CHAPTER 3

METAL JOINING AND CUTTING

The structural and/or electrical joining of metals is accomplished by one of three basic methods: soldering, brazing, or welding. This chapter provides information regarding the methods, procedures, tools, and consumable materials required for each metal-joining process. Additionally, pertinent current specifications and standards are referenced.

3.1 DEFINITIONS

3.1.1 Brazing

One of the general groups of welding, wherein two metals are joined by heating to a temperature above 800^{o}F and coalescence results below the melting point of the metals. Non-ferrous filler metal is used with a melting point below that of the base metal and is distributed in the closely fitted lap or butt joints by capillary action. Brazing requires less heat than welding and therefore may be used to join metals that may be injured by higher heats.

3.1.2 Flux

A chemically active compound that is capable of promoting the wetting of metals with solder or filler metal. Flux also dissolves or removes any oxides, to prevent additional oxidation of the solder or filler metal and base metal during heating, and to remove other impurities.

3.1.3 Soft Soldering

The processes for making soldered electrical and electronic connections in which a low-temperature melting solder alloy of lead and tin is brought to fusion temperature and will flow below 426^{o}C (800^{o}F).

3.1.4 Solder

A single metal, or an alloy of two or more metals which, when melted, is used to join metallic surfaces through the phenomena of wetting. The major constituents of solder are usually tin and lead.

3.1.5 Soldering

A joining process wherein two or more metals are bonded together as one (coalescense) by heating, generally below 800^{o}F, and by using a non-ferrous filler (solder) that has a melting point below that of the base metals. The filler metal is usually distributed between the mating surfaces by capillary action.

3.1.6 Welding

A process wherein localized coalescence of metal is achieved by heating to suitable temperatures, with or without the application of pressure, and with or without the use of filler metal. The filler metal (rod or wire) is of the same approximate chemical composition as the base metal, and has a melting point about the same as or below that of the base metals, but always above 800°F.

3.1.7 Wetting

The adhesion of a liquid to a solid surface.

3.2 REFERENCES

3.2.1 Soldering

- QQ-S-571 Solder: Tin Alloy; Lead-Tin Alloy; and Lead Alloy.
- MIL-F-14256 Flux, Soldering, Liquid (Rosin Base).
- MIL-STD-454 Standard General Requirements for Electronic Equipment, (Requirement 5)

3.2.2 Brazing and Welding

- MIL-W-6858 Welding, Resistance: Aluminum, Magnesium, Non-Hardening Steels or Alloys, Nickel Alloys, Heat-Resisting Alloys, and Titanium Alloys; Spot and Seam.
- MIL-W-8604 Welding of Aluminum Alloys, Process For
- MIL-W-8611 Welding Metal Arc and Gas, Steels, and Corrosion and Heat Resistant Alloys, Process For
- MIL-W-8939 Welding, Resistance, Electronic Circuit Modules.
- MIL-W-18326 Welding of Magnesium Alloys, Gas and Arc, Manual and Machine Processes For.
- MIL-STD-22 Welded - Joint Designs
- MIL-STD-1261 Welding Procedure for Constructional Steels

3.3 SOLDERING MATERIALS

3.3.1 Solder

The most common solders are alloys of lead and tin in various proportions with certain other metals for controlling the character of the alloy. The alloy does not liquify immediately as temperature is raised; it goes from a solid to a plastic mass, then semi-liquid, and finally liquid. Maximum joint-strength and flow-action is obtained from an alloy of 63% tin and 37% lead and is prescribed as the most effective for general use in electronic work. Solder containing a 60/40 ratio is also recommended. Figure 3-1 shows the temperature at which solder with various tin-lead ratios passes from solid to plastic and finally to liquid state. The 63/37 composition of solder becomes plastic at 361° and quickly liquifies as does the 60/40 solder. The brief interval in the plastic state for each type of solder makes it possible to avoid cold-solder joints.

3.3.2 Flux

Only non-corrosive and non-conducting rosin fluxes shall be used for soldering electrical connections. Most metals require a good flux of the proper type if a sound connection is to be made. It is used to prevent the formation of undesirable oxides during the soldering process. Rosin fluxes are available in two forms: paste (for separate application) and rosin flux imbedded in the solder (for automatic application).

3.3.3 Multiple-Core Solder

Multiple-core solder (see figure 3-2) combines solder and flux in one wire to ensure that the entire surface receives adequate flux. Core solder must be placed in such a position that the flux can flow and cover the joint as the solder melts.

3.4 SOLDERING TOOLS

Soldering-tool temperature should be as high as possible without damaging either components or substrates. Ideal soldering temperatures are generally in the 550°F to 650°F range, although some applications may require higher or lower temperatures.

The electric soldering iron (figure 3-3) is typical of the type of iron in general use for the soldering of joints and connections in electronic equipment. The two principle requirements for the selection of particular size soldering irons are:

- The size and shape of the iron (determined by the work to be performed and by the amount of heat necessary to produce an acceptable connection or joint).

- The tip should heat the connection or joint rapidly to soldering temperature with negligible change in tip temperature. Care should be exercised when using small-tip soldering irons to permit temperature recovery of the tip between soldering operations.

Generally, the heating element of the iron is in the metal barrel and surrounds part of the tip. When the iron is plugged in, the element becomes hot and heats the barrel and tip. The copper tip is fastened to the barrel by threads or a setscrew and may be removed for repair or replacement.

Soldering irons are rated in watts and vary in sizes from 20 - 500 watts, with the size for normal electronic work being between 20 and 60 watts. Figure 3-3 illustrates a typical "pencil type" soldering iron with automatic control of output and temperature. Temperature is controlled by proper tip selection. Figure 3-4 depicts a typical, low voltage, single soldering station for general micro-soldering applications. It comes in 550°F, 650°F, and 750°F models with a built-in non-heat sinking stand. It also contains an isolation-transformer for protection of voltage-sensitive devices.

Figure 3-5 shows a typical low voltage soldering station where temperature is controlled by the selection of soldering tips. It has the same features as the model described above. Generally the tips consist of high conductivity copper, plated with iron and then aluminized in the non-working area. Then the iron tip is pre-tinned. Aluminizing prevents oxidation of the iron plating, scaling, solder "creep-up" and freezing of the tip in the tool, eliminating the most common difficulties associated with soldering tool tips.

One style of tip contains a small ferromagnetic sensing element on the shank. The sensing element is coded by number to indicate idle temperature in degrees F. Thus a change of tips is all that is necessary to adapt the tool to an entirely different temperature range. Idle temperatures of 500°, 600°, 700°, 800° and 900°F are available.

Optimum performance and maximum tip life depend on proper tip selection considering temperature, configuration, application, and use. The tip should have a maximum working surface physically compatible with the size of the joint to be soldered, and should be the shortest tip with the thickest cross section which is compatible with accessibility and visual requirements.

Tools with temperature-sensing tips are selected according to the required temperature and shape. This depends on the nature of the soldering application. Proper tip temperature selection is that which results in a satisfactory production rate. Tip life is directly related to tip temperature, the lower the temperature, the longer the tip life. Where heat-sensitive components are involved, the heat rating of the component should be the governing factor.

Generally, lower temperatures are used for printed circuit work or temperature-sensitive assemblies, higher temperatures are usually required for larger joints to be soldered at higher production rates.

3.4.1 Selection and Care of Soldering Tips

The following points should be adhered to in the selection and care of soldering tips:

DO...use a stand which will prevent the barrel and/or tip from touching metal parts thereby limiting tool performance from heat sink. Heat sinking a controlled tool results in shorter element and tip life.

DO...keep tip tinned...wipe only before using.

DO...use rosin or activated rosin fluxes for electrical soldering.

DO...remove tips and clean tips and sockets regularly. Frequency of cleanings should be determined by the type of work and usage.

DO...use a suitable cleaner for rosin based fluxes; such as isopropyl alcohol or equivalent.

DON'T...use chloride or acid containing fluxes, as this reduces tip life (except those applications where special fluxes are necessary).

DON'T...remove excess solder before storing heated tool.

DON'T...file or attempt to reshape tip, this will destroy tip coating.

DON'T...use anti-seize compounds on tip or socket as these parts are already protected from oxidation.

3.4.2 Torch Soldering Equipment

Large parts which cannot be heated with a soldering iron, and which are not suitable for resistance soldering, or where electrical power is not available, may be soldered with an open flame or torch. A gasoline blow torch or a smaller propane or butane torch may be used to provide the heat. The correct technique is to heat the work and let the work heat the solder. Apply flux before heating. Bring the connection or joint up to soldering temperature and apply the solder.

3.4.3 Soldering-Iron Holder

A soldering-iron holder satisfactory for the size of iron used should be provided to house the iron between soldering operations. A built-in thermostatic control may be used to maintain a predetermined soldering-tip temperature while the iron is in the holder. Such a control should be inspected periodically to verify temperature setting.

3.4.4 Thermal Shunt

A thermal shunt (heat shunt or heat sink) should be of such material, size, and shape that adequate protection will be provided to the parts involved while offering minimum interference to the soldering operation. The shunt should permit rapid application and removal with minimum effort. It may be held in place by friction, spring tension, or any other suitable means, provided the wire's insulation or the terminal's finish is not damaged. An efficient clamp-type thermal shunt can be constructed by attaching a piece of copper in each jaw of an alligator clip. Thermal shunts should always be used to protect semiconductors and other heat-sensitive parts from damage caused by the heat from soldering irons.

3.4.5 Variable-Temperature Soldering Iron

Wattage control devices which permit selection of the desired output of a soldering iron are available from commercial sources. These devices permit manual selection and control of the desired soldering iron tip temperature with automatic correction for voltage fluctuations and can handle any load up to 800 watts.

3.5 SOLDERING METHODS

3.5.1 Electric Iron Soldering Procedure

Proper use of the soldering iron and careful attention to details will result in making good solder joints of maximum conductivity and strength. The following requirements and procedures are to be observed:

a. The work area, bench, and tools must be reasonably clean. Leads, joints, connections, etc., to be soldered must not be handled unnecessarily, since handling contaminates the surface, resulting in faulty soldered joints.

b. Sufficient insulation shall be stripped from the wire or leads so that no insulation will touch the solder connection. In stripping insulation, care shall be taken to avoid nicking or otherwise damaging the wire or the remaining insulation. The number of damaged or severed strands in a single lead shall not exceed the limits given in table 3-1.

c. The proper heat range and tip should be selected. The tip should be inspected for excessive oxidation and surface corrosion. If necessary, remove pits with a fine metal-cutting file and rub the tip on fine sandpaper. Make sure the tip is firmly inserted and tightened in the holder.

d. Heat the iron for the required length of time and apply rosin solder to the tip surface. The tip should be tinned and carry a bright smooth layer on the surface for effective heat transfer to the soldered area. Lightly wipe the tip with a clean cloth to remove excess solder and flux residue.

e. All wires and part leads, with or without attached terminals, which do not already have a solderable coating, shall be tinned (solder coated) before soldering. The distance between the end of the wire's insulation or the body of the part and the beginning of the tinned portion shall be not less than the outside diameter of the wire insulation. Special care should be exercised so as not to expose any copper to the elements in order to avoid corrosion. Suggested tinning lengths are given in table 3-2.

f. Leads and wires shall be mechanically secured to their terminals or to each other prior to soldering. Such mechanical securing shall prevent motion between the parts of a joint during the soldering operation. Leads and wires shall be wrapped around terminals for a minimum of one-half and no more than one full turn. Exception is made in the case of those small parts to which such mechanical securing would be impracticable, such as eyelets, connector solder cups, or slotted terminal posts. No lead-extension shall be allowed. Figure 3-6 illustrates a proper wire wrap-around.

g. Apply flux, if necessary, to the surface of the area. Place the flat side of the iron against the surface to be soldered. The area to be joined shall be heated above the liquid temperature of the solder. Apply the solder directly to the surface on the side opposite the soldering iron tip as shown in figure 3-7. The solder melting temperature is reached in 5 to 10 seconds; therefore the soldering iron and the solder must be applied simultaneously. Do not apply the solder directly to the iron as the flux will not flow down the iron and the solder will not bond properly to the joint. Permit only enough solder to flow to completely cover the joint. Avoid excessive time and temperature to prevent unreliable joints and damage to parts.

3.5.2 Non-Electric Iron Soldering

Non-electric iron soldering can be performed by use of a gasoline torch to heat the soldering iron or by the direct flame method directly on a joint or surface to be soldered.

a. Gasoline Torch Soldering Procedure

(1) Fill the torch with colorless no-lead gasoline. Pump air into the torch, light and adjust the flame in accordance with the specific instructions of the manufacturer.

(2) Place the soldering iron on the torch holder and allow the flame to strike the head of the iron. Do not place the tip in the flame.

(3) Heat the iron until the tip will melt the solder.

(4) Use the iron for soldering in the same manner as an electric iron. Reheat iron frequently to maintain temperature for satisfactory melting of solder.

b. Acetylene Torch Soldering Procedure. An acetylene torch should be used for work requiring quick heat at high temperature. The complete unit consists of a cylinder of acetylene gas that has a regulator valve, a section of rubber hose, and a brass torch nozzle. Various size torch tips are available. Some torches contain a pressure gage installed on the regulator valve.

NOTE

Personnel should not operate an acetylene torch unless they are trained in the action and effects of acetylene gas and fully qualified to operate the equipment.

c. Alcohol or Butane Gas Torch Soldering Procedure. An alcohol or butane gas torch may be used for light work where a moderately hot flame is required. These are relatively easy and safe to operate. The torch produces a blue flame which will be played on the area to be soldered.

3.6 SOLDERING INSPECTION

Perform a visual inspection of the soldered area (see figure 3-8). Good soldered joints, regardless of construction, will have like characteristics. The solder shall be clean, smooth, and bright (the degree of brightness will vary with the solder alloy used). The joined surfaces shall be covered with a solder coating that leaves the general outline of the surfaces visible. A smooth fillet between the surfaces shall taper to a feathered edge away from the joint. Inspection procedures shall not damage any leads, wires, insulation, or components.

The following defects (some of which are illustrated in figure 3-8, C through F, shall be unacceptable:

- o Evidence of charring, burning, or other heat damage.
- o Disturbed joint caused by relative motion between the wire or lead and the terminal when slight pressure is exerted against the lead wire.
- o Splattering of flux or solder on adjacent connections or parts.
- o Solder points.
- o Rosin joints, which have a chalky, rough appearance (trapped flux results in high electrical resistance).
- o Cold joints, which have a dull, frosted, "piled-up" appearance, resulting from non-wetting. Cold joints have weak mechanical connections and high electrical resistance. A cold joint may give intermittent operation and induce noise.
- o Pitted joints, showing small scars or holes.
- o Excessive solder (the solder completely obscures the joint configuration).
- o Loose parts resulting from excessive heat.

3.7 BRAZING MATERIALS

3.7.1 Filler Metals

Filler metals used in brazing will conform to the specifications listed in paragraphs 2.1 and 2.2 of MIL-B-7883, except that copper brazing filler metal shall be deoxidized copper without residual deoxidizing agents. Filler metal may be hand-held, and fed into the joints (face feeding) or preplaced as wire, washers, clips, slugs, or powder.

3.7.2 Flux

Flux may be applied in the form of powder, paste, vapor, gas, or coating on filler rods. Flux application is generally not required when parts are to be joined by the molten flux (dip) brazing process, or in furnace brazing when an inert or reducing atmosphere is used. The correct flux to be used depends on the brazing method used. (Paragraphs 2.1 and 2.2 of MIL-B-7883 list the specifications for individual fluxes.)

3.8 BRAZING METHODS

Brazing operations are inherently dangerous, and personnel involved must observe all safety rules and practices to avoid accidents or injuries. The hazards involved include fire, explosion, toxic gas, eye injury, and electric shock. Only personnel who have passed qualification tests and demonstrated their ability will be permitted to operate welding equipment. Qualification tests for welders are listed in MIL-STD-248. Military specification MIL-B-7883 prescribes the general fabrication and quality requirements for the brazing of metals commonly used in electronic equipment.

3.8.1 Preparation for Brazing

The mating surfaces and adjacent areas of all parts to be joined are to be thoroughly cleaned to remove all oil, grease, paint, dirt, scale, artificial oxide films, conversion coatings, or any other foreign substance. The parts to be joined must be fitted together properly and all burrs removed to permit proper fitting and flow of the filler material. The parts should be held in position and proper alignment by jigs, clamps, supports or be self-fixturing. The fixtures must permit expansion of the parts during heating and contraction during cooling. Brazing is generally done by one of the following methods:

- Torch or gas burner brazing
- Furnace brazing
- Induction brazing
- Resistance brazing
- Dip brazing

3.8.2 Torch Brazing

Torch brazing may use acetylene, propane, city gas, natural gas and hydrogen with air, compressed air, or oxygen as fuel for the flame. The parts are preheated with a neutral or slightly reduced flame to bring the entire joint uniformly to the liquid temperature of the filler material but no higher than necessary to provide a satisfactory joint. The amount of heat transferred to the base metal with a given flame depends on the distance the torch is held from the metal. Localized or overheating is to be avoided. The flame should be kept in a constant circular motion to spread the heat evenly. The filler metal is introduced at one edge of the joint or in a groove provided for one of the mating surfaces and flows by capillary action to fill the space between the metals. Once the filler metal has started to flow the heat should not be increased. After the joint has cooled, all traces of the flux should be removed to prevent corrosion of the parts.

3.8.3 Furnace Brazing

Furnace brazing uses the heat of a gas-fired, electrical, or other type of furnace to raise the parts to brazing temperature. It must have temperature controlling devices to automatically control furnace temperatures. Fluxes may be used, although reducing or inert atmospheres are more common since they eliminate the postbraze cleaning necessary with fluxes. The parts are assembled with proper fit and alignment and the filler placed in such relation as to obtain the best joint possible. The complete assembly is placed in the furnace and the heat is brought to brazing temperature in the shortest time possible. The parts remain in the furnace until the filler metal has melted and formed the desired bonding. After brazing the assembly is cooled and cleaned.

3.8.4 Induction Brazing

Induction brazing uses a high-frequency current to generate the necessary heat in the part by induction. The mating surfaces are coated with flux, the filler metal placed in position and the joint-area heated by placing within or near a suitable induction coil. The best method of heat control for this type of brazing is by controlling the amount of time the assembly is within or near the coil. After the bond is formed the part must be thoroughly cleaned to remove the flux.

3.8.5 Resistance Brazing

Resistance brazing uses a standard resistance welding machine to supply the heat. Either preplacement or face feeding of the filler metal may be used. The assembled parts are placed between two electrodes and current passes through the joint. The current and electrode size is selected so that the heat will be distributed over a large enough area to allow the brazing alloy to flow freely, but not large enough to cause overheating. Precise control of the amount of heat to the joint is usually achieved by timing the flow of current.

3.8.6 Dip Brazing

Dip brazing involves the immersion of parts in a molten bath. The bath may be either molten brazing filler metal or molten salts (usually brazing flux). The former is limited to small parts such as electrical connections; the latter is capable of handling large assemblies. The assembly is dipped into the molten bath at a uniform rate. Brazing times depend on the shape and cross section of the assembly. Brazing is complete when the filler metal has flowed evenly into the joints. At this point, the assembly is removed slowly from the bath so as not to cause loss of the molten filler metal. The merit of dip brazing is that the joint is virtually completed all over the assembly at one time.

3.9 BRAZE JOINTS

The requirements for a good joint may be any or all of the following: mechanical strength, electrical conductivity, pressure tightness, and good performance at elevated and subzero temperatures. The strength of the joint depends on the strength of the filler metal, the joint clearance, and the absence of defects such as porosity, slag inclusions, and unbrazed areas or voids.

3.9.1 Basic Designs

The three basic joint designs used for brazing are lap, butt, and scarf joints. Combinations and variations of these will meet most requirements (see figure 3-9). Generally, lap joints are stronger than butt or scarf joints.

3.9.2 Joints for Electrical Conduction

The main factor in the design of electrical joints is good conductivity. Lap joints should be used where the design will permit. A rule of thumb method used to obtain maximum conductivity is to establish a lap length 1-1/2 times the thickness of the thinner member.

3.9.3 Joint Clearances

Joint clearance should be considered for maximum strength. Room temperature clearance is a satisfactory guide with similar metals of about equal mass. Where dissimilar metals, or greatly differing masses of similar metals are concerned, unequal expansion may require that careful judgment be used to obtain the correct clearance (see table 3-3).

3.9.4 Service at Elevated Temperatures

Brazed assemblies subject to service at elevated temperatures lose strength as the temperature increases. Designs must take these losses into consideration. Table 3-4 gives continuous and maximum service temperatures for various filler metals.

3.10 WELDING MATERIALS

3.10.1 Welding Rods

Welding rods, welding wire, and electrodes used in the welding of various base metals must be capable of producing satisfactory welds when used by qualified operators with satisfactory equipment. The type of rod, wire, or electrode selected will depend on the physical properties of the base metals involved, the type of weld and joint used, the welding method used, and other factors. Filler metal used in the welding of dissimilar metals must be compatible with both base metals in maintaining the physical properties and corrosion resistance of the base metals.

3.10.2 Welding Fluxes

The flux used in welding can be manually applied to the welding rod or it may be in the coating applied to the rod during manufacture. In some cases it may be applied directly to the joint. The flux must be capable of removing the oxides present or generated during the welding process, all other impurities, and not significantly increase the carbon content of the weld metal.

3.11 WELDING METHODS

Exact welding procedures for all methods are too involved to detail. Many publications of military and civilian organizations, including the American Welding Society, publish detailed instructions and procedures for all types of welding operations. Arc and gas welding will be performed only by operators who have passed the applicable certification tests and have a certificate of proficiency in accordance with MIL-STD-248 or MIL-T-5021. The safety regulations and practices applicable to welding operations will be strictly complied with. The types of welding commonly used include:

- Metal arc
- Atomic hydrogen
- Inert gas tungsten arc
- Oxygas
- Resistance
- Carbon arc

3.11.1 Metal Arc Welding

Metal arc welding is a process by which an electric arc between a metal electrode and the base metal causes the metal in the path of the arc stream to melt to a molten state. Subsequently, the molten metal solidifies and fuses the metal pieces together. The value of current and voltage used determines the depth of penetration of the weld. Correct arc length will vary with the size and type electrode used and the amount of heat required. The shorter the arc, the easier it is to maintain and control.

Metal arc welding may be performed with either DC or AC welding power sources using covered electrodes which shield the arc and metal from the air. (Shielding excludes the oxygen and nitrogen of the air, thus eliminating the formation of oxides and nitrides which decrease weld-metal ductility and strength.) The arc should not be advanced too rapidly. The rate of advance can be determined by watching the solidifying metal. Any undercutting which appears should be filled before the arc is advanced. Best results are obtained if the weld is allowed to cool between successive beads. When welding shapes of unequal thickness, the arc should be directed so that both pieces being welded are heated equally.

3.11.2 Atomic-Hydrogen Welding

In atomic-hydrogen welding a jet of hydrogen is projected into an arc formed between two tungsten electrodes. The arc breaks up the hydrogen molecules into hydrogen atoms, which recombine into molecules when striking the relatively cold welded area. The heat is thus derived from the arc and the disassociation and recombination of the hydrogen molecule; the latter provides the greater amount of heat. The heat can be controlled by moving the arc closer to or farther away from the base metal. This process is particularly suitable for welding alloys as there is a minimum loss of alloying ingredients. The process is more effective on thinner sections, as high currents necessary for heavy sections burn away tungsten electrodes. Two advantages derived from use of hydrogen are: it furnishes the heat for fusion and it serves as a blanket to exclude the atmosphere from the weld area. Flux is not normally required except for aluminum, copper, and their alloys.

3.11.3 Inert Gas Tungsten Arc Welding

This method involves an arc between a non-consumable tungsten wire electrode and the work to be welded (see figure 3-10). A shield of inert gas such as argon, helium, or a mixture of these gases is projected around the arc and the filler rod. The use of inert gas envelopes permits the welding of aluminum, magnesium, stainless steels, copper, nickel, and alloys without flux. Welding power sources may be either AC or DC. Power-source selection depends on the metal being welded and the results desired. A second process of this type uses a filler-type consumable electrode. A method similar to inert gas tungsten arc welding is shielded metal arc welding. The main difference is that the protective gas is released from a coating on the rods in contrast to the gas being delivered from an external source.

3.11.4 Oxygas Welding

The heat for oxygas welding is supplied by burning a mixture of oxygen with a suitable combustible gas. Acetylene gas is the one most commonly used with oxygen because of its high flame temperature. The temperature generated is so far above the melting point of all commercial metals that it provides a means for the rapid localized melting essential in welding. Hydrogen can be used as the combustible gas in welding metals that have low melting points such as lead and thin aluminum sheets.

The components required for oxygas welding are a torch, a supply of oxygen and acetylene, and hoses and regulators for each gas. The torch serves to receive and mix the gases properly, and to shape and direct it at the correct angle.

The type of flame produced depends on the ratio of the mixture of gases. There are three distinct types of flames:

a. Neutral. This is a flame with a balanced 1:1 mixture of oxygen and acetylene. It consists of an inside brilliant cone surrounded by a faintly luminous envelope flame. It will not react with any material with which it comes in contact.

b. Carburizing. This flame has an excess of acetylene and consists of three recognizable zones: a sharply defined inner cone, an intermediate cone of whitish color and a bluish outer envelope. The length of the intermediate zone indicates the amount of excess acetylene. The flame is capable of rapid reduction of oxides and some molten metals will absorb a portion of the excess carbon produced by the excessive acetylene.

c. Oxidizing. This flame has an excess of oxygen and can rapidly form oxides on the metals being welded. The flame resembles the neutral flame but the inner cone is shorter.

Most metals can be oxygas welded. A neutral flame is usually satisfactory. The flame is applied until the metal is just under the melting temperature. The flame is then concentrated on a local area. When a small puddle appears, the end of the welding rod is placed into the puddle and the correct amount of metal is added. The rod should be moved around to get the metal just where it is wanted. The molten metal from the rod should not be allowed to flow on metal that is not in a molten state. The flame should be kept moving ahead of the puddle to melt the metal. The welding speed is important in that welding too rapidly produces poor penetration, while welding too slowly will result in burning, piling up of slag, or other defects. Aluminum, stainless steel, magnesium, copper and brass should, where possible, be welded with a blanket arc such as inert-gas shielded electric arc welding.

3.11.5 Resistance Welding

In resistance welding, coalescence is produced by the heat generated by the resistance of two pieces of metal placed between two low resistance electrodes when subjected to a low-voltage, high-amperage current. By applying pressure to the pieces at the contact point, after the temperature of the metal reaches the plastic stage, fusion of the two metals will result. The resistance of the welding circuit is maximum at the interface of the parts to be joined. The duration of the current application must be short so as to limit the zone of melting; otherwise an inferior weld will result.

The electrodes are of copper alloyed with such metals as molybdenum and tungsten, with high electrical conductivity, good thermal conductivity, and sufficient mechanical strength to withstand the high pressures to which they are subjected. The electrodes should be watercooled. The resistance at the surfaces of contact between the work and the electrodes must be kept low.

Resistance welding includes:

a. Spot Welding. Spot welding machines vary from small portable to large stationary machines. The parts to be welded are lapped and held in place under pressure and the current applied (see figure 3-11). The size and shape of the electrodes control the size and shape of the weld. The spacing of welds must be such that the welding current will not shunt through the previously made weld.

b. Seam Welding. Seam welding is similar to spot welding except that a series of spot welds are produced by circular or wheel type electrodes. The welds may be a series of closely spaced individual spot welds, overlapping spot welds, or a continuous weld nugget.

c. Butt Welding. It is limited to joining together members of about equal cross section. The parts are brought together, held under pressure, and a current passed through the contact area. Pressure and current are maintained throughout the welding cycle, although pressure is initiated at a low value and increased as the surfaces become plastic from the current.

d. Flash Welding. In flash welding, the parts are brought close together with current flowing. An arc is formed from the flashing action. When the metal becomes molten, heavy pressure is applied to the pieces to produce a weld.

3.11.6 Carbon Arc Welding

This type of welding uses a non-consumable carbon electrode. Since no metal is transferred through the arc stream, the carbon arc serves only as a source of heat. When filler metal is required, it must be fed into the welding zone in rod form. Diameter of the carbon point should be about half the diameter of the carbon used. The taper should be gradual back to the point where it is gripped in the holder. The carbon should be gripped as closely to the arc as possible to reduce vaporization of the rod. This method may be used with or without an inert gas blanket.

3.12 WELDING-JOINT SELECTION

The type of joint selected for a particular application depends on the size, thickness, and kind of metals used and the load-bearing and physical-stress requirements. The five basic types of welded joints (see figure 3-12) are the butt, corner, edge, tee, and lap joints.

3.13 METAL-CUTTING WITH HEAT

All metals will burn when heated to their respective kindling temperature and exposed to oxygen. The cutting equipment heats the metal to its kindling point and directs a stream of pure oxygen against the heated region. Once cutting is started its continuation is achieved by moving the heat source and oxygen jet along the desired path.

3.13.1 Torch Cutting

Flame cutting is one of the fastest methods of cutting metal. The torch nozzle is constructed so that the preheating flame plays on an area to heat it bright red, then the oxygen jet is directed on the area. Fast combustion takes place to remove the metal. The path of cutting should be premarked with soapstone. A center punch can be used to make marks along the soapstone line. The start of the cut will usually be at an edge of the workpiece where preheating is rapid. With the tip of the flame's inner cone in contact with the metal, a small area is brought to a bright red temperature. The oxygen trigger valve is then opened to direct oxygen against the heated area. Opening the valve slowly will prevent spatter. As the torch is moved along the soapstone line, cutting will be sustained as long as the torch is not moved too fast. A narrow portion of the metal is removed along the path of the torch.

3.13.2 Electric Arc Cutting

There are three types of arc cutting in general use. Arc-oxygen cutting, uses an action similar to flame oxygen cutting. The oxygen is introduced through a tubular electrode to cause oxidation and erosion of the metal. The other two types, carbon arc and solid core metal arc, do not use oxygen. The heat derived from the arc simply melts a path through the metal. In solid core metal arc cutting, another benefit is available in that the coating shields the electrode against side arcing, thereby allowing the electrode to penetrate deeper into a cut. Special electrodes are usually used, although regular welding electrodes may be used in an emergency. Electric arc cutting requires somewhat higher currents than welding. Higher heats are possible than with oxygen-flame cutting, thereby permitting metals such as cast iron to be cut with more ease.

Table 3-1. Limit of Damaged Strands

NUMBER OF STRANDS	MAXIMUM ALLOWABLE NICKED OR BROKEN STRANDS
Less than 7	0
7-15	1
16-18	2
19-25	3
26-36	4
37-40	5
41 or more	6

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Table 3-2. Suggested Tinning Lengths

WIRE SIZE	TINNING LENGTH
#18 and smaller	2/3 of stripped length
#16 and larger	1/3 of stripped length
Coaxial Cable and Shielded Conductors	3/16 inch

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Table 3-3. Recommended Brazing-Temperature Clearances

FILLER METAL	JOINT CLEARANCE, INCHES
Boron - Aluminum - Silicon Gp	0.006 - 0.010 for length of lap less than 1/4" 0.010 - 0.025 for length of lap greater than 1/4"
Boron - Copper - Phosphorous Gp	0.001 - 0.005
Boron - Silver Gp	0.002 - 0.005
Boron - Copper - Gold Gp	0.002 - 0.005
Boron - Copper Gp	0.002 - 0.002*
Boron - Copper - Zinc Gp	0.002 - 0.005
Boron - Magnesium Gp	0.004 - 0.010
Boron - Nickel - Chromium Gp	0.002 - 0.005
Boron - Silver - Manganese Gp	0.002 - 0.005
NOTE: In case of round or tubular members this means a clearance on the radius. *For maximum strength use 0.000 clearance or a press fit.	

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Table 3-4. Service Temperatures for Brazing Filler Metals

FILLER METAL	SUGGESTED LIMITING CONTINUOUS SERVICE TEMPERATURE °F	SUGGESTED MAXIMUM SERVICE TEMPERATURE °F
Boron - Copper - Phosphorous Gp	300	300
Boron - Silver Gp	400	500
Boron - Copper - Fire Gp	400	500
Boron - Copper Gp	400	900
Boron - Silver - Manganese Gp	500	900
Boron - Nickel - Chromium Gp	1000	2000

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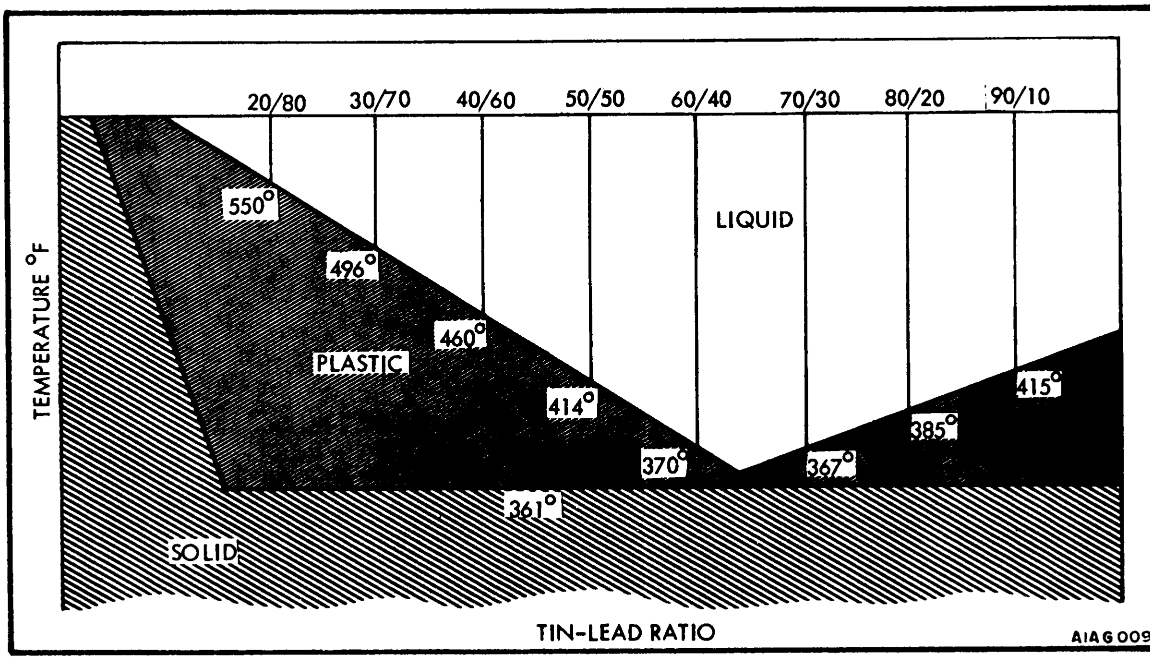

Figure 3-1. Solder Melting Range

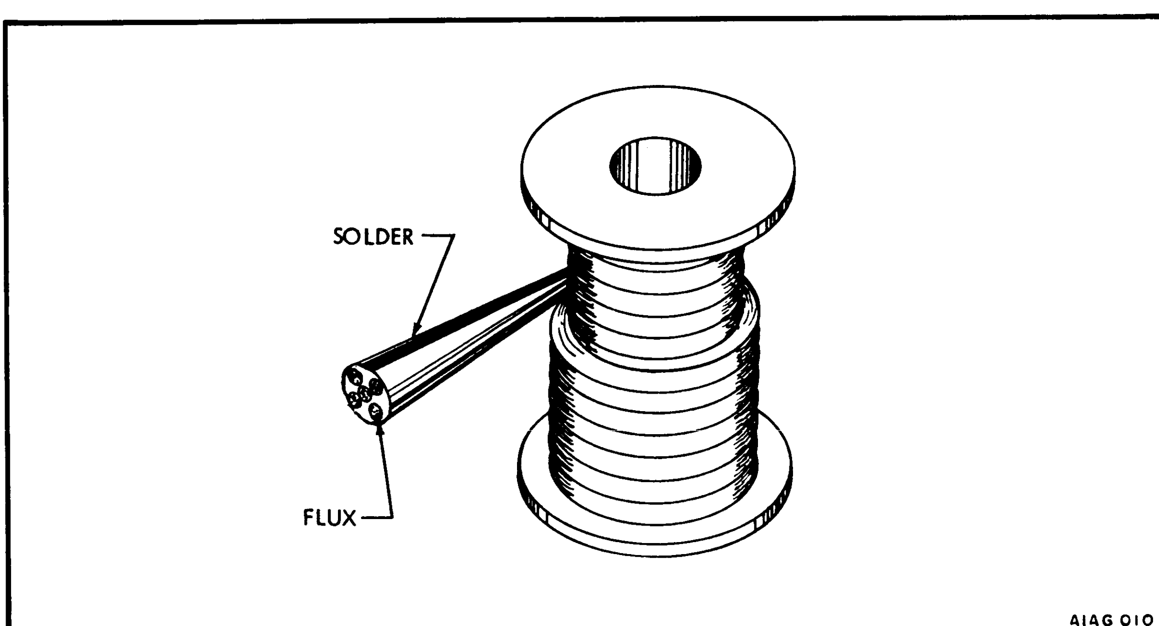

Figure 3-2. Multiple-Core Solder

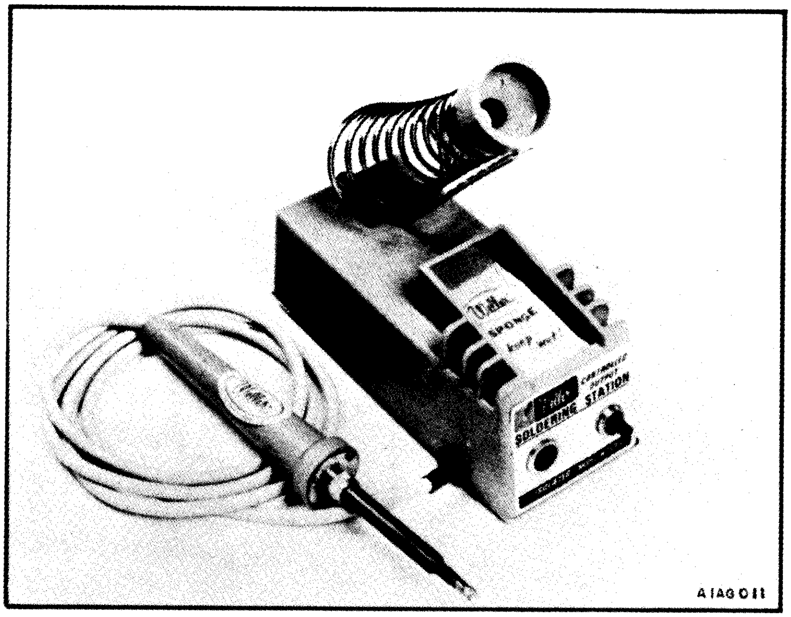

Figure 3-3. Typical "Pencil Type" Soldering Iron

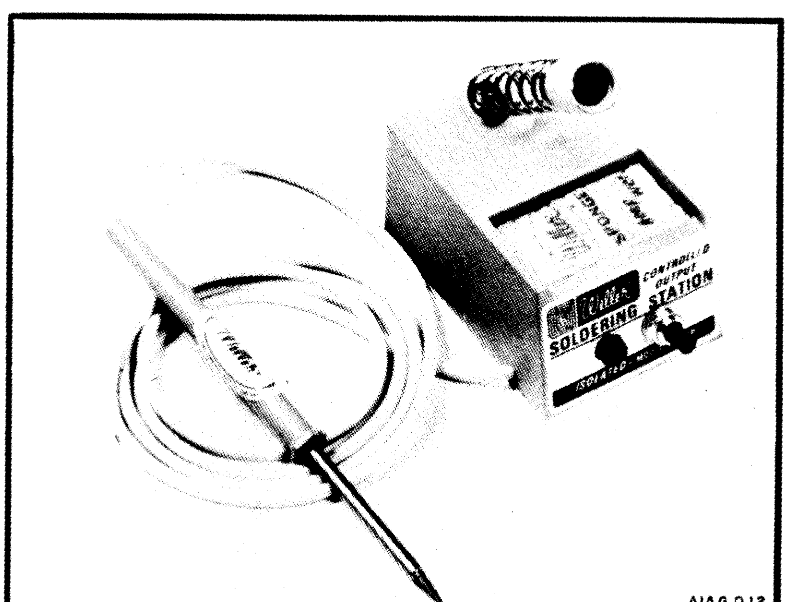

Figure 3-4. Typical Low Voltage Soldering Station

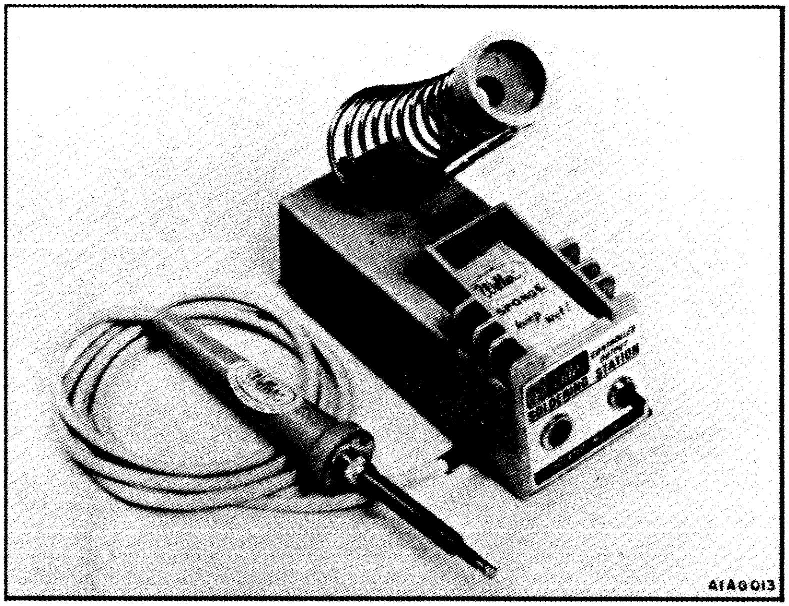

Figure 3-5. Typical Low Voltage Soldering Iron With Temperature Controlling Tips

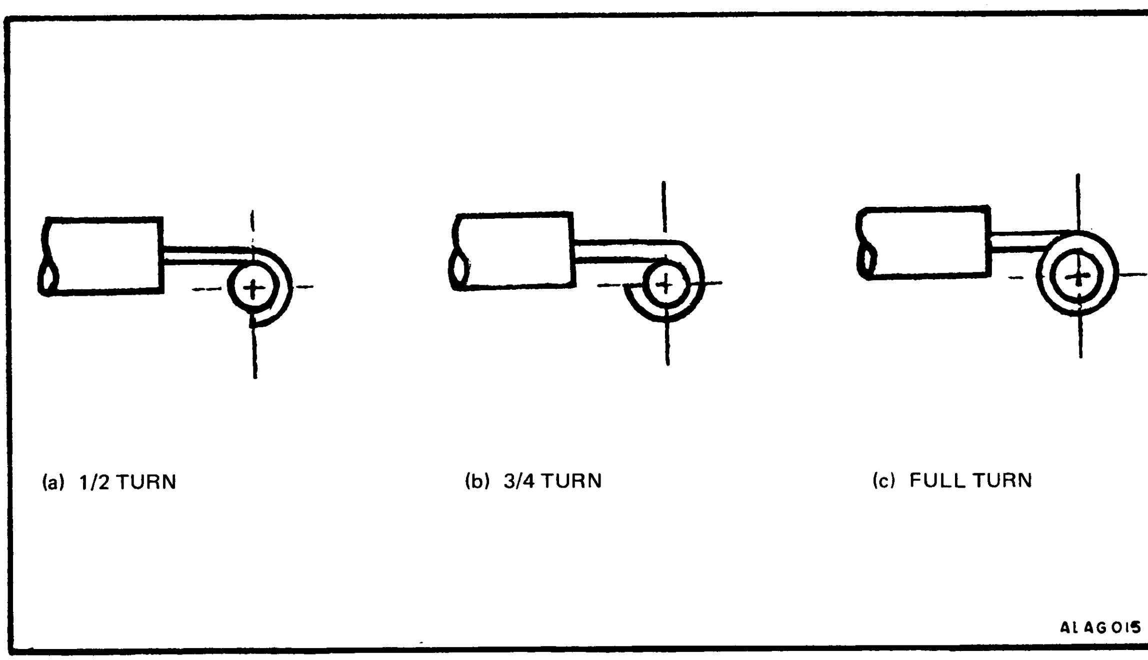

Figure 3-6. Terminal Wire Wrap-Around

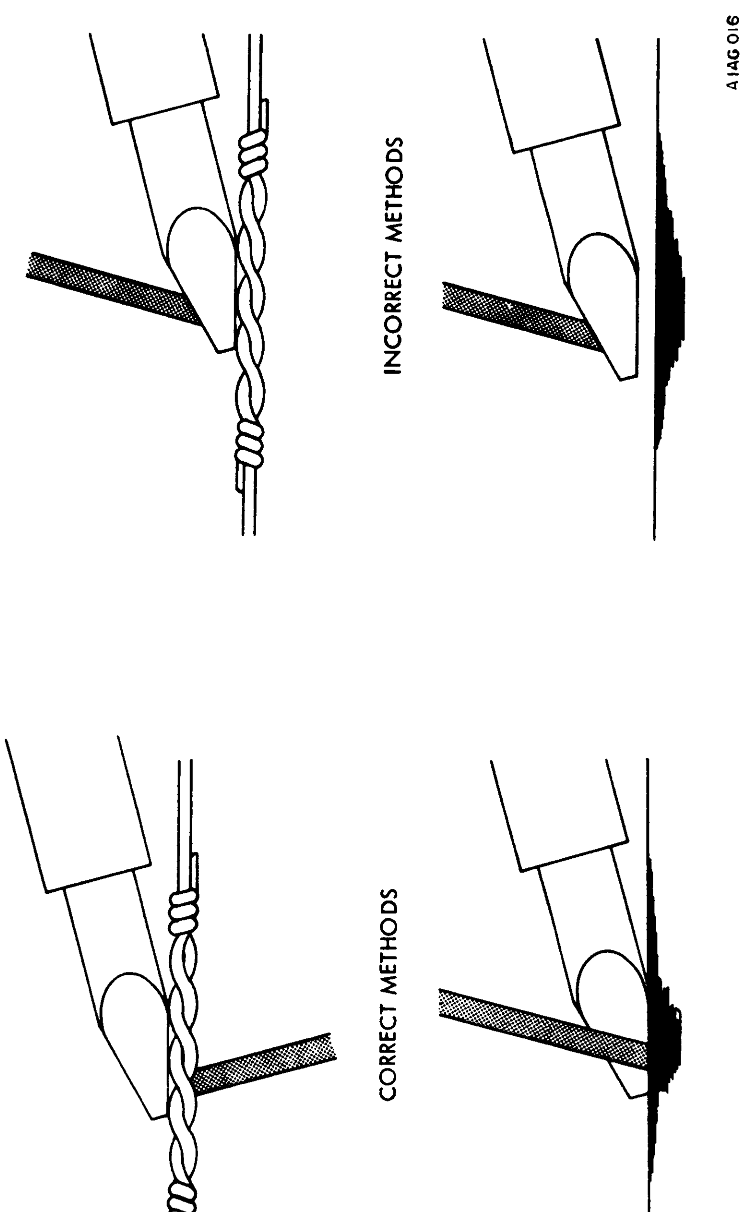

Figure 3-7. Method of Applying Soldering Iron

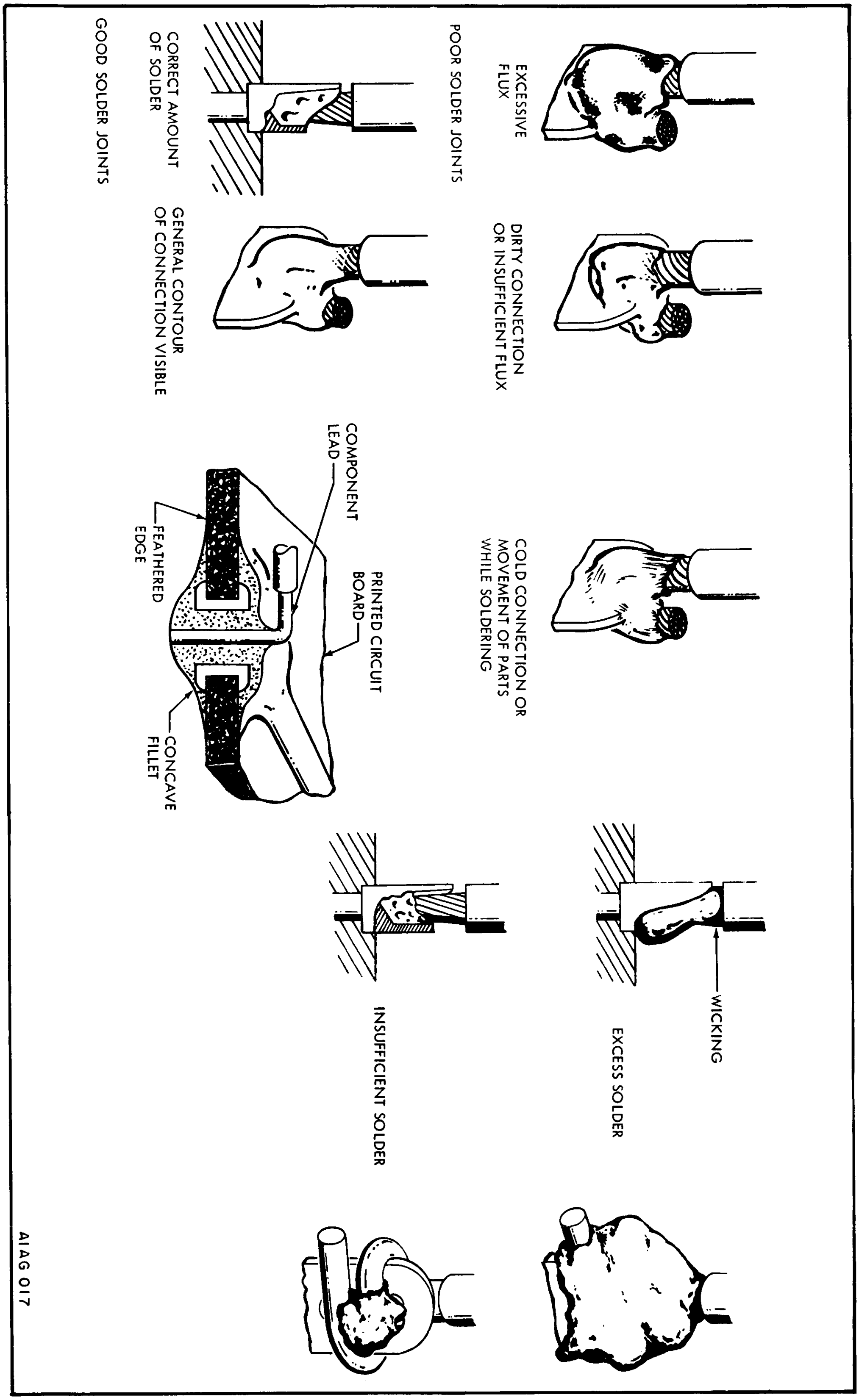

Figure 3-8. Examples of Soldered Joints

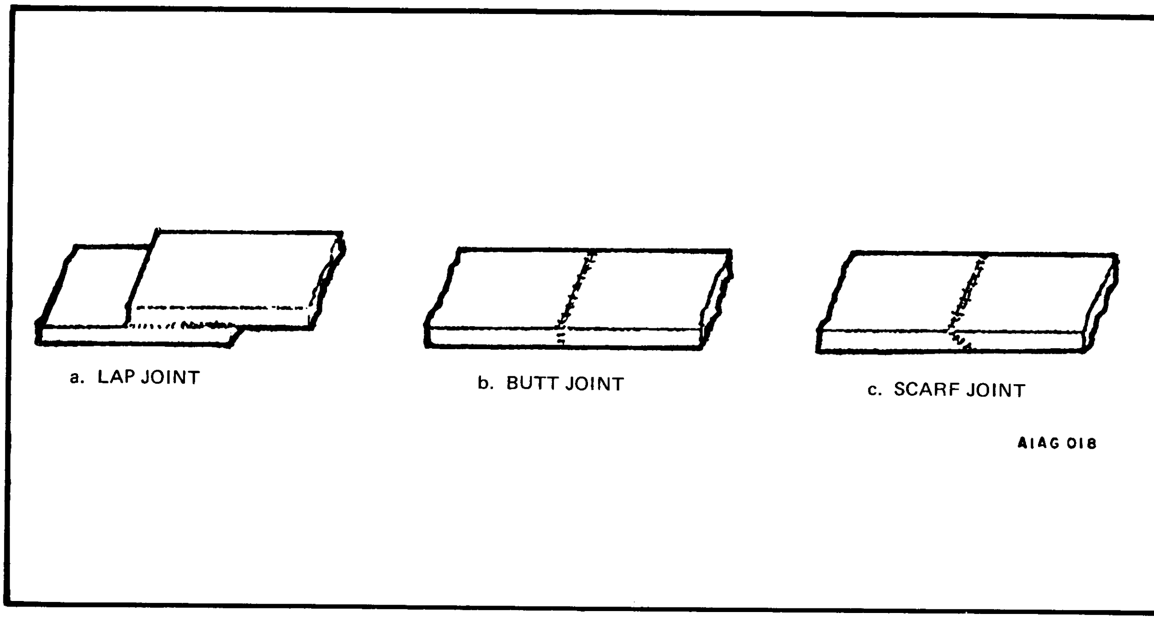

Figure 3-9. Basic Joints for Brazing

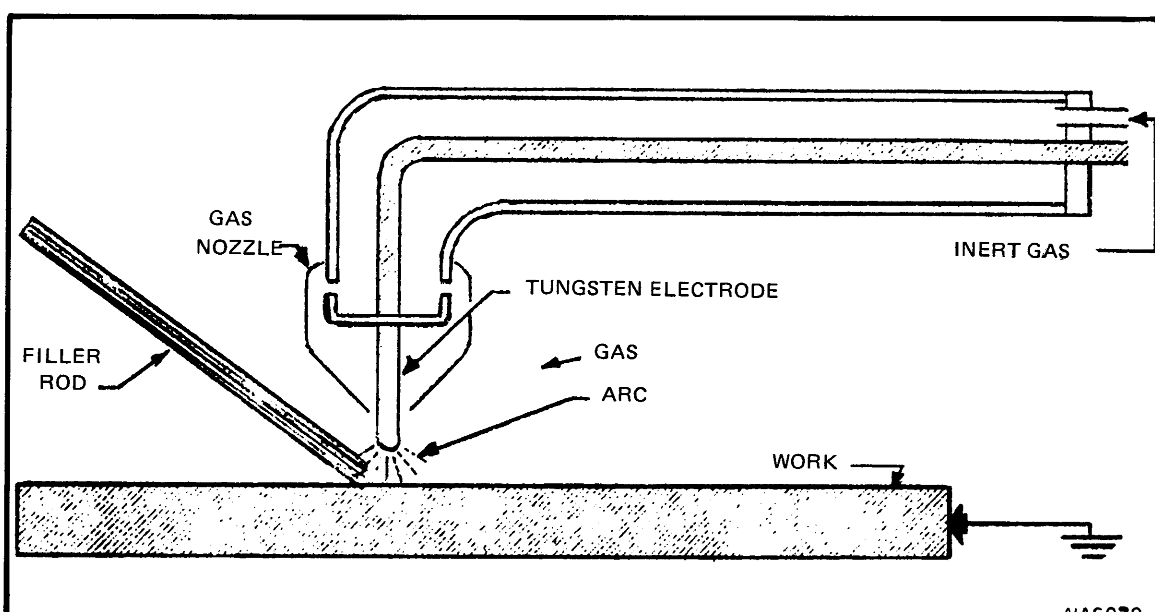

Figure 3-10. Inert-Gas Tungsten-Arc Welding

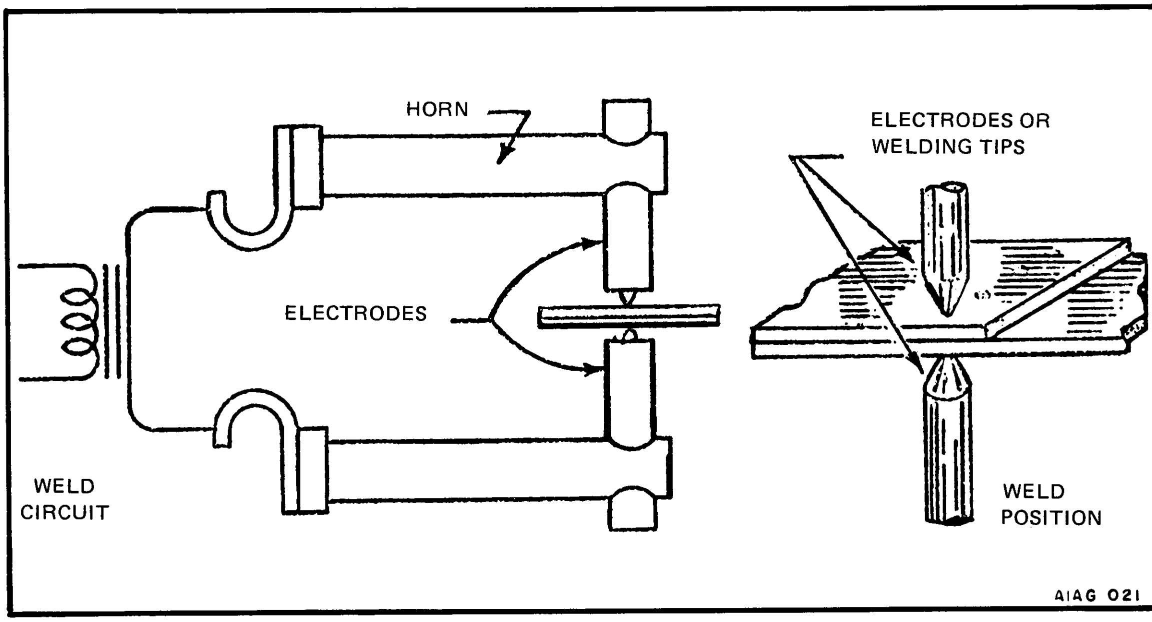

Figure 3-11. Basic Spot-Welding Circuit

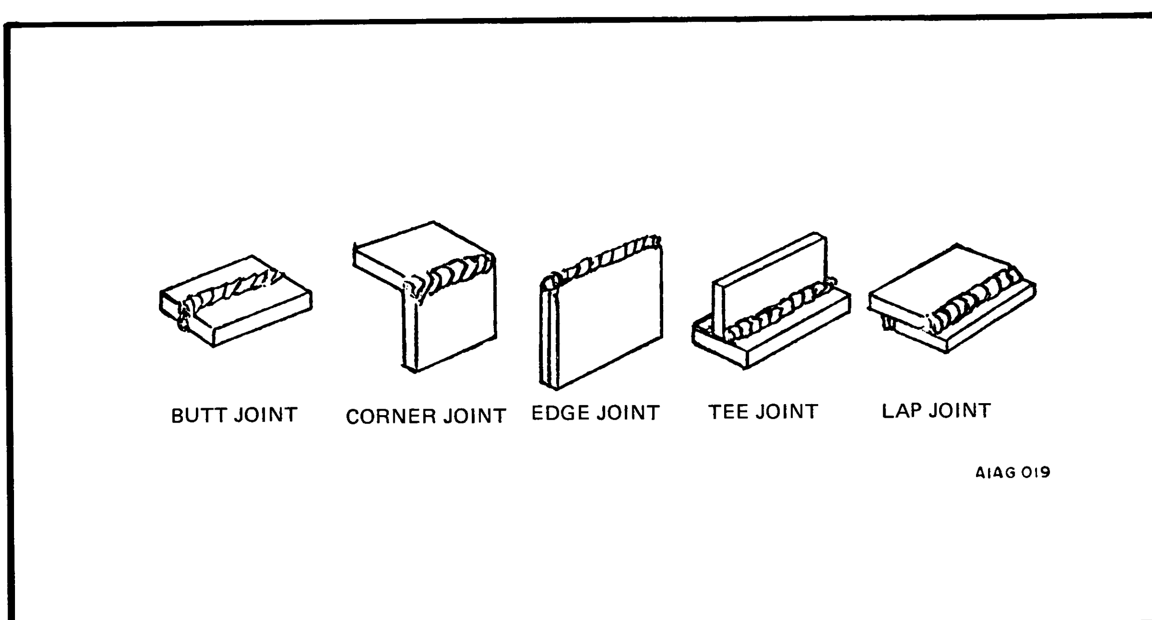

Figure 3-12. Common Weld-Joints