8.2 FUSION WELDING

Types of welding processes

Welding is a material joining process for a permanent combining of two (or more) parts that involves melting and subsequent solidification of the material from two parts thus forming a strong joint between them. The assemblage of parts is called a *weldment*.

There are two groups of welding processes according to the state of the base material during the welding process:

❶ Liquid-state welding (*fusion welding*), and
❷ *Solid-state welding.*

Fusion welding is by far the more important category. In fusion welding, the base material is heat to melt. The most important processes in this group fall in the following categories:

- *Oxyfuel gas welding:* an oxyfuel gas produces a flame to melt the base material;
- *Arc welding:* heating and melting of the material is accomplished by an electric arc;
- *Resistance welding:* the source of heat is the electrical resistance on the interface between two parts held together under pressure.

In *solid-state welding*, two parts are jointed together under pressure or a combination of pressure and heat. If heat is applied, the contact temperature is below the melting point of the base metal. Two welding processes are the most popular from this group,

- *Diffusion welding:* parts coalesce by solid-state diffusion;
- *Friction welding:* coalescence is achieved by the heat of friction between two parts;

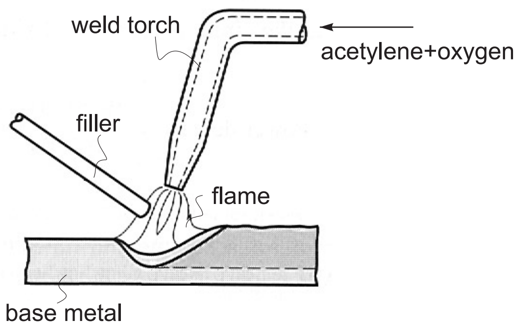
Most of the processes for fusion welding and for solid-state welding are discussed in the present section.

Oxyfuel gas welding

Oxyfuel gas welding is the term used to describe the group of fusion operations that burn various fuels mixed with oxygen to perform welding or cutting and separate metal plates and other parts. The most important oxyfuel gas welding process is oxyacetylene welding.

Oxyacetylene welding (OAW) is a fusion welding process performed by a high-temperature flame from combustion of acetylene and oxygen. The flame is directed by a welding torch and a filler metal in the form of rod is added if the process is applied to weld. Composition of the filler must be similar to that of the base metal.

A typical oxyacetylene welding operation is sketched in the figure.

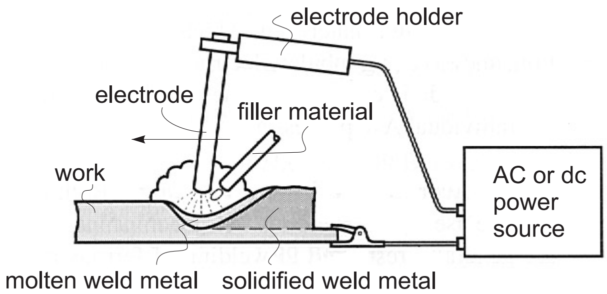


Oxyfuel gas welding operation.

Oxyacetylene welding uses equipment that is relatively inexpensive and portable. It is therefore an economical, versatile process that is well suited to low-quantity production and repair jobs. It is rarely used on the welding of sheet and plate stock thicker than 6 mm because of the advantages of arc welding in such applications. Although OAW can be mechanized, it is usually performed manually and is hence dependent on the skill of the welder to produce a high-quality weld joint.

Arc welding with consumable electrodes

Arc welding (AW) is a fusion welding process in which coalescence of the metals is achieved by the heat from an electric arc between an electrode and the work. A generic AW process is shown in the figure:



The basic configuration of an arc welding operation.

An electric arc is a discharge of electric current across a gap in a circuit. To initiate the arc in an AW process, the electrode is brought into contact with the work and then quickly separated from it by a short distance. The electric energy from the arc thus formed produces temperatures of 5000° C or higher, sufficiently hot to melt any metal. A pool of molten metal, consisting of base metal(s) and filler metal (if one is used), is formed near the tip of the electrode. In most arc welding processes, filler metal is added during the operation to increase the volume and strength of the weld joint. As the electrode is moved along the joint, the molten weld pool solidifies in its wake.

Movement of the electrode relative to the work is accomplished by either a human welder (manual welding) or by mechanical means (machine welding, automatic welding, or robotic welding).

In manual arc welding, the quality of the weld joint is very dependent on the skill and experience of the human welder. The weld quality is much better in the machine, automatic, and robotic welding.

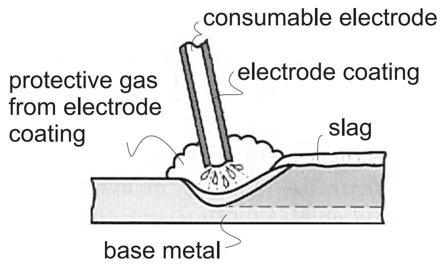
Electrodes in AW process are classified as

- *consumable*, which melts continuously in the process of arc welding thus providing the required filler material, and
- *non-consumable*, which resist melting by the arc. The filler material must be supplied separately.

The same classification is applied to the arc welding processes; some of the most important processes based on consumable electrodes are discussed in this section, and processes, which use non-consumable electrodes are included in the next section.

Shielded Metal Arc Welding

Shielded Metal Arc Welding (SMAW) is an arc welding process that uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding. The process is illustrated in the figure:



Shielded metal arc welding operation.

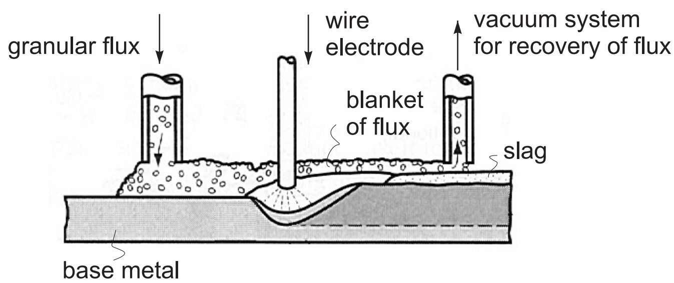
The coated welding stick (SMAW is sometimes called *stick welding*) is typically 200 to 450 mm long and 1.5 to 9.5 mm in diameter. The heat of the welding process melts the coating to provide a protective atmosphere and slag for the welding operation.

During operation the bare metal end of the welding stick is clamped in an electrode holder connected to the power source. The holder has an insulated handle so that it can be held and manipulated by a human welder. Currents typically used in SMAW range between 30 and 300 A at voltages from I5 to 45 V depending on the metals being welded, electrode type and length and depth of weld penetration required.

Shielded metal arc welding is usually performed manually. Common applications include construction, pipelines, machinery structures, shipbuilding, fabrication job shops, and repair work. It is preferred over oxyfuel welding for thicker sections above 5 mm because of its higher power density. The equipment is portable and low cost, making SMAW highly versatile and probably the most widely used of the AW welding processes. Base metals include steels, stainless steels, cast irons, and certain nonferrous alloys.

Submerged Arc Welding

Submerged arc welding (SAW) is an arc welding process that uses a continuous, consumable bare wire electrode. The arc shielding is provided by a cover of granular flux. The electrode wire is fed automatically from a coil into the arc. The flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper, as shown in the figure.



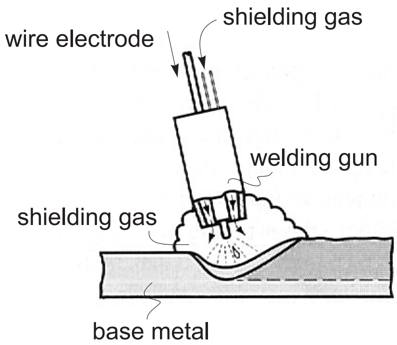
Submerged arc welding operation.

The blanket of granular flux completely submerges the arc welding operation, preventing sparks, spatter, and radiation that are so hazardous in other arc welding processes. The portion of the flux closest to the arc is melted, mixing with the molten weld metal to remove impurities and then solidifying on top of the weld joint to form a glasslike slag. The slag and infused flux granules on top provide good protection from the atmosphere and good thermal insulation for the weld area. This results in relatively slow cooling and a high-quality weld joint. The infused flux remaining after welding can be recovered and reused. The solid slag covering the weld must be chipped away usually by manual means.

This process is widely used for automated welding of structural shapes, longitudinal and circumferential seams for large-diameter pipes, tanks, and pressure vessels. Because of the gravity feed of the granular flux, the parts must always be in a horizontal orientation.

Gas Metal Arc Welding

Gas Metal Arc Welding (GMAW) is an arc welding process in which the electrode is a consumable bare metal wire and shielding is accomplished by flooding the arc with a gas. The bare wire is fed continuously and automatically from a spool through the welding gun, as illustrated in the figure.



Gas metal arc welding operation.

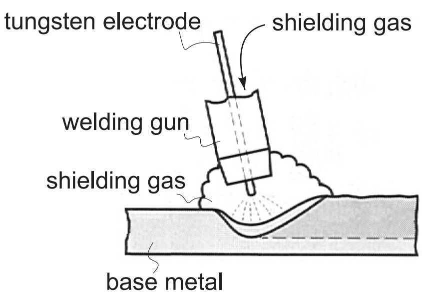
Wire diameters ranging from 1 to 6 mm are used in GMAW, the size depending on the thickness of the pats being joined. Gases used for shielding include inert gases such as argon and helium and active gases such as carbon dioxide. Selection of gases depends mainly on the metal being welded.

Inert gases are used for welding aluminum alloys and stainless steel and in this case the process is often referred to as *MIG/MAG welding* (for metal-inert gas/metal-argon welding).

In welding steel, carbon dioxide (CO_2), which is less expensive than inert gases, is used. Hence, the term *CO_2 welding* is applied.

Arc welding with non-consumable electrodes

Several arc welding processes use non-consumable electrodes.



Gas tunsten arc welding operation.

Gas Tungsten Arc Welding

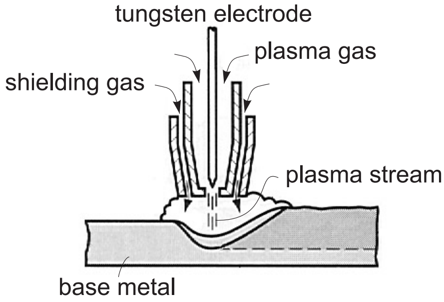
Gas Tungsten Arc Welding (GTAW) is an arc welding process that uses a non-consumable tungsten electrode and an inert gas for arc shielding. Shielding gases typically used include argon, helium or a mixture of these gases. The GTAW process can be implemented with or without a filler metal. The figure illustrates the latter case. When thin sheets are welded to close tolerances, filler metal is usually not added. When a filler metal is used, it is added to the weld pool from a separate rod or wire. The term *TIG welding* (tungsten inert gas welding) is often applied to this process.

GTAW is applicable to nearly all metals in a wide range of stock thickness. It can also be used for joining various combinations of dissimilar metals. Its most common applications are for aluminum and stainless steel.

The process can be performed manually or by machine and automated methods for all joint types. Advantages of GTAW in the applications to which it is suited include high-quality welds, no weld spatter because no filler metal is transferred across the arc, and little or no post-weld cleaning because no flux is used.

Plasma Arc Welding

Plasma Arc Welding (PAW) is a special form of gas tungsten arc welding in which a plasma arc is directed at the weld area. The tungsten electrode is contained in a specially designed nozzle that focuses a high-velocity stream of inert gas (for example, argon or argon-hydrogen mixtures, and helium) into the region of the arc to produce a high-velocity plasma jet of small diameter and very high-energy density, as in the figure:



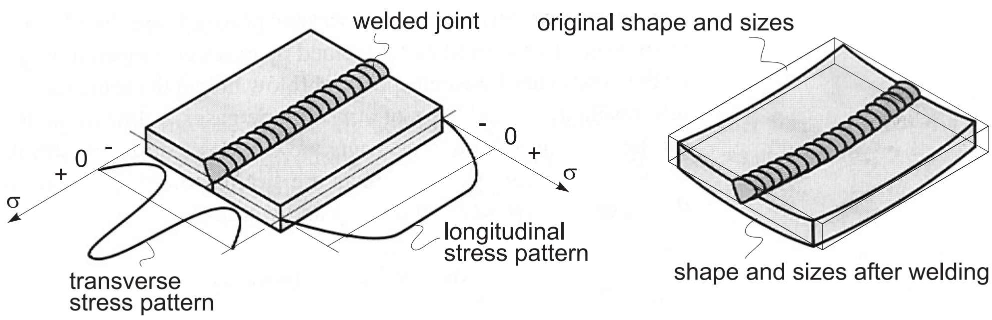
Gas metal arc welding operation.

Temperatures in plasma arc welding reach 30,000° C or greater, hot enough to melt any known metal.

Plasma Arc Welding is used as a substitute for GTAW in applications such as automobile subassemblies, metal cabinets, door and window frames, and home appliances. The process can be used to weld almost any metal, including tungsten.

Weld quality in arc welding

The rapid heating and cooling in localized regions of the work during fusion welding, especially arc welding, result in thermal expansion and contraction, which cause transverse and longitudinal residual stresses in the weldment. These stresses is likely to cause distortion of the welded assembly:



(*Left*) transverse and longitudinal residual stress pattern; and (*Right*) likely distortion in the welded assembly.

The welding begins at one end and travels to the opposite end of the welded joint. As it proceeds, the molten metal quickly solidifies behind the moving arc. The portions of the work immediately adjacent to the weld bead become extremely hot and expand, while portions removed from the weld remain relatively cool. This results in an additional shrinkage across the width of the weldment, as seen in the figure. Residual stresses and shrinkage also occur along the length of the weld bead.

Various techniques can be employed to minimize distortion in a weldment. Some of these techniques include the following:

- *Welding fixtures* that physically restrain movement of the parts during welding;
- *Tack welding* at multiple points along the joint to create a rigid structure prior to continuous welding;
- *Preheating* the base parts, which reduces the level of thermal stresses experienced by the parts;
- Stress relief *heat treatment* of the welded assembly.

In addition to residual stresses and distortion in the final assembly, other defects can also occur in welding,

- *Cracks*: Fracture-type interruptions either in the weld or in the base metal a djacent to the weld. This type is perhaps the most serious welding defect because it constitutes a discontinuity in the metal that causes significant reduction in the strength of the weldment. Generally, this defect can and must be repaired.

- *Cavities*: These include various porosity and shrinkage voids. *Porosity* consists of small voids in the weld metal formed by gases entrapped during solidification. Porosity usually results from inclusion of atmospheric gases, or contaminants on the surfaces. *Shrinkage voids* are cavities formed by shrinkage during solidification.

- *Solid inclusions*: Solid inclusions are any nonmetallic solid material entrapped in the weld metal. The most common form is slag inclusions generated during the various welding processes that use flux.

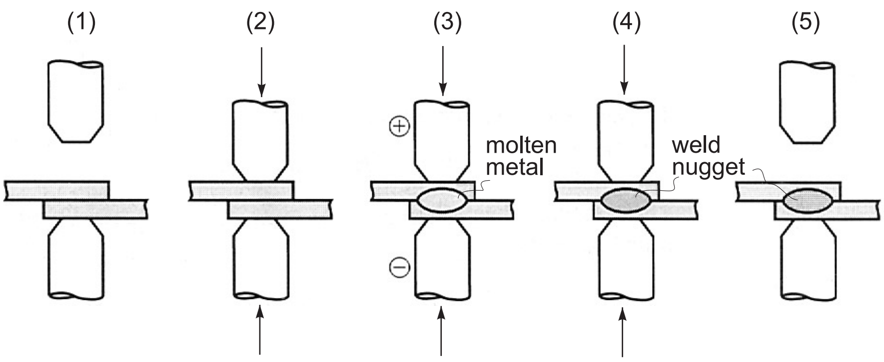
- *Incomplete fusion*: Fusion does not occur throughout the entire cross section of the joint.

Resistance welding

Resistance welding (RW) is a group of fusion welding processes that utilizes a combination of heat and pressure to accomplish coalescence. The heat required is generated by electrical resistance to current flow at the interface of two parts to be welded. The resistance welding processes of most commercial importance are *spot* and *seam welding*.

Resistance Spot Welding

Resistance spot welding (RSW) is a resistance welding process in which fusion of the base metal is achieved at one location by opposing electrodes. The cycle in a spot welding operation consists of the steps depicted in the figure:



Steps in a spot welding cycle: (1) parts inserted between open electrodes, (2) electrodes close and force is applied, (3) weld time (current is switched), (4) current is turned off but force is maintained, and (5) electrodes are opened, and the welded assembly is removed.

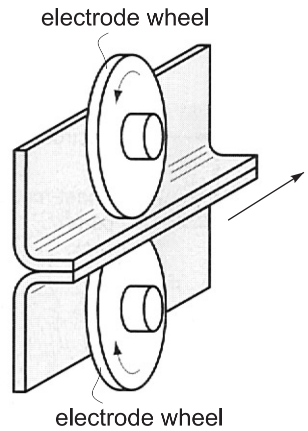
Resistance spot welding is widely used in mass production of automobiles, appliances, metal furniture, and other products made of sheet metal of thickness 3 mm or less.

Because of its widespread industrial use, various machines and methods are available to perform spot welding operations. The equipment includes rocker arm and press-type spot welding machines for larger work.

For large, heavy work, portable spot welding guns are available in various sizes and configurations. They are widely used in automobile final assembly plants to spot-weld the sheet-metal car bodies. Human workers operate some of these guns, but industrial robots have become the preferred technology.

Resistance Seam Welding

In *Resistance Seam Welding* (RSEW), the electrodes are two rotating wheels as shown in the figure:



Gas metal arc welding operation.

In the process of welding, a series of overlapping spot welds is made along the lap joint. The process is capable of producing airtight joints, and its industrial applications include the production of gasoline tanks, automobile mufflers, and various others fabricated sheet-metal containers.

The spacing between the weld nuggets in resistance seam welding depends on the motion of the electrode wheels relative to the application of the weld current. In the usual method of operation, called *continuous motion welding*, the wheel is rotated continuously at a constant velocity, and current is turned on at timing intervals consistent with the desired spacing between spot welds along the seam so that overlapping weld spots are produced. But if the frequency of current switching is reduced sufficiently, there will be spacing between the weld spots, and this method is termed *roll spot welding*. In another variation, the welding current remains on at a constant level so that a truly *continuous welding seam* is produced. These variations are depicted in the figure:

Different types of seam welding, (from left to right) conventional seam welding, roll spot welding, continuous resistance seam welding.

Since the operation is usually carried out continuously, rather than discretely, the seams should be along a straight or uniformly curved line. Sharp comers and similar discontinuities should be avoided.