arrow, and a tail. Note that the term *welding symbol* refers to the total symbol, which includes all information

needed to specify the weld(s) required whereas the term *weld symbol* refers only to part of the information required on the welding symbol. It is just the symbol for a specific type of weld.

Reference Line: A reference line is a horizontal line with all the other required information (weld symbols, dimensions etc) drawn on or around it. It must be placed on the drawing near the joint it describes.

Arrow: The arrow simply connects the reference line to the joint or area to be welded. Quite often, there are two sides to the joint to which the arrow points, and therefore two potential places for a weld. For example, when two steel plates are joined together into a T shape, welding may be done on either side of the stem of the T.



The weld symbol distinguishes between the two sides of a joint by using the arrow and the spaces above and below the reference line. The side of the joint to which the arrow points is known as the *arrow side*, and its weld is made according to the instructions given below the reference line. The other side of the joint is known as the *other side*, and its weld is made according to the instructions given above the reference line. The *below* and *above* rules apply regardless of the arrow's direction.

Tail: The tail of the welding symbol is used only when necessary to include a specification, process, or other reference information.

Basic Weld Symbols

Basic weld symbols are shown below:

Bead	Fillet	Plug or Slot	Slot	Seam	GROOVE OR BUTT							
					Square	V	Bevel	U	J	Flare V	Flare Bevel	Back Weld
												

BASIC WELD SYMBOLS

Each type of weld has its own basic symbol, which is typically placed near the center of the reference line (and above or below it, depending on which side of the joint it's on). The symbol is a small drawing that can usually be interpreted as a simplified cross-section of the weld. In the descriptions below, the symbol is shown in both its arrow-side and other-side positions.

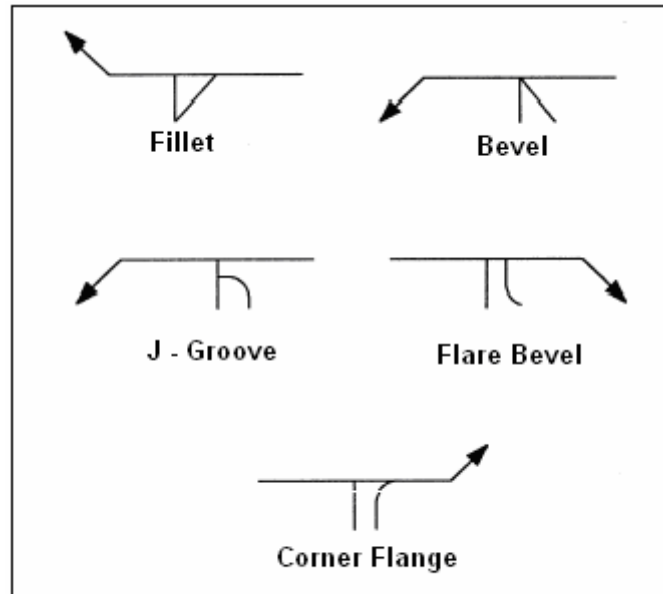
Fillet Weld	Groove Welds	Plug Weld
	       	

Position of symbols in drawings

The location of welds is classified on the drawings by specifying:

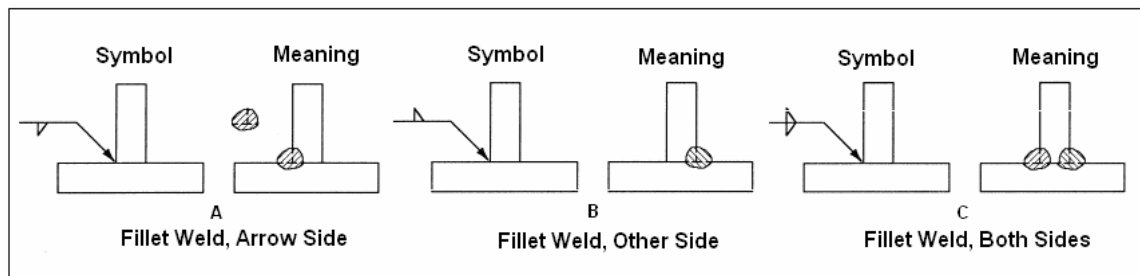
- Position of the arrow line
- Position of the reference line and
- The position of the symbol

Figure below shows weld symbols as applied to the reference line. The position of arrow line with respect to the weld has no special significance. The arrow line joins one end of the reference line such that it forms an angle with it and shall be completed by an arrowhead. The reference line is a straight line drawn parallel to the bottom edge of the drawing. Notice that the vertical leg of the weld symbol is shown drawn to the left of the slanted leg. Regardless of whether the symbol is for a fillet, bevel, J-groove, or flare-bevel weld, the vertical leg is always drawn to the left.



WELD SYMBOLS APPLIED TO REFERENCE LINE

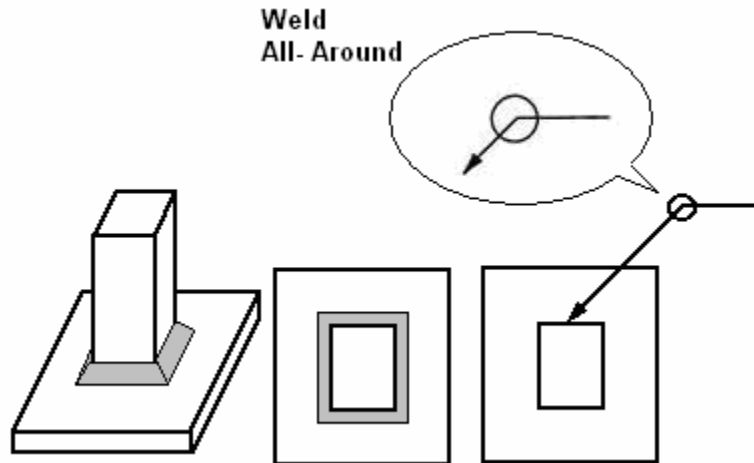
Figure below shows the significance of the positions of the weld symbols position on the reference line. In view A the weld symbol is on the lower side of the reference line that is termed the *arrow side*. View B shows a weld symbol on the upper side of the reference line that is termed the *other side*. When weld symbols are placed on both sides of the reference line, welds must be made on both sides of the joint (view C).



SPECIFYING WELD LOCATIONS

Weld All Around and Field Weld

There are two other elements that may be seen on the reference line that provide information about the weld. One is a circle around the place where the leader line connects to the reference line and indicates the weld is "all around". This means the weld extends all the way around the joint the arrow is pointing at. The all around element is only used when it is possible to weld all the way around a single surface (see below).



The other element seen on the reference line resembles a flag and is located where the leader line joins the reference line. This element is called a "field weld" and means the weld will be done in another location. For instance, this weld may be applied at the job site not in the shop. Sometimes clarification will be given in the welding symbol tail or as a specification on the print.



Field Weld Symbol

Contours

In addition to basic weld symbols, some welding symbols may show a contour finish that details how the weld shape must be finished after welding. Contour symbols are used with weld symbols to show how the face of the weld is to be formed. In addition to contour symbols, finish symbols are used to indicate the method to use for forming the contour of the weld. Some of the most common supplementary symbols are shown in figure below.

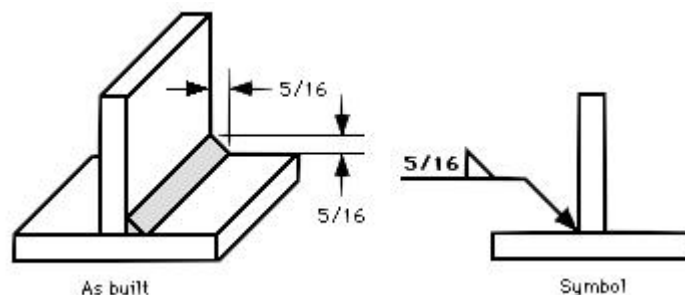
Flat by Contour	Flat by Machining	Flat by Grinding	Flat by Chipping
Convex Contour	Convex by Machining	Convex by Grinding	Convex by Chipping
Concave Contour	Concave by Machining	Concave by Grinding	Concave by Chipping

SUPPLEMENTARY SYMBOLS

When a finish symbol is used, it shows the method of finish, not the degree of finish; for example, a C is used to indicate finish by chipping, an M means machining, and a G indicates grinding.

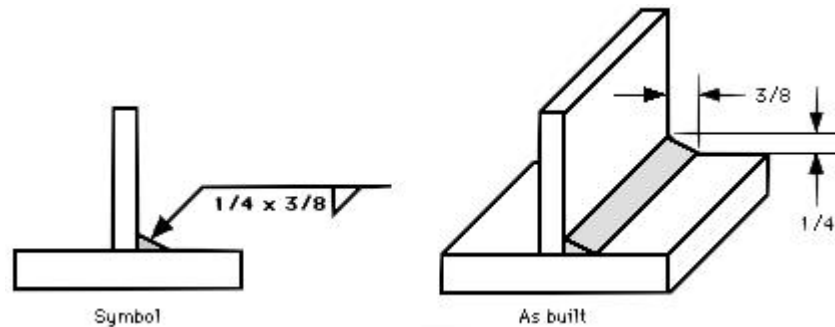
FILLET WELD REPRESENTATION

The fillet weld symbol is roughly triangular in cross-section, although its shape is not always a right triangle or an isosceles triangle. Weld metal is deposited in a corner formed by the fit-up of the two members and penetrates and fuses with the base metal to form the joint. (Note: for the sake of graphical clarity, the drawings below do not show the penetration of the weld metal. Recognize, however, that the degree of penetration is important in determining the quality of the weld.)

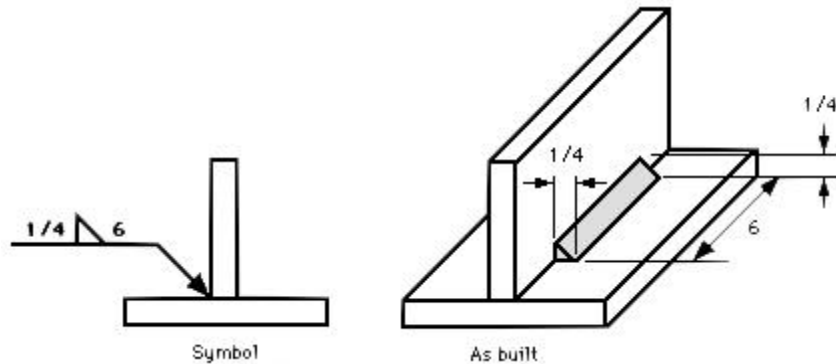


The perpendicular (straight up and down) leg of the triangle is always drawn on the left side of the symbol, regardless of the orientation of the weld itself. The leg size is written to the left of the weld symbol. If the two legs of the weld are to be the same size, only one dimension is given; if the weld is to have unequal legs (much less common than the equal-legged weld), both dimensions are given and there is an indication on the drawing as to which leg is longer.

The welding symbol above shows that the weld is to be done on the other side and the thickness of the weld is $\frac{5}{16}$.



The length of the weld is given to the right of the symbol.



If no length is given, then the weld is to be placed between specified dimension lines (if given) or between those points where an abrupt change in the weld direction would occur (like at the end of the plates in the example above).

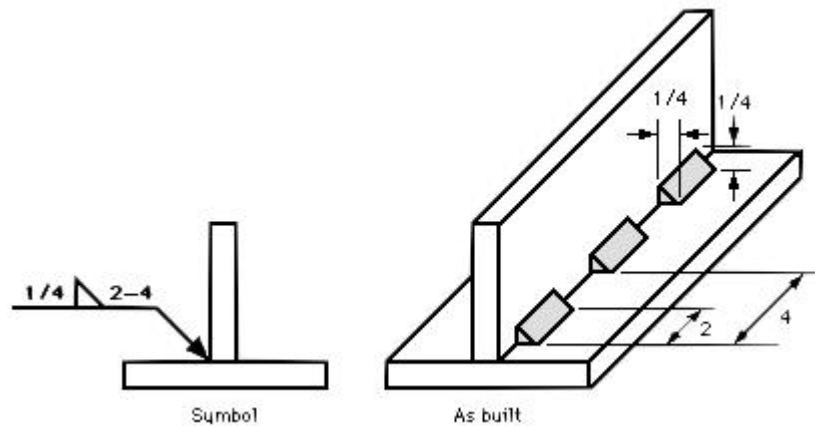
The Length & Pitch of Intermittent Welds

An intermittent weld is one that is not continuous across the joint, but rather is a given length of weld separated by a given space between them. This method of welding may be used to control heat distortion or where the joint strength requirements allow. Intermittent welding can save time and money if a long weld is not necessary.

Used more frequently than the length alone, the length and pitch (length first, spacing second) are two numbers located at the right of the fillet weld symbol.

The length appears first as before followed by a hyphen then the pitch is shown.

The pitch refers to a dimension from the center of one weld to the center of the next weld.

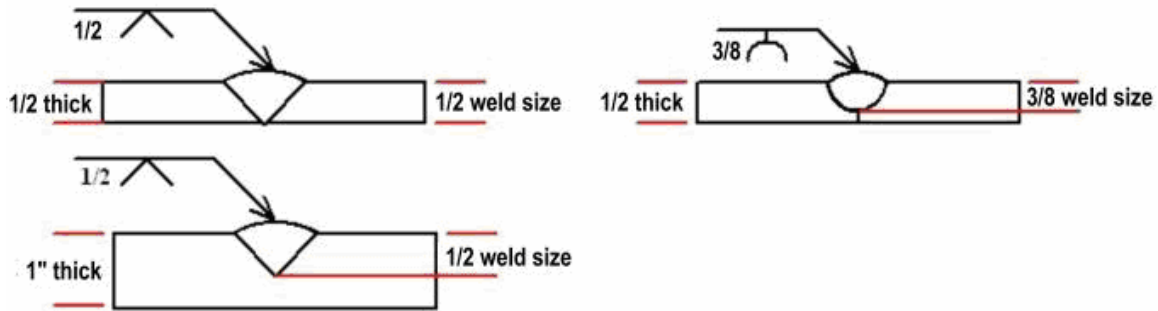


The pitch is not the space between welds but a measurement from center to center of the welds. To get the spacing for layout subtract the length of one weld from the pitch.

The intermittent welds may be chain intermittent or staggered intermittent. Chain intermittent the welds on both sides of the joint are opposite each other and resemble a chain. Staggered intermittent the welds on the opposite side are usually started in the gap between the welds on the first side. The welds then appear staggered.

GROOVE WELD REPRESENTATION

The groove weld size is given in two dimensions and like the fillet weld it is placed to the left of the weld symbol. The first size given is the depth of the groove and is the dimension used to prepare the edge preparation. The depth of groove is measured from the surface of the joint to the bottom of the preparation.

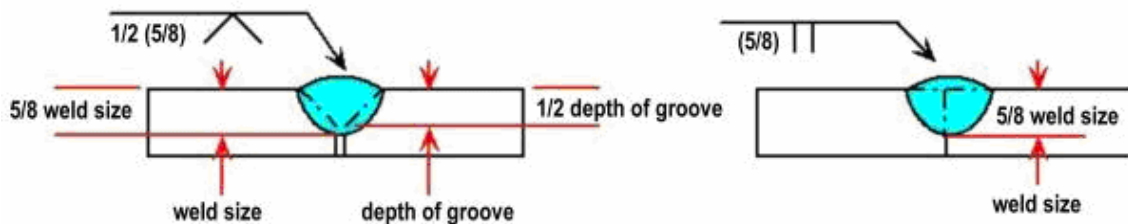


The depth of groove does not include weld reinforcement or root penetration.

The second size given is the actual weld size and is enclosed in parentheses to distinguish it from the groove size, or depth of groove.

The actual weld size is again measured from the surface of the groove through the bottom of the groove but now includes the expected penetration of the weld. On a square groove only the weld size is given.

The weld size does not include face reinforcement or root reinforcement.



Groove Opening & Angle

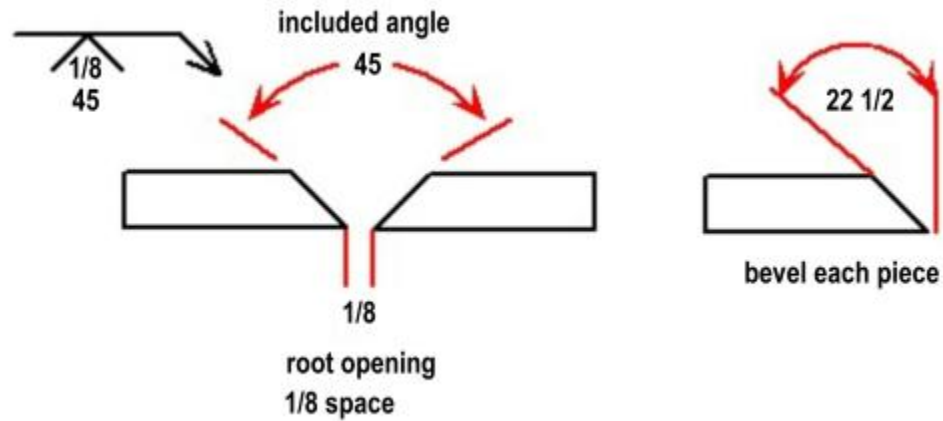
Two other important elements for preparing and welding the groove are the root opening and the groove angle. The root opening, when used, dimensions the space between the joint to be welded and is placed inside the weld symbol. The groove angle is also placed inside the weld symbol and is given in degrees.

The groove angle for a V groove is given as the included angle so that means the edge bevel or chamfer for each piece is 1/2 of the degrees given.

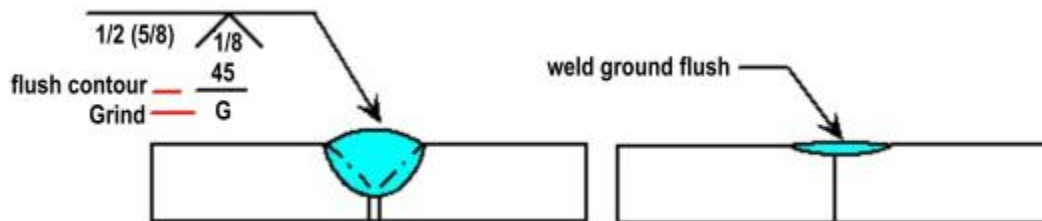
For example; a 45 degree included angle means bevel each member at 22½ degrees. J grooves angles may be detailed elsewhere on the drawing. The root opening and groove angle are separate elements and may or may not appear together depending on the joint requirements.

On some drawings the root opening or groove angle will be covered in a note or specification on the drawing for all similar symbols, and does not appear on the symbol.

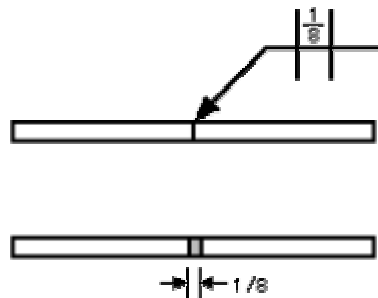
The Welder must always read all information given on a drawing.



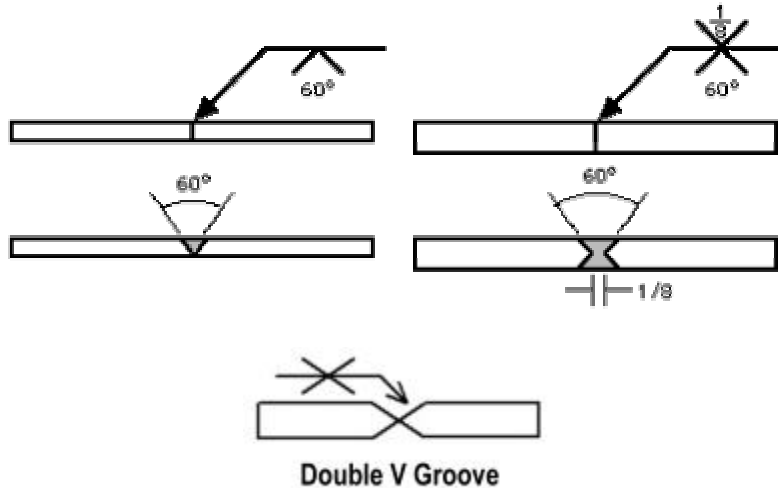
Contour & Finishing – The same contour symbols that apply to fillet welds may be used with groove welding and are placed above the weld symbol.



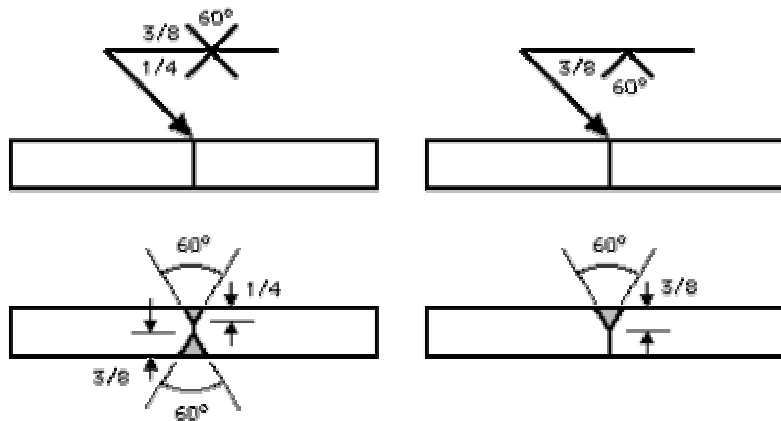
Square Groove - The square groove weld, in which the "groove" is created by either a tight fit or a slight separation of the edges. The amount of separation, if any, is given on the weld symbol.



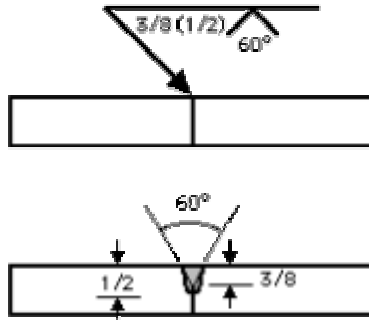
V-Groove- The V-groove weld, in which the edges of both pieces are chamfered, either singly or doubly, to create the groove. The angle of the V is given on the weld symbol, as is the separation at the root (if any).



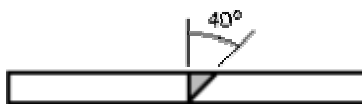
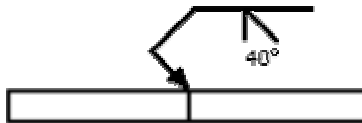
If the depth of the V is not the full thickness--or half the thickness in the case of a double V--the depth is given to the left of the weld symbol.



If the penetration of the weld is to be greater than the depth of the groove, the depth of the effective throat is given in parentheses after the depth of the V.



Bevel Groove - The bevel groove weld, in which the edge of one of the pieces is chamfered and the other is left square. The bevel symbol's perpendicular line is always drawn on the left side, regardless of the orientation of the weld itself. The arrow points toward the piece that is to be chamfered. This extra significance is emphasized by a break in the arrow line. (The break is not necessary if the designer has no preference as to which piece gets the edge treatment or if the piece to receive the treatment should be obvious to a qualified welder.) Angle and depth of edge treatment, effective throat, and separation at the root are described using the methods discussed in the V-groove section above.

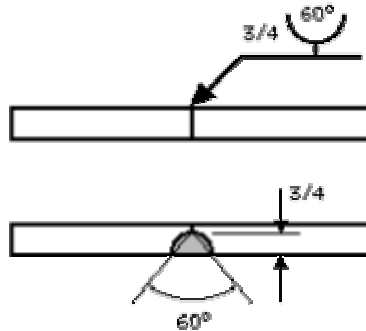


Bevel Groove

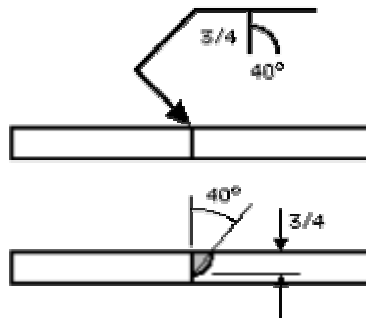


Double Bevel

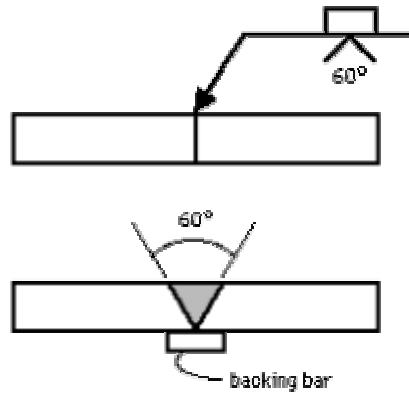
U-Groove- The U-groove weld, in which the edges of both pieces are given a concave treatment. Depth of edge treatment, effective throat, and separation at the root are described using the methods discussed in the V-groove section.



J-Groove - The J-groove weld, in which the edge of one of the pieces is given a concave treatment and the other is left square. It is to the U-groove weld what the bevel groove weld is to the V-groove weld. As with the bevel, the perpendicular line is always drawn on the left side and the arrow (with a break, if necessary) points to the piece that receives the edge treatment. Depth of edge treatment, effective throat, and separation at the root are described using the methods discussed in the V-groove section.

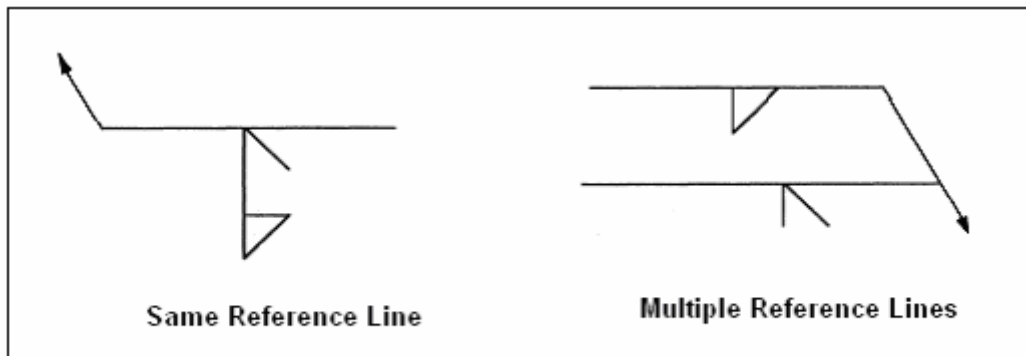


When a backing bar is used to achieve complete joint penetration, its symbol is placed across the reference line from the basic weld symbol. If the bar is to be removed after the weld is complete, an "R" is placed within the backing bar symbol.



Multiple-Weld Symbols

When you are fabricating a metal part, there are times when more than one type of weld is needed on the same joint; for example, a joint may require both a bevel groove weld and a fillet weld. Two methods of illustrating these weld symbols are shown in Figure - below. Note that in each welding symbol, the bevel groove weld is to be completed first, followed by the fillet weld.



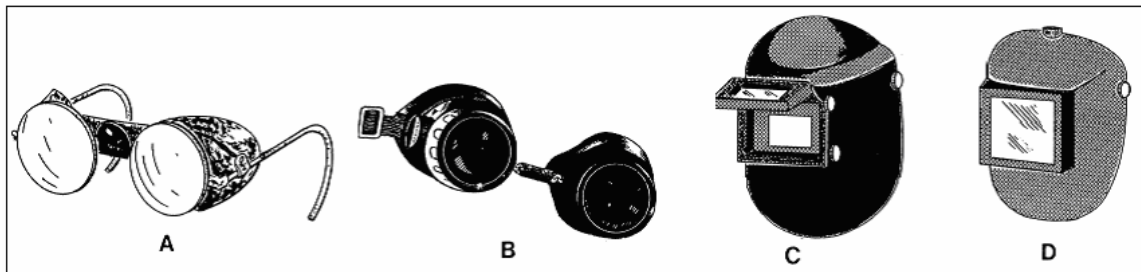
REPRESENTING MULTIPLE WELDS

SECTION 7

WELDING SAFETY

Arc welding is a safe process when sufficient measures are taken to protect the welder from potential hazards and when proper operating practices are followed. Major hazards welders can encounter if these dangers are overlooked include fumes and gases, arc rays and sparks, and electric shock. This section describes the practices applicable to the personal safety of the operator and personnel working nearby and provides information on the safety equipment such as protective clothing, eye protection devices etc.

Proper eye protection is of the utmost importance. Eye protection is necessary because of the hazards posed by stray flashes, reflected glare, flying sparks, and globules of molten metal. Devices used for eye protection include helmets and goggles. Welders use a helmet with a dark lens and goggles with weld specific lenses that vary in shades of darkness, because the brightness of the light produced vary with the type of metal being welded. Figure – below shows several types of eye protection devices in common use.



EYE PROTECTION DEVICES

Note - In addition to providing eye protection, helmets also provide a shield against flying metal and ultraviolet rays for the entire face and neck.

Flash goggles (view A) are worn under the welder's helmet and by persons working around the area where welding operations are taking place. This spectacle type of goggles has side shields and may have either an adjustable or nonadjustable nose bridge.

Eyecup or **cover** types of goggles (view B) are for use in fuel-gas welding or cutting operations. They are contoured to fit the configuration of the face. These goggles must be fitted with a shade of filter lens that is suitable for the type of work being done.

Note - The eyecup or cover type of goggles is NOT to be used as a substitute for an arc-welding helmet.

For electric arc-welding and arc-cutting operations, a helmet having a suitable filter lens is necessary. The helmet shown in view C has an opening, called a window, for a flip-up filter lens 2 inches by 4 1/4 inches second is to eliminate the harmful infrared and ultraviolet exposure.

The helmet shown in view D has a 4 1/2-inch by 5 1/4-inch window. The larger window affords the welder a wider view and is especially useful when the welder is working in a confined place where head and body movement is restricted. When welding in locations where other welders are working, the welder should wear flash goggles beneath his helmet to provide protection from the flashes caused by the other welders' arcs. The flash goggles will also serve as eye protection when chipping the slag from a previous weld deposit.

Helmets and welding goggles used for eye protection are made from a nonflammable insulating material. They are fitted with a removable protective colored filter and a clear cover lens.

Note - The purpose of the clear cover lens is to protect the filter lens against pitting caused by sparks and hot metal spatter. The clear lens must be placed on the outside of the filter lens. The clear lens should be replaced when it impairs vision.

Filter lenses are furnished in a variety of shades, which are designated by number. The lower the number, the lighter the shade; the higher the number, the darker will be the shade. The filter lens shade number selected depends on the type of work and somewhat on the preference of the user. Remember, a filter lens serves two purposes. The first is to diminish the intensity of the visible light to a point where there is no glare and the welding area can be clearly seen.

Rule of thumb: When selecting the proper shade of filter lens for electric-arc welding helmets place the lens in the helmet and look through the lens as if you were welding. Look at an exposed bare light bulb and see if you can distinguish its outline and if you can, then use the next darker shade lens. Repeat the test again. When you no longer see the outline of the bulb, then the lens is of the proper shade. Remember that this test

should be performed in the same lighting conditions as the welding operation is to be performed. Welding in a shop may require a shade lighter lens than if the same job were being performed in bright daylight. For field operations, this test may be performed by looking at a bright reflective object.

WARNING - Never look at the welding arc without proper eye protection. Looking at the arc with the naked eye could lead to permanent eye damage. If you receive flash burns, they should be treated by medical personnel.

A variety of special welder's clothing is used to protect parts of the body. The clothing selected varies with the size, location, and nature of the work to be performed. During any welding or cutting operation, you should always wear flameproof gauntlets. For gas welding and cutting, five-finger gloves like those should be used. For electric-arc welding, use the two-finger gloves (or mitts) should be used.



WELDING GLOVES AND MITTS

Both types of gloves protect the hands from heat and metal spatter. The two-finger gloves have an advantage over the five-finger gloves in that they reduce the danger of weld spatter and sparks lodging between the fingers. They also reduce finger chafing which sometimes occurs when five-finger gloves are worn for electric-arc welding.

Many light-gas welding and brazing jobs require no special protective clothing other than gloves and goggles. Even here, it is essential that you wear your work clothes properly. Sparks are very likely to lodge in rolled-up sleeves, pockets of clothing, or cuffs of trousers or overalls. Sleeves should be rolled down and the cuffs buttoned. The shirt collar, also, should be fully buttoned. Trousers should not be cuffed on the outside, and pockets not protected by button-down flaps should be eliminated from the front of

overalls and aprons. All other clothing must be free of oil and grease. Wear high top-safety shoes; low-cut shoes are a hazard because sparks and molten metal could lodge in them, especially when you are sitting down.

Medium- and heavy-gas welding, all-electric welding, and welding in the vertical or overhead welding position require special flameproof clothing made of leather or other suitable material. This clothing is designed to protect you against radiated heat, splashes of hot metal, or sparks. This clothing consists of aprons, sleeves, combination sleeves and bib, jackets, and overalls. They afford a choice of protection depending upon the specific nature of the particular welding or cutting job. Sleeves provide satisfactory protection for welding operations at floor or bench level.



WELDER'S PROTECTIVE CLOTHING

The cape and sleeves are particularly suited for overhead welding, because it protects the back of the neck, top of the shoulders, and the upper part of the back and chest. Use of the bib, in combination with the cape and sleeves, gives added protection to the chest and abdomen. The jacket should be worn when there is a need for complete all-around

protection to the upper part of the body. This is especially true when several welders are working in close proximity to one another. Aprons and overalls provide protection to the legs and are suited for welding operations on the floor.

To prevent head burns during overhead welding operations, you should wear leather or flameproof caps under the helmet. Earplugs also should be worn to keep sparks or splatter from entering and burning the ears. Where the welder is exposed to falling or sharp objects, combination welding helmet/hard hats should be used. For very heavy work, fire-resistant leggings or high boots should be worn. Shoes or boots having exposed nail heads or rivets should NOT be worn. Oilskins or plastic clothing must NOT be worn in any welding operation.

Note - If leather protective clothing is not available, then woolen clothing is preferable to cotton. Woolen clothing is not as flammable as cotton and helps protect the operator from the changes in temperature caused by welding. Cotton clothing, if used, should be chemically treated to reduce its flammability.
