Manufacturing / Manufacturing Process/Welding Processes

[Video]

Notes

Welding Processes

Electric Arc Welding

In welding, generation of heat by an electric arc is one of the most efficient methods. Approximately, 50% of the energy is liberated in the form of heat. The electric-arc welding process makes use of the heat produced by the electric arc to fusion-weld metallic pieces. This is one of the most widely used welding processes, mainly because of the ease of use and high production rates that can be achieved economically.

Principle of Arc

An arc is generated between two conductors of electricity, cathode and anode (considering direct current, DC), when they are touched to establish the flow of current and then separated by a small distance. An arc is a sustained electric discharge through the ionized gas column, called plasma, between the two electrodes.

It is generally believed that electrons liberated from the cathode move towards the anode and are accelerated in their movement. When they strike the anode at high velocity, a large amount of heat is generated. Also, when the electrons are moving through the air gap between the electrodes, also called the arc column, they collide with the ions in the ionized gas column between the electrodes. The positively charged ions, move from the anode and impinge on the cathode, thus liberation heat. About 65 to 75% of the total heat is liberated at the anode by the striking electrons. A temperature of the order of $6000^{o}C$ is generated at the anode.

In order to produce the arc, the potential difference between the two electrodes (voltage) should be sufficient to allow them to move across the air gap. The larger air gap requires higher potential differences. If the air gap becomes too large for the voltage, the arc may be extinguished. Here, we may make use of an analogy of a person walking on the road. Suddenly, when a deep trench comes in his way, the person would try to jump across it, if it is a short one. But if it is a broader one, then he may move back a little; come running towards the trench and try to jump over it. If it is too broad, he may abandon the idea of jumping across it. The energy spent in jumping is much more than what is spent while normal walking. In the case of an arc, the extra energy spent crossing the air gap is liberated as heat.

For convenience of explanation, we have chosen a direct current arc for the above description. But even with an arc of the alternating current (AC), it would be similar, with the main difference that the cathode and anode would change continuously and as a result, the temperature across the arc would be more uniform compared to a DC arc.

Arc – Welding Equipment:

The main requirement in an arc-welding set-up is the source of electric power. They are essentially of two types.

1. Alternating current (AC) machines
2. Direct current (DC) machines

Though DC arc-welding is more expensive than AC welding, it is generally preferred because of the control of heat input offered by it and about 70% of the heat is liberated near the anode in DC arc-welding. Hence, If more heat is required at the workpiece side, such as for thicker *sheets or for the work materials which have higher thermal conductivity such as aluminium and copper, the workpiece can be made as the anode, liberating large heat neat it. This is termed straight polarity or DCEN (direct current electrode negative). This gives rise to a higher penetration as shown in Figure 9.1(a). However, for thinner materials, where less heat is required in the weld zone, the polarity could be reversed by making the workpiece negative. This is termed reversed polarity or DCEP (direct current electrode positive). In reversed polarity, the penetration is small, as in Figure 9.1(b). In the case of AC welding, the bead obtained is somewhere in between the above two types and is shown in Figure 9.1 (c).*

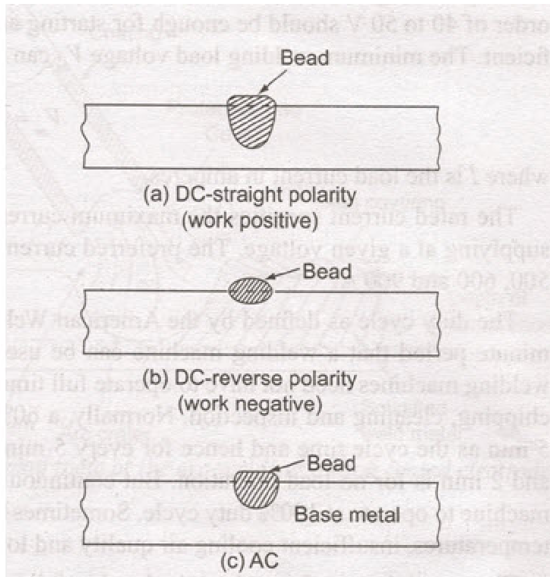

Figure 9.1 Weld penetration as affected by the polarity of the workpiece

A typical AC arc-welding set-up using the transformer is shown in Figure 9.2. The workpiece is kept on a metallic table to which the ground lead of the secondary windings of the welding transformer is connected. The other lead of the secondary is connected to an electrode holder into which the electrode is gripped. When the electrode is brought into contact with the work, welding takes place.

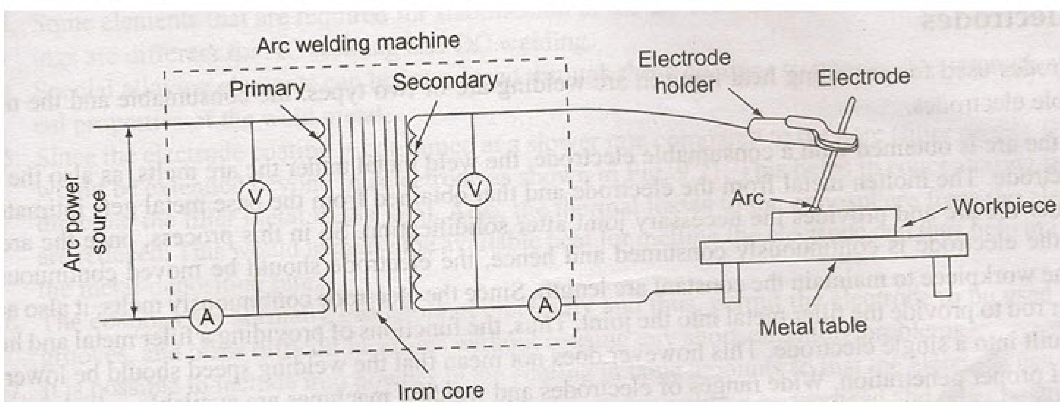

Figure 9.2 Sectional view of representation of the arc-welding set-up

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General Technology of Arc Welding

Before describing the individual AW processes, it is instructional to examine some of the general technical issues that apply to these processes.

Electrodes:

The electrodes used for providing heat input in arc welding are of two types: the consumable and the non-consumable electrodes.

Consumable electrodes provide the source of the filler metal in arc welding. These electrodes are available in two principal forms: rods (also called sticks) and wire. Welding rods are typically 225 – 450 mm long and 9.5 mm or less in diameter. The problem with consumable welding rods, at least in production welding operations, is that they must be changed periodically, reducing arc time of the welder. Consumable weld wire has the advantage that it can be continuously fed into the weld pool from spools containing long lengths of wire, thus avoiding the frequent interruptions that occur when using welding sticks. In both rod and wire forms, the electrode is consumed by the arc during the welding process and added to the weld joint as filler metal.

Non consumable electrodes are made of tungsten (or carbon, rarely), which resists melting by the arc. Despite its name, a nonconsumable electrode is gradually depleted during the welding process (vaporization is the principal mechanism), analogous to the gradual wearing of a cutting tool in a machining operation. For AW processes that utilize non consumable electrodes, any filler metal used in the operation must be supplied by means of a separate wire that is fed into the weld pool.

Arc Shielding:

At the high temperatures in arc welding, the metals being joined are very chemically reactive to oxygen, nitrogen, and hydrogen in the air. The mechanical properties of the weld joint can be seriously degraded by these reactions. Thus, some means is provided in nearly all AW processes to shield the arc from the surrounding air. Arc shielding is accomplished by covering the electrode tip, arc, and molten weld pool with a blanket of gas or flux, or both, which inhibit exposure of the weld metal to air.

Common shielding gases include argon and helium, both of which are inert. In the welding of ferrous metals with certain AW processes, oxygen and carbon dioxide are used, usually in combination with Ar and/or He, to produce an oxidizing atmosphere or to control weld shape.

A flux is used to prevent the formation of oxides and other unwanted contaminants, or to dissolve them and facilitate removal. During welding, the flux melts and becomes a liquid slag, covering the operation and protecting the molten weld metal. The slag hardens upon cooling and must be removed later by chipping or brushing. Flux is usually formulated to serve several additional functions, including (1) providing a protective atmosphere for welding, (2) stabilizing the arc, and (3) reducing spattering.

[Top]

Manual Metal-arc Welding

Manual metal-arc welding, also called shielded metal-arc welding (SMAW), is the most extensively used manual welding process, which is done with stick (coated) electrodes. Though in USA, its use is decreasing in comparison to the other arc-welding processes, in India, it still is the most-used arc-welding process. This process is highly versatile and can be used extensively for both simple as well as sophisticated jobs. Further, the equipment is less expensive than those used in most of the other arc-welding processes. Welds by this process can be made in any position.

A job of any thickness can be welded by shielded metal-arc welding. But very small thickness below 3 mm may give rise to difficulties in welding because of their lack of rigidity. Similarly, very large thicknesses above 20 mm may take a long time for filling up the joint groove.

The shielded metal arc welding can be done with either an AC or DC power source. The typical range of the current usage may vary from 50 to 500 A with voltages from 20 to 40 V.

The main disadvantage of the shielded metal-arc welding process is the slow speed. Further, a lot of electrode material is wasted in the form of unused end, slag and gas. There are more chances of slag inclusions in the bead. Also, special precautions are needed to reduce moisture pick-up so that it does not interfere with the welding.

The typical shielded-metal arc-welding set-up is shown in Figure 9.3. The electrodes for the welding operation should be selected properly, depending on the requirements of the welding.

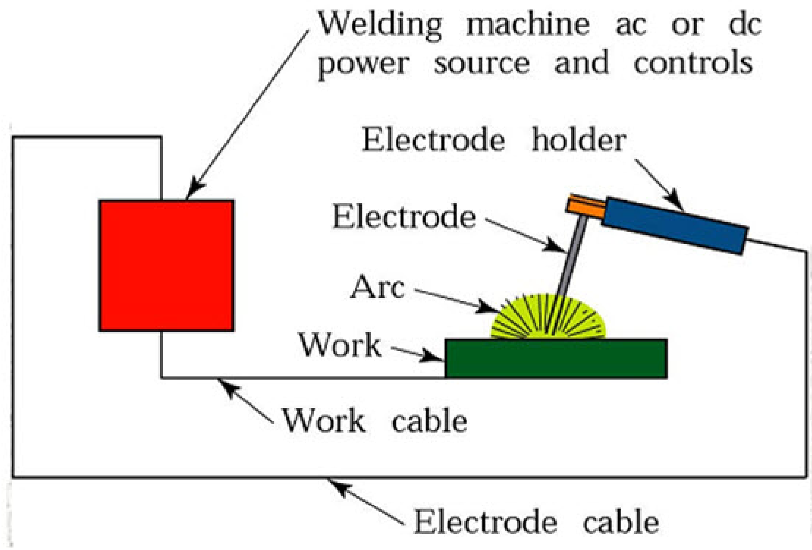

Figure 9.3 Schematic illustration of the shielded metal-arc welding operations (also known as stick welding, because the electrode is in the shape of a stick).

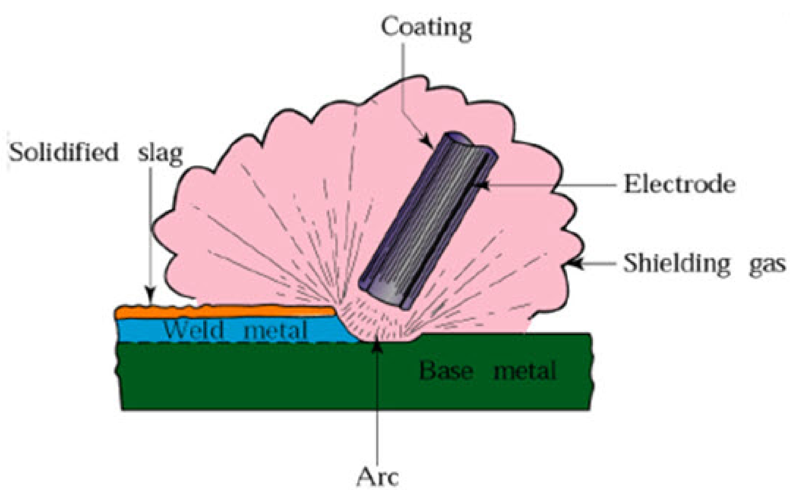

Figure 9.4 Schematic illustration of the shielded metal-arc welding process. About 50% of all large-scale industrial welding operations use this process.

Having chosen the electrode, the welding machine is set and the edge made ready for welding. To start the arc, first the welder has to make a contact between the electrode and the workpiece so that current flow is established. Then the electrode should be moved away from the workpiece by very small amount so that the arc is established. To accomplish this, generally two different methods are employed, which are shown in Figure 9.5.

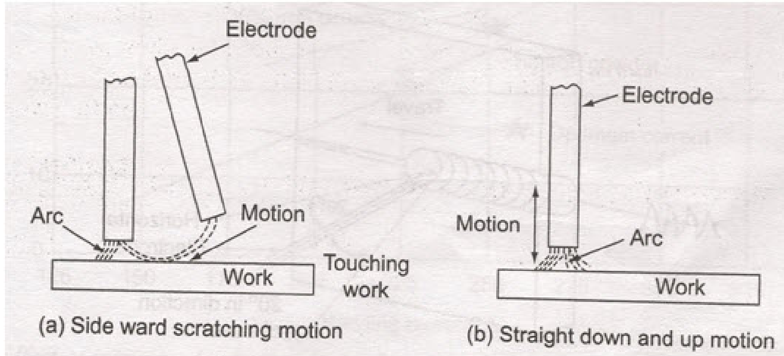

Figure 9.5 Method of striking an arc

In the first method shown in Figure 9.5 (a), the electrode is moved in an arc so that it will scratch the work metal and thus establish the current flow. The normal distance by which the electrode is separated from the work metal is the same as that of the diameter of the electrode wire. The scratching method is an easier method and is generally preferred by beginners. However, the electrode should be brought back immediately to the point of start where the welding should take place, otherwise the base metal will unnecessarily get defaced by the weld-metal deposit.

The other method shown in Figure (b), which is generally preferred by experienced welders, is called tapping start. In this, 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 which is the same as the electrode wire diameter. Unless the motion is swift, there are chances that the electrode itself would get welded to the base metal plate.

After establishing the correct arc length, the welder should move the electrode along the length of the joint maintaining the arc. The intense heat generated under the arc starts melting the metal, with the metal at the centre of the arc being at the highest temperature. When the electrode is moved in the forward direction, the bead is formed. The electrode should be moved downwards continuously to maintain the arc length, and at the same time it should be moved sideways in a weaving motion to maintain the bead width. After completing a sideward weaving motion, the electrode is moved forward to form a new puddle, which is separated from the previous puddle by a small distance of the order of 1.5 mm. This is what is seen as ripples on the welded joint, as shown in Figure 9.6. This would be continued till the joint is completely filled.

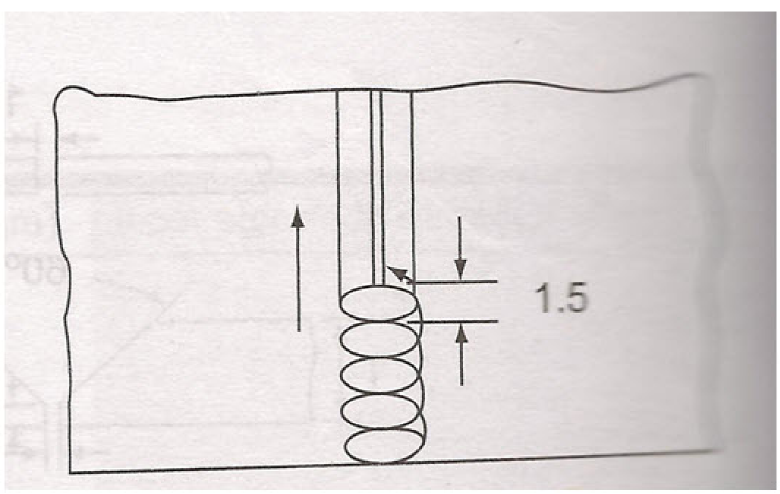

Figure 9.6 Movement of the electrode in a circular fashion with forward movement to obtain the bead.

At the end of the welding, if the arc is abruptly extinguished, the arc crater would not be filled and hence, a depression would be left in the joint. Therefore, the arc has to be slowly extinguished by the gradual decrease of the welding current, which ensures a complete filling of the arc crater.

In multipass welding, as shown in Figure 9.7, the brittle slag coating present on the bead after the root pass is made is chipped off and then the area is cleaned with a wire brush, before the second pass is commenced. The same procedure is followed for all the subsequent passes.

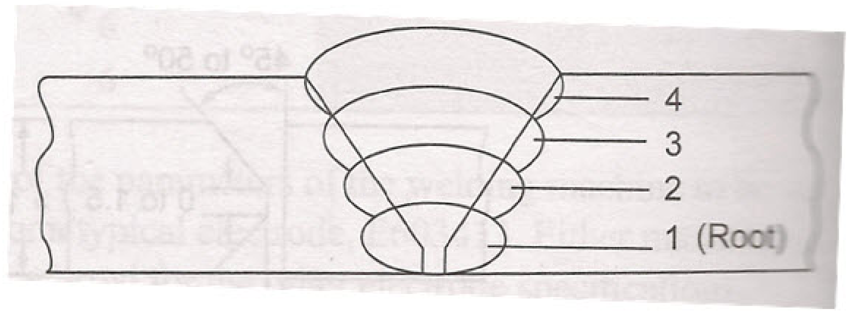

Figure 9.7 A typical multipass bead formed by manual metal arc welding

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Gas Metal Arc Welding

Gas metal arc welding (GMAW) is an AW 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 Figure 9.8. A welding gun is shown in Figure 9.9. Wire diameters ranging form 0.8 to 6.5 mm are used in GMAW, the size depending on the thickness of the parts being joined and the desired deposition rate. Gases used for shielding include inert gases such as argon and helium, and active gases such as carbon dioxide. Selection of gases (and mixtures of gases) depends on the metal being welded, as well as other factors. Inert gases are used for welding aluminum alloys and stainless steels, while CO_2 is commonly used for welding low and medium carbon steels. The combination of bare electrode wire and shielding gases eliminates the slag covering on the weld bead and thus precludes the need for manual grinding and cleaning of the slag. The GMAW process is therefore ideal for making multiple welding passes on the same joint.

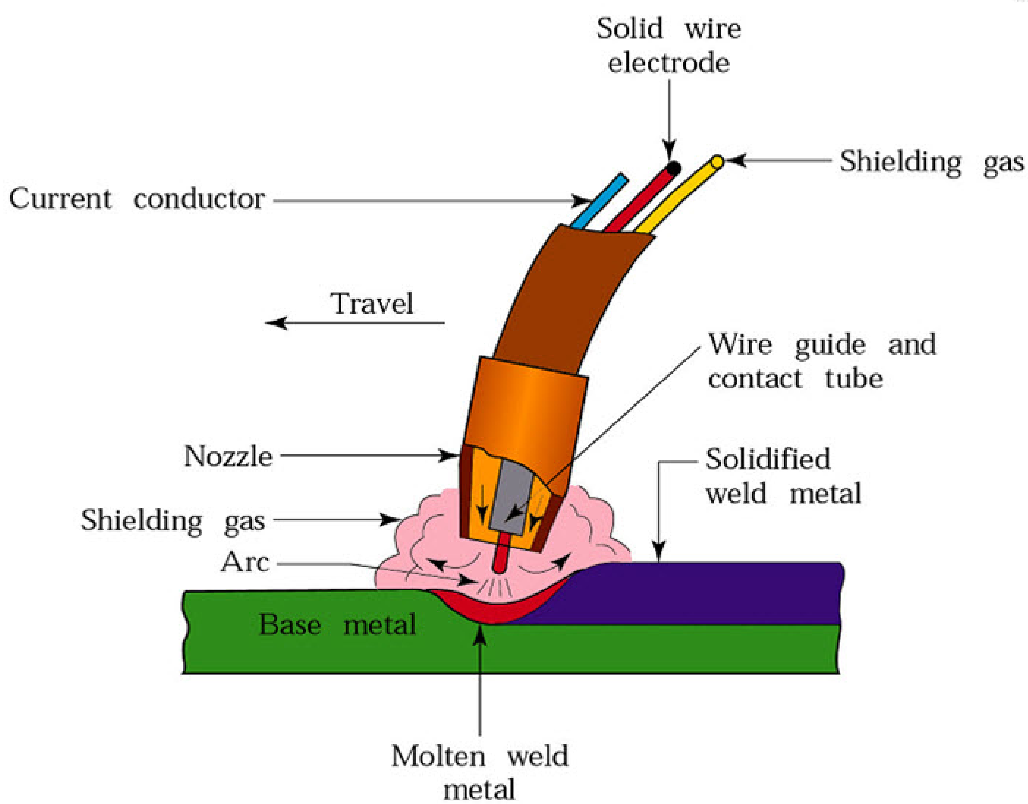

Figure 9.8 Schematic illustration of the gas metal-arc welding process, formerly known as MIG (for metal inert gas) welding.

Figure 9.9 Welding gun for gas metal arc welding

The various metals on which GMAW is used and the variations of the process itself have given rise to a variety of names for gas metal arc welding. When the process was first introduced in the late 1940s, it was applied to the welding of aluminum using inert gas (argon) for arc shielding. The name applied to this process was MIG welding (for metal inert gas welding). When the same welding process was applied to steel, it was found that inert gases were expensive and CO_2 was used as a substitute. Hence the term CO_2 welding was applied. Refinements in GMAW for steel welding have led to the use of gas mixtures, including CO_2 and argon, and even oxygen and argon.

GMAW is widely used in fabrication operations in factories for welding a variety of ferrous and non ferrous metals. Because it uses continuous weld wire rather than welding sticks, it has a significant advantage over SMAW in terms of arc time when performed manually. For the same reason, it also lends itself to automation of arc welding. The electrode stubs remaining after stick welding also wastes filler metal, so the utilization of electrode material is higher with GMAW. Other features of GMAW include elimination of slag removal (since no flux is used), higher deposition rates than SMAW, and good versatility.

[Top]

Submerged Arc Welding

This process, developed during the 1930s, was one of the first AW processes to be automated. Submerged arc welding (SAW) is an arc-welding process that uses a continuous, consumable bare wire electrode, and 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 Figure 9.10. The blanket of granular flux completely submerges the welding operation, preventing sparks, spatter, and radiation that are so hazardous in other AW processes. Thus, the welding operator in SAW need not wear the somewhat cumbersome face shield required in the other operations (safety glasses and protective gloves, of course, are required). 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 glass-like slag. The slag and unfused flux granules on top provide good protection from the atmosphere and good thermal insulation for the weld area, resulting in relatively slow cooling and a high-quality weld joint, noted for toughness and ductility. As depicted in the sketch, the unfused flux remaining after welding can be recovered and reused. The solid slag covering the weld must be chipped away, usually by manual means.

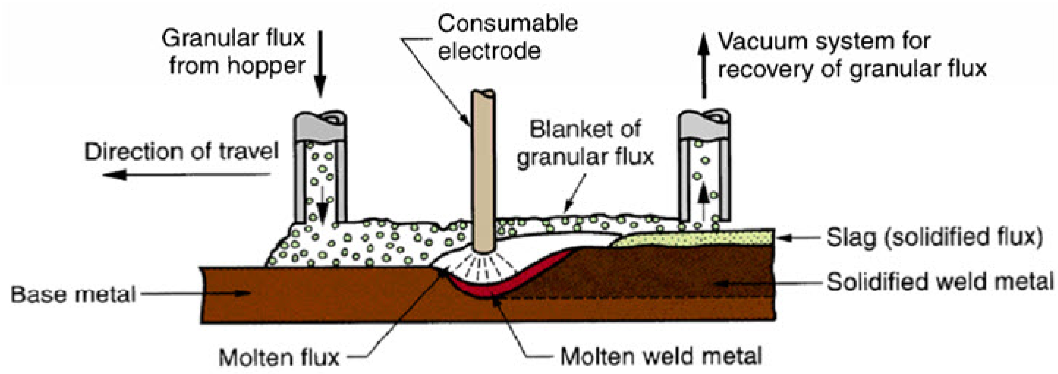

Figure 9.10 Submerged arc welding

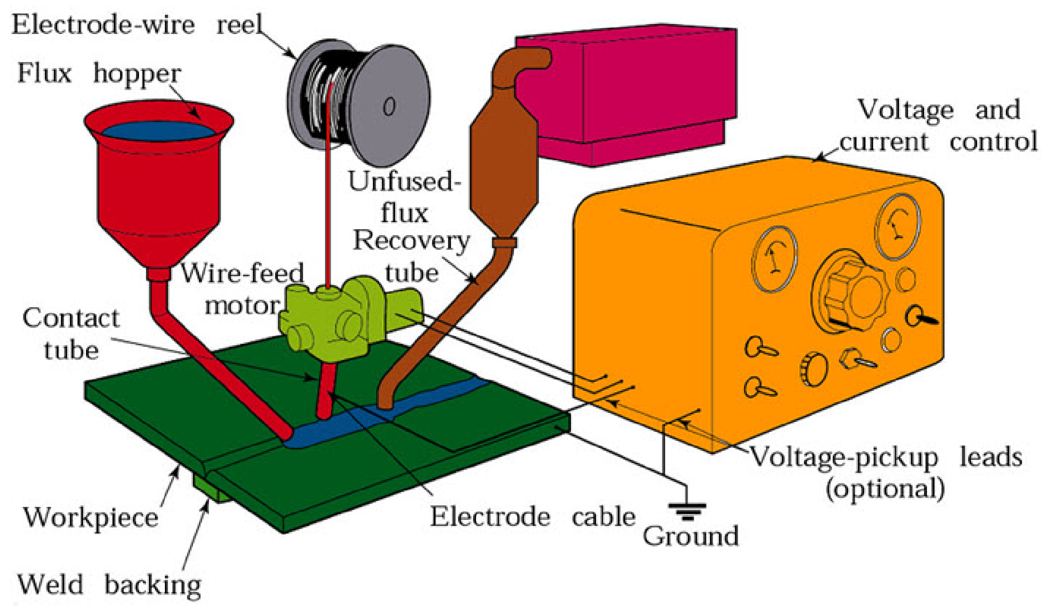

Figure 9.11 Schematic illustration of the submerged-arc welding process and equipment. The unfused flux is recovered and reused. (Source: American Welding Society).

Submerged arc welding is widely used in steel fabrication for structural shapes (e.g., welded I-beams); longitudinal and circumferential seams for large diameter pipes, tanks, and pressure vessels; and welded components for heavy machinery. In these kinds of applications, steel plates of 25 mm thickness and heavier are routinely welded by this process. Low-carbon, low-alloy, and stainless steels can be readily welded by SAW; but not high-carbon steels, tool steels, and most nonferrous metals. Because of the gravity feed of the granular flux, the parts must always be in a horizontal orientation, and a backup plate is often required beneath the joint during the welding operation.

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AW Processes – Non consumable Electrodes

The AW processes discussed above use consumable electrodes. Gas tungsten arc welding, plasma arc welding, and several other processes use non consumable electrodes.

Gas Tungsten Arc Welding

Gas Tungsten arc welding (GTAW) is an AW process that uses a non consumable tungsten electrode and an inert gas for arc shielding. The term TIG welding (tungsten inert gas welding) is often applied to this process (in Europe, WIG welding is the term – the chemical symbol for tungsten is W, for Wolfram). The GTAW process can be implemented with or without a filler metal. Figure 9.12 illustrates the former case i.e. with filler metal. When a filler metal is used, it is added to the weld pool from a separate rod or wire, being melted by the heat of the arc rather than transferred across the arc as in the consumable electrode AW processes. Tungsten is a good electrode material due to its high melting point of 3410^{o} C. Typical shielding gases include argon, helium, or a mixture of these gas elements.

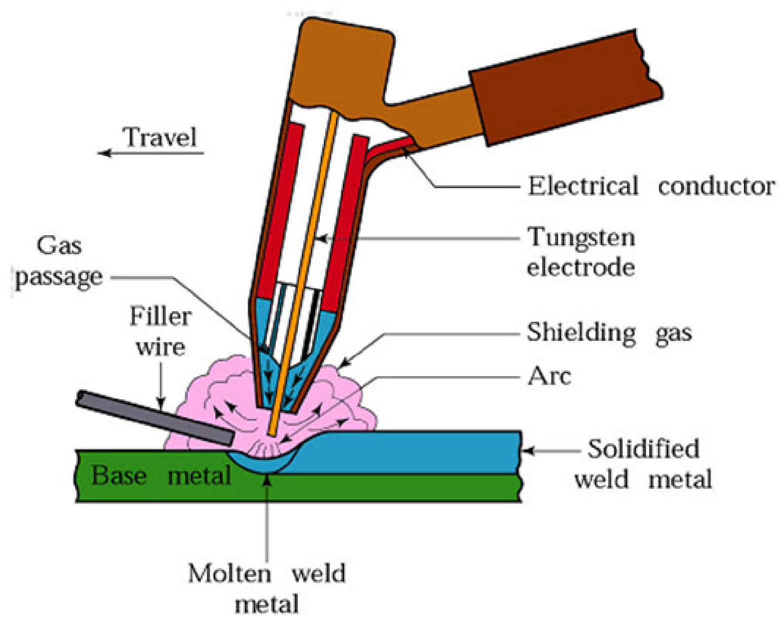

Figure 9.12 The gas tungsten-arc welding process, formerly known as TIG (for tungsten inert gas) welding.

GTAW is applicable to nearly all metals in a wide range of stock thicknesses. It can also be used for joining various combinations of dissimilar metals. Its most common applications are for aluminum and stainless steel. Cast irons, wrought irons, lead, and of course tungsten are difficult to weld by GTAW. In steel welding applications, GTAW is generally slower and more costly than the consumable electrode AW processes, except when thin sections are involved and very high quality welds are required. When thin sheets are TIG welded to close tolerances, filler metal is usually not added. 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 now post weld cleaning because no flux is used.

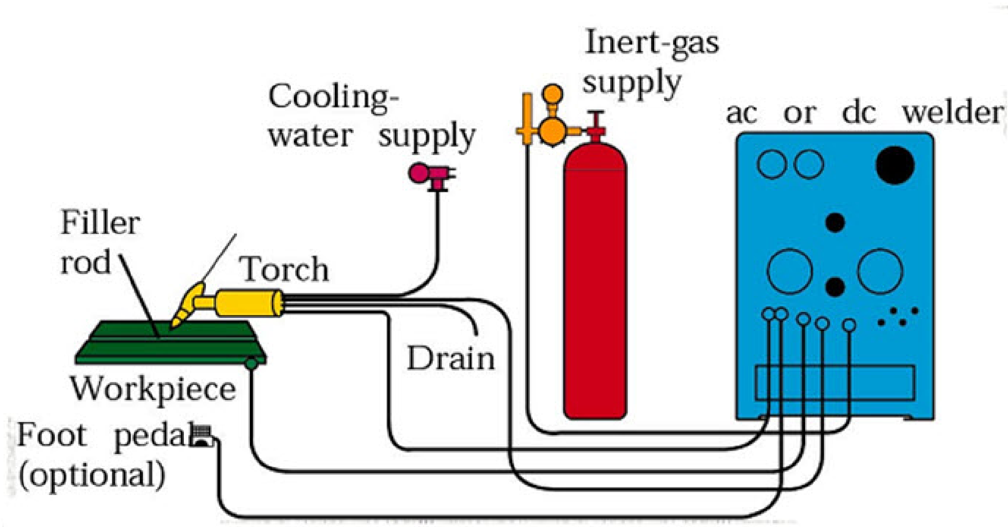

Figure 9.13 Equipment for gas tungsten-arc welding operations. (Source: American Welding Society.)

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OXYFUEL GAS WELDING

Oxyfuel gas welding (OFW) is the term used to describe the group of FW operations that burn various fuels mixed with oxygen to perform welding. The OFW processes employ several types of gases, which is the primary distinction among the members of this group. Oxyfuel gas is also commonly used in cutting torches to cut and separate metal plates and other parts. The most important OFW process is oxyacetylene welding.

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. A filler metal is sometimes added, and pressure is occasionally applied in OAW between the contacting part surfaces. A typical OAW operation is sketched in Figure 9.14.When filler metal is used, it is typically in the form of a rod with diameters ranging from 1.6 to 9.5 mm. Composition of the filler must be similar to that of the base metals. The filler is often coated with a flux that helps to clean the surfaces and prevent oxidation, thus crating a better weld joint.

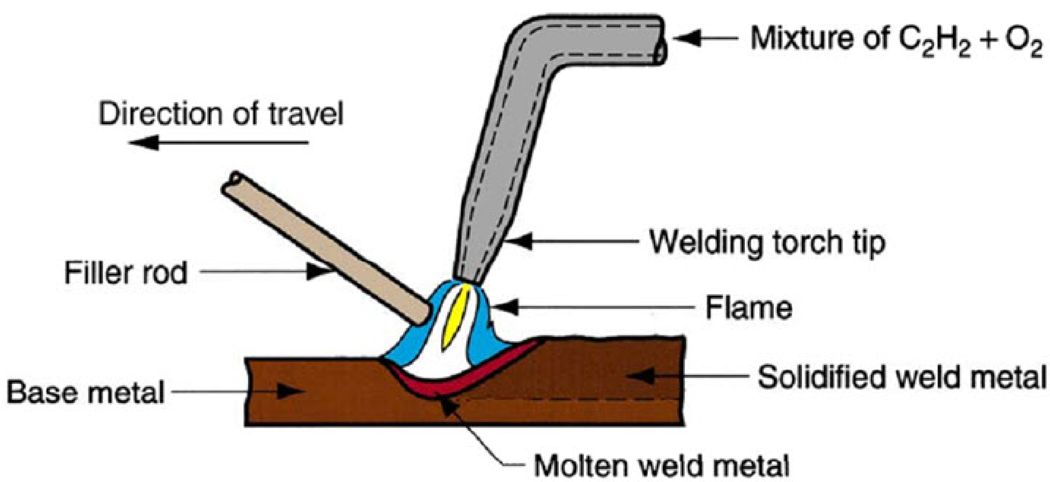

Figure 9.14 A typical oxyacetylene welding operation

Acetylene (C_2H_2) is the most popular fuel among the OFW group because it is capable of higher temperatures than any of the others – up to 3480^oC. The flame in OAW is produced by the chemical reaction of acetylene and oxygen in two stages. The first stage is defined by the reaction

$$C_2H_2 + O_2 \longrightarrow 2CO + H_2 + heat \qquad (1)$$

The products of which are both combustible, which leads to the second-stage reaction

$$2CO + H_2 + 1.5O_2 \longrightarrow 2CO_2 + H_2O + heat \qquad (2)$$

The two stages of combustion are visible in the oxyacetylene flame emitted from the torch. When the mixture of acetylene and oxygen is in the ration 1:1, as described in Equation (1), the resulting neutral flame is shown in Figure 9.15.The first-stage reaction is seen as the inner cone of the flame (which is bright white), while the second-stage reaction is exhibited by the outer envelope (which is nearly colorless but with tinges ranging from blue to orange). The maximum temperature of the flame is reached at the tip of the inner cone; the second-stage temperatures are somewhat below those of the inner cone. During welding, the outer envelope spreads out and covers the work surfaces being joined, thus shielding them from the surrounding atmosphere.

Total heat liberated during the two stages of combustion is 55×10^6 J/m^3 of acetylene. However, because of the temperature distribution in the flame, the way in which the flame spreads over the work surface, and losses to the air, power densities and heat transfer factors in oxyacetylene welding are relatively low; f_1 = 0.10 – 0.30.

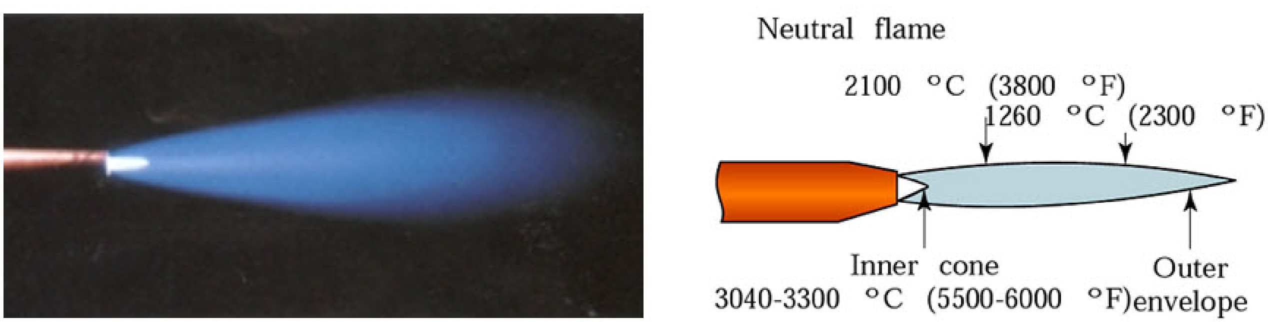

Figure 9.15 The neutral flame from an oxyacetylene torch, indicating temperatures achieved

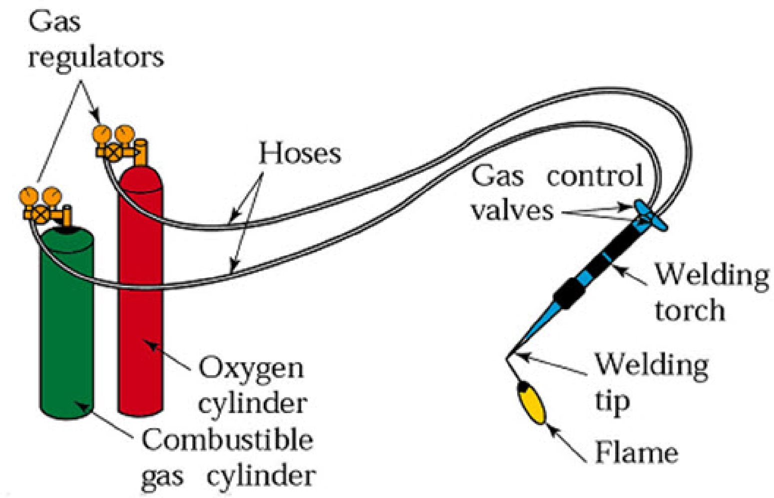

Figure 9.16 Basic equipment used in oxy fuel-gas welding. To ensure correct connections, all threads on acetylene fittings are left-handed, whereas those for oxygen are right-handed. Oxygen regulators are usually painted green, acetylene regulators red.

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