Soldering, Brazing, and Braze Welding Processes

OBJECTIVES

After completing this chapter, the student should be able to:

• Compare the difference between soldering and brazing.
• List the advantages of soldering and/or brazing.
• Explain tensile strength, shear strength, ductility, fatigue resistance, and corrosion resistance as they relate to the strength of a joint.
• Explain why flux is used in soldering and brazing.
• Discuss the advantages and disadvantages of the five methods of heating material for soldering or brazing.
• Describe what factors must be considered when selecting a filler metal.
• Discuss the applications for common soldering and brazing alloys.
• Describe the preparation needed for a part before it is soldered or brazed.

KEY TERMS

- brazing alloys
- corrosion resistance
- dip soldering
- ductility
- elastic limit
- eutectic composition
- fatigue resistance
- furnace
- induction
- liquid-solid phase
- bonding
- low-fuming alloys
- paste range
- phase
- shear strength
- soldering alloys
- tensile strength

INTRODUCTION

Soldering and brazing are similar processes. Both processes can be used to produce strong, durable joints. Both processes can use similar alloying metals. Both processes can be completed with or without flux. The only difference is that
soldering is done at a lower temperature, below 840°F (449°C), and brazing is done at a higher temperature, above 840°F (449°C). In both processes, the filler metal is melted, and the base metal is heated. At some point in the heating process a change occurs between the way the molten solder or braze metal and the heated metal surface react to each other. Before this temperature point is reached, the liquid metal often beads up, forming little balls sitting on the hot surface. At a high enough temperature the solder or braze metal flows out over the base metal surface and a strong bond is formed between the molten metal and base metal. The term wetting is used to describe the flowing out across the surface of the molten metal. Sometimes a flux may be required to remove a light surface oxide from the base metal surface and to promote wetting, but with or without a flux, the process the same.

Because soldering and brazing are similar processes, both are classified by the American Welding Society (AWS) as liquid-solid phase bonding. The term liquid is used in reference to the fact that the filler metal is melted. The term solid is used because the base material or materials are not melted. The phase refers to that temperature at which bonding takes place between the solid base material and the liquid filler metal. The term bonding refers to the attraction that exists between the cooled solidified filler metal and the base metal. The terms material or materials are used because both soldering and brazing can be used to join both metals and nonmetals. The most common nonmetals that are joined are ceramics. If done correctly, the bond can result in a joint that has four or five times the tensile strength of that of the filler metal that was used to join the parts.

**ADVANTAGES OF SOLDERING AND BRAZING**

Some advantages of soldering and brazing as compared to other methods of joining include the following:

- Low temperature—Since the base metal does not have to melt, a lower-temperature heat source can be used.
- May be permanently or temporarily joined—Since the base metal is not damaged, parts may be disassembled at a later time by simply reapplying heat. The parts then can be reused. However, the joint is solid enough to be permanent, Figure 19-1.
- Dissimilar materials can be joined—It is easy to join dissimilar metals, such as copper to steel, aluminum to brass, and cast iron to stainless steel, Figure 19-2. It is also possible to join nonmetals to each other or nonmetals to metals. Ceramics are easily brazed to each other or to metals.
- Speed of joining
  a. Parts can be preassembled and dipped or furnace soldered or brazed in large quantities, Figure 19-3.
  b. A lower temperature means less time in heating.
- Less chance of damaging parts—A heat source can be used that has a maximum temperature below the temperature that may cause damage to the parts, Figure 19-4.
- Slow rate of heating and cooling—Because it is not necessary to heat a small area to its melting temperature and then allow it to cool quickly to a solid,
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Reach the proper phase temperature. Capillary action is the force that pulls water up into a paper towel or pulls a liquid into a very fine straw, Figure 19-6. This results in a very strong joint that uses very little filler metal.

Braze welding does not use capillary action to pull filler metal into a tightly fitted joint, Figure 19-5B. The same brazing alloy can be used for both brazing and braze welding. It is only how the filler metal reacts with the joint that makes the difference between brazing and braze welding. The parts joined by braze welding may have a very open or loose fitting. The filler metal may be used to fill a large joint gap or space. Braze welding uses more filler metal than brazing. Parts joined by braze welding are not as strong as those joined by brazing if they were both made with the same filler metal.

Parts of varying thicknesses can be joined—Very thin parts or a thin part and a thick part can be joined without burning or overheating them.

• Easy realignment—Parts can easily be realigned by reheating the joint and then repositioning the part.

Brazing and Braze Welding

Brazing is divided into two major categories named brazing and braze welding. In the brazing process the parts that are being joined must be fitted together very snugly. The joint spacing is very small, approximately 0.025 in. (0.6 mm) to 0.002 in. (0.06 mm), Figure 19-5A. This small spacing allows capillary action to draw the filler metal into the joint when the parts reach the proper phase temperature. Capillary action is the force that pulls water up into a paper towel or pulls a liquid into a very fine straw, Figure 19-6. This results in a very strong joint that uses very little filler metal.

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Examples of brazing and braze welding joint designs are shown in Figure 19-7. Some joints may contain areas of both brazing and braze welding. For example, the small fillet added to a copper sleeved joint could be classified as braze welding, while the filler metal that was pulled into the joint gap would be classified as brazing.

### PHYSICAL PROPERTIES OF THE JOINT

#### Tensile Strength

The tensile strength of a joint is its ability to withstand being pulled apart, Figure 19-8. A brazed joint can be made that has a tensile strength four to five times higher than the filler metal itself. If a few drops of water are placed between two smooth and flat panes of glass and the panes are pressed together, a tensile force is required to pull the panes of glass apart. The water, which has no tensile strength itself, has added tensile strength to the glass joint.

The glass is being held together by the surface tension of the water. As the space between the pieces of glass decreases, the tensile strength increases. The same action takes place with a soldered or brazed joint. As the joint spacing decreases, the surface tension increases the tensile strength of the joint, Table 19-1.

#### Shear Strength

The shear strength of a brazed joint is its ability to withstand a force parallel to the joint, Figure 19-9. For a solder or braze joint, the shear strength depends upon the amount of overlapping area of the base parts. The greater the area that is overlapped, the greater is the strength.

#### Ductility

Ductility of a joint is its ability to bend without failing. Most soldering and brazing alloys are ductile metals, so the joint made with these alloys is also ductile.
materials to the filler metal will determine the corrosion resistance. Using the proper filler metal with the base materials that are listed in this chapter will result in corrosion-free joints. However, using filler metals on base materials that are not recommended in this chapter may result in a joint that looks good when completed but will eventually corrode. For example, a brass brazing rod that contains copper (Cu) and zinc (Zn) (BCuZn) will make a nice looking joint on stainless steel. But the zinc in the brass will combine with the nickel in the stainless steel if the part is kept hot for too long. As a result, a corrosive, brittle structure is formed in the joint, reducing strength.

**FLUXES**

**General**

Fluxes used in soldering and brazing have three major functions:

- They must remove any oxides that form as a result of heating the parts.
- They must promote wetting.
- They should aid in capillary action.

The flux, when heated to its reacting temperature, must be thin and flow through the gap provided at the joint. As it flows through the joint, the flux absorbs and dissolves oxides, allowing the molten filler metal to be pulled in behind it, Figure 19-11. After the joint is complete, the flux residue should be easily removable.

Fluxes are available in many forms, such as solids, powders, pastes, liquids, sheets, rings, and washers, Figure 19-12. They are also available mixed with the filler metal, inside the filler metal, or on the outside.
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Sheets, rings, and washers may be placed within the joints of an assembly before heating so that a good bond inside the joint can be ensured. Paste and liquids can be injected into a joint from tubes using a special gun, Figure 19-14. Paste, powders, and liquids may be brushed on the joint before or after the material is heated. Paste and powders may also be applied to the end of the rod by heating the rod and dipping it in the flux. Most powders can be made into a paste, or a paste can be thinned by adding distilled water; see manufacturers’ specifications for details. If water is used, it should be distilled because tap water may contain minerals that will weaken the flux.

Some liquid fluxes may also be added to the gas when using an oxyfuel gas torch for soldering or brazing. The flux is picked up by the fuel gas as it is bubbled through the flux container and is then carried to the torch where it becomes part of the flame.

Flux and filler metal combinations are most convenient and easy to use, Figure 19-15. It may be necessary to stock more than one type of flux-filler metal combination for different jobs. In cases where the flux covers the outside of the filler metal, it may be damaged by humidity or chipped off during storage.

Using excessive flux in a joint may result in flux being trapped in the joint, weakening the joint, or causing the joint to leak or fail.

**NOTE:** Most of the fluxes used for brazing and soldering are not harmful to the environment. However, large quantities of even the most benign materials introduced accidentally or intentionally into the environment can cause damage. Even lemon juice, a common electronic soldering flux, in large enough quantities can cause harm to the environment. Before disposing of any soldering or brazing fluxes, read the material safety data sheet (MSDS) carefully and follow its recommended procedures. Keeping our environment clean and safe is everyone’s responsibility.

**Fluxing Action**

The use of fluxes does not eliminate the need for good joint cleaning. Fluxes will not remove oil, dirt, paint, glues, heavy oxide layers, or other surface contaminants.

Soldering fluxes are chemical compounds such as muriatic acid (dilute hydrochloric acid), sal ammoniac (ammonium chloride), or rosin. Brazing fluxes are chemical compounds such as fluorides, chlorides, boric acids, and alkalies. These compounds
Flux can be purchased with the filler metal or separately.

The reactivity of a flux is greatly affected by temperature. As the parts are heated to the soldering or brazing temperature, the flux becomes more active. Some fluxes are completely inactive at room temperature. Most fluxes have a temperature range within which they are most effective. Care should be taken to avoid overheating fluxes. If they become overheated or burned, they will stop working as fluxes, and they become a contamination in the joint. If overheating has occurred, the welder must stop and clean off the damaged flux before continuing.

Fluxes that are active at room temperature must be neutralized (made inactive) or washed off after the job is complete. If these fluxes are left on the joint, premature failure may result due to flux-induced corrosion. Fluxes that are inactive at room temperature may not have to be cleaned off the part. However, if the part is to be painted or auto body filler is to be applied, fluxes must be removed.

**SOLDERING AND BRAZING METHODS**

**General**

Soldering and brazing methods are grouped according to the method with which heat is applied: torch, furnace, induction, dip, or resistance.
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Torch Soldering and Brazing

Oxyfuel or air-fuel torches can be used either manually or automatically, Figure 19-16. Acetylene is often used as the fuel gas, but it is preferable to use one of the other fuel gases having a higher heat level in the secondary flame, Figure 19-17. The oxyacetylene flame has a very high temperature near the inner cone, but it has little heat in the outer flame. This often results in the parts being overheated in a localized area. Such fuel gases as MAPP®, propane, butane, and natural gas have a flame that will heat parts more uniformly. Often torches are used that mix air with the fuel gas in a swirling or turbulent manner to increase the flame’s temperature, Figure 19-18. The flame may even completely surround a small diameter pipe, heating it from all sides at once, Figure 19-19.

Some advantages of using a torch include the following:

- Versatility—Using a torch is the most versatile method. Both small and large parts in a wide variety of materials can be joined with the same torch.
- Portability—A torch is very portable. Any place a set of cylinders can be taken or anywhere the hoses can be pulled into, can be soldered or brazed with a torch.

Some of the disadvantages of using a torch include the following:

- Speed—The flame of the torch is one of the quickest ways of heating the material to be joined, especially on thicker sections.
- Overheating—When using a torch, it is easy to overheat or burn the parts, flux, or filler metal.
- Skill—A high level of skill with a torch is required to produce consistently good joints.
- Fires—It is easy to start a fire if a torch is used around combustible (flammable) materials.

Furnace Soldering and Brazing

In this method the parts are heated to their soldering or brazing temperature by passing them through or putting them into a furnace. The furnace may be heated by electricity, oil, natural gas, or any other locally available fuel. The parts may be passed through the furnace on a conveyor belt in trays or placed on the belt itself, Figure 19-20. The parts may also be
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loaded in trays to be placed in a furnace that does not use a conveyor belt, Figure 19-21.

Some of the advantages of using a furnace include the following:

- Temperature control—The furnace temperature can be accurately controlled to ensure that the parts will not overheat.
- Controlled atmosphere—The furnace can be filled with an inert gas to prevent oxides from forming on the parts.
- Uniform heating—The uniform heating of the parts reduces stresses and distortion.
- Mass production—By using a furnace, it is easy to produce a high quantity of parts.

**FIGURE 19-18** Examples of torch tips and handles that use air-fuel mixtures for brazing. ESAB Welding & Cutting Products

**FIGURE 19-19** Heating characteristics of oxy MAPP® compared with oxyacetylene on round materials. © Cengage Learning 2012

**FIGURE 19-20** Furnace brazing permits the rapid joining of parts on a production basis. American Welding Society
Lack of temperature control—The electrical resistance of the part increases as the part heats up. This, in turn, increases the temperature produced.

Incomplete penetration—Because the inside of the part is not directly heated, it may be too cool to permit the filler metal to flow fully through the joint.

Dip Soldering and Brazing

Two types of dip soldering or brazing are used: molten flux bath and molten metal bath. With the molten flux method, the soldering or brazing filler metal in a suitable form is preplaced in the joint, and the assembly is immersed in a bath of molten flux, as shown in Figure 19-23. The bath supplies the heat needed to preheat the joint and fuse the solder or braze metal, and it provides protection from oxidation.

With the molten metal method, the prefluxed parts are immersed in a bath of molten solder or braze metal, which is protected by a cover of molten flux. This method is confined to wires and other small parts. Once they are removed from the bath, the ends of the wires and parts must not be allowed to move until the solder or braze metal has solidified. As with all soldering or brazing operations, any movement of the parts as they cool from a liquid through the paste range to become a solid will result in microfractures in the filler metal. In electronic parts these microfractures cause

The induction method of heating uses a high-frequency electrical current to establish a corresponding current on the surface of the part, Figure 19-22. The current on the part causes rapid and very localized heating of the surface only. There is little, if any, internal heating of the part except by conductivity of heat from the surface.

The advantage of the induction method is:

- Speed—Very little time is required for the part to reach the desired temperature.

Some of the disadvantages of the induction method include the following:

- Distortion—The very localized heating may result in some distortion.
Resistance Soldering and Brazing

The resistance method of heating uses an electric current that is passed through the part. The resistance of the part surfaces at the joint face to the current flow results in the heat needed to produce the bond. The flux and filler metal are usually preplaced.

The machine used in this method resembles a spot welder.

Some of the advantages of the resistance-heating method include the following:

- Localized heating—The heat can be localized so that the entire part may not get hot.
- Speed—A wide variety of spots can be made on the same machine without having to make major adjustments on the machine.
- Multiple spots—Many spots can be joined in a small area without disturbing joints that are already made.

Some of the disadvantages of the resistance-heating method include the following:

- Distortion—Localized heating may result in distortion.
- Conductors—Parts must be able to conduct electricity.
- Joint design—Lap joints in plate are the only joint designs that can be made.

Special Methods

A few other methods of producing soldered or brazed parts are used that do not entirely depend upon heat to produce the joint. The ultrasonic method uses high-frequency sound waves to produce the bond or to aid with heat in the bonding, Figure 19-24. Another process uses infrared light to heat the part for soldering or brazing.

FILLER METALS

General

The type of filler metal used for any specific joint should be selected by considering as many of the criteria listed in Figure 19-25 as possible. Welders must decide which factors they feel are most important and then base their selection on that decision.

Soldering and brazing metals are alloys—that is, a mixture of two or more metals. Each alloy is available
in a variety of percentage mixtures. Some mixtures are stronger, and some melt at lower temperatures than other mixtures. Each one has specific properties. Almost all of the alloys used for soldering or brazing have a paste range. A paste range is the temperature range in which a metal is partly solid and partly liquid as it is heated or cooled. As the joined part cools through the paste range, it is important that the part not be moved. If the part is moved, the solder or braze metal may crumble like dry clay, destroying the bond.

**EXPERIMENT 19-1**

**Paste Range**

This experiment shows the effect on bonding of moving a part as the filler metal cools through its paste range. The experiment also shows how metal can be “worked” using its paste range. You will need tin-lead solder composed of 20 to 50% tin, with the remaining percentage being lead. You also will need a properly lit and adjusted torch, a short piece of brazing rod, and a piece of sheet metal. Using a hammer, make a dent in the sheet metal about the diameter of a quarter (25¢), Figure 19-26.

In a small group, watch the effects of heating and cooling solder as it passes through the paste range. Using the torch, melt a small amount of the solder into the dent and allow it to harden. Remelt the solder slowly, frequently flashing the torch off and touching the solder with the brazing rod until it is evident that the solder has all melted. Once the solder has melted, stick the brazing rod in the solder and remove the torch. As the solder cools, move the brazing rod in the metal and observe what happens, Figure 19-27.

As the solder cools to the uppermost temperature of its paste range, it will have a rough surface appearance as the rod is moved. When the solder cools more, it will start to break up around the rod. Finally, as it becomes a solid, it will be completely broken away from the rod. Now slowly reheat the solder and work the surface with the rod until it can be shaped like clay. If the surface is slightly rough, a quick touch
Tin-lead solders are most commonly used on electrical connections, air-conditioning and refrigeration drain piping, and for architectural accents where good corrosion resistance is needed. Tin-lead solders must never be used for water piping. Most health and construction codes will not allow tin-lead solders for use on water or food handling equipment.

**CAUTION**

Tin-lead solders must not be used where lead could become a health hazard in things such as food and water.

### Tin-Antimony

This family of solder alloys has a higher tensile strength and lower creep than the tin-lead solders. The most common alloy is 95/5, 95% tin and 5% antimony. This is often referred to as “hard solder.” The use of “C” flux, which is a mixture of flux and small flakes of solder, makes it easier to fabricate quality joints. This mixture of flux and solder draws additional solder into the joint as it is added.

Tin-antimony solders are used for plumbing because they are lead-free and for refrigeration work.

### Tin-Antimony-Lead

Antimony is added to tin-lead solders in amounts up to 6% to increase the strength and mechanical properties of the alloy. Tin-antimony-lead solder alloys can be used when higher joint strength is required. However, the higher antimony content may form a very brittle joint if used on aluminum, zinc, or zinc-coated metals.

### Cadmium-Silver

These solder alloys have excellent wetting, flow, and strength characteristics, but they are expensive. The silver in this solder helps improve wetting and strength. Cadmium-silver alloys melt at a temperature of around 740°F (393°C); they are called high-temperature solders because they retain their strength at temperatures above most other solders. These solder alloys can be used to join aluminum to itself or other metals—for example, to piping that is used in air-conditioning equipment.
CAUTION
When silver soldering on food-handling equipment, use a cadmium-free silver solder.

CAUTION
If the cadmium is overheated, the fumes can be hazardous unless the area is properly ventilated.

Table 19-3  Melting, Solidification, and Paste Range Temperatures for Tin-Lead Solders

Cadmium-Zinc
Cadmium-zinc alloys have good wetting action and corrosion resistance on aluminum and aluminum alloys. The melting temperature is high, and some alloys have a wide paste range, Table 19-4.

Brazing Alloys
The American Welding Society’s classification system for brazing alloys uses the letter B to indicate that the alloy is to be used for brazing. The next series of letters in the classification indicates the atomic symbol

<table>
<thead>
<tr>
<th>Cadmium</th>
<th>Zinc</th>
<th>Completely Liquid</th>
<th>Completely Solid</th>
<th>Paste Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.5%</td>
<td>17.5%</td>
<td>509°F (265°C)</td>
<td>509°F (265°C)</td>
<td>No paste range</td>
</tr>
<tr>
<td>40.0%</td>
<td>60.0%</td>
<td>635°F (335°C)</td>
<td>509°F (265°C)</td>
<td>126°F (52°C)</td>
</tr>
<tr>
<td>10.0%</td>
<td>90.0%</td>
<td>750°F (399°C)</td>
<td>509°F (265°C)</td>
<td>241°F (116°C)</td>
</tr>
</tbody>
</table>

Table 19-4  Cadmium-Zinc Alloys
of metals used to make up the alloy, such as CuZn (copper and zinc). There may be a dash followed by a letter or number to indicate a specific alloyed percentage. The letter R may be added to indicate that the braze metal is in rod form. An example of a filler metal designation is BRCuZn-A, which indicates a copper-zinc brazing rod with 59.25% copper, 40% zinc, and 0.75% tin. Table 19-5 provides a list of the base metals and the most common alloys used to join the base metals. Not all of the available brazing alloys have an AWS classification. Some special alloys are known by registered trade names.

Copper-Zinc

Copper-zinc alloys are the most popular brazing alloys. They are available as regular and low-fuming alloys. The zinc in this braze metal has a tendency to burn out if it is overheated. Overheating is indicated by a red glow on the molten pool, which gives off a white smoke. The white smoke is zinc oxide. If zinc oxide is breathed in, it can cause zinc poisoning. Using a low-fuming alloy helps eliminate this problem. Examples of low-fuming alloys are RCuZn-B and RCuZn-C.

<table>
<thead>
<tr>
<th>Base Metal</th>
<th>Brazing Filler Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>BAisi, aluminum-silicon</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>BCuZn, brass (copper-zinc)</td>
</tr>
<tr>
<td></td>
<td>BCu, copper alloy</td>
</tr>
<tr>
<td></td>
<td>BAg, silver alloy</td>
</tr>
<tr>
<td>Alloy steel</td>
<td>BAg, silver alloy</td>
</tr>
<tr>
<td></td>
<td>BNI, nickel alloy</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>BAg, silver alloy</td>
</tr>
<tr>
<td></td>
<td>BAu, gold base alloy</td>
</tr>
<tr>
<td></td>
<td>BNI, nickel alloy</td>
</tr>
<tr>
<td>Cast iron</td>
<td>BCuZn, brass (copper-zinc)</td>
</tr>
<tr>
<td>Galvanized iron</td>
<td>BCuZn, brass (copper-zinc)</td>
</tr>
<tr>
<td>Nickel</td>
<td>BAu, gold base alloy</td>
</tr>
<tr>
<td></td>
<td>BAg, silver alloy</td>
</tr>
<tr>
<td></td>
<td>BNI, nickel alloy</td>
</tr>
<tr>
<td>Nickel-copper</td>
<td>BNI, nickel alloy</td>
</tr>
<tr>
<td></td>
<td>BAg, silver alloy</td>
</tr>
<tr>
<td>Copper</td>
<td>BCuZn, brass (copper-zinc)</td>
</tr>
<tr>
<td>Silicon-bronze</td>
<td>BCuZn, brass (copper-zinc)</td>
</tr>
<tr>
<td></td>
<td>BAg, silver alloy</td>
</tr>
<tr>
<td>Tungsten</td>
<td>BCuP, copper-phosphorus</td>
</tr>
</tbody>
</table>

Table 19-5 Base Metals and Common Brazing Filler Metals Used to Join the Base Metals

Copper-Zinc and Copper-Phosphorus A5.8

The copper-zinc filler rods are often grouped together and known as brazing rods. The copper-phosphorus rods are referred to as phos-copper. Both terms do not adequately describe the metals in this group. There are vast differences among the five major classifications of the copper-zinc filler metals, as well as among the five major classifications of the copper-phosphorus filler metals. The following material describes the five major classifications of copper-zinc filler rods.

Class BRCuZn is used for the same application as BCu fillers. The addition of 40% zinc (Zn) and 60% copper (Cu) improves the corrosion resistance and aids in this rod’s use with silicon-bronze, copper-nickel, and stainless steel.

Class BRCuZn-A is commonly referred to as naval brass and can be used to fuse weld naval brass. The addition of 17% tin (Sn) to the alloy adds strength and corrosion resistance. The same types of metal can be joined with this rod as could be joined with BRCuZn.

Class BRCuZn-B is a manganese-bronze filler metal. It has a relatively low melting point and is free flowing. This rod can be used to braze weld steel, cast iron, brass, and bronze. The deposited metal is higher than BRCuZn or BRCuZn-A in strength, hardness, and corrosion resistance.

Class BRCuZn-C is a low-fuming, high silicon (Si) bronze rod. It is especially good for general-purpose work due to the low-fuming characteristic of the silicon on the zinc.
Class BRCuZn-D is a nickel-bronze rod with enough silicon to be low fuming. The nickel gives the deposit a silver-white appearance and is referred to as white brass. This rod is used to braze and braze weld steel, malleable iron, and cast iron and for building up wear surfaces on bearings.

**Copper-Phosphorus**

This alloy is sometimes referred to as phos-copper. It is a good alloy to consider for joints where silver braze alloys may have been used in the past. Phos-copper has good fluidity and wettability on copper and copper alloys. The joint spacing should be from 0.001 in. (0.03 mm) to 0.005 in. (0.12 mm) for the strongest joints. Heavy buildup of this alloy may cause brittleness in the joint. Phosphorus forms brittle iron phosphide at brazing temperatures on steel. Copper-phos or copper-phos-silver should not be used on copper-clad fittings with ferrous substrates because the copper can easily be burned off, exposing the underlying metal to phosphorus embrittlement.

The copper-phosphorus (BCuP group) rods are used in air-conditioning applications and in plumbing to join copper piping. The phosphorus makes the rod self-fluxing on copper. This feature is one of the major advantages of copper-phosphorus rods. The addition of a small amount of silver, approximately 2%, helps with wetting and flow into joints.

Class BCuP-1 has a low-wetting characteristic and a lower flow rate than the other phos-copper alloys. This type of filler metal should be preplaced in the joint. The major advantage of this type of filler metal is its increased ductility.

Classes BCuP-2 and BCuP-4 both have good flow into the joint. The high phosphorus content of the rods makes them self-fluxing on copper. Both of these classes are used often for plumbing installations.

Classes BCuP-3 and BCuP-5 both have high surface tension and low flow so that they are used when close fit-ups are not available.

**Copper-Phosphorus-Silver**

This alloy is sometimes referred to as sil-phos. Its characteristics are similar to copper-phosphorus except the silver gives this alloy a little better wetting and flow characteristics. Often it is not necessary to use flux with alloys containing 5% or more of silver when joining copper pipe. This is the most common brazing alloy used in air-conditioning and refrigeration work. When sil-phos is used on air-conditioning compressor fittings that are copper-clad steel, care must be taken to make the braze quickly. If the fitting is heated too much or for too long, the copper cladding can be burned off. With this burn-off, the phosphorus can make the steel fitting very brittle, and embrittlement can cause the fitting to crack and leak sometime later.

**Silver-Copper**

Silver-copper alloys can be used to join almost any metal, ferrous or nonferrous, except aluminum, magnesium, zinc, and a few other low-melting metals. This alloy is often referred to as silver braze and is the most versatile. It is among the most expensive alloys, except for the gold alloys.

**Nickel**

Nickel alloys are used for joining materials that need high strength and corrosion resistance at an elevated temperature. Some applications of these alloys include joining turbine blades in jet engines, torch parts, furnace parts, and nuclear reactor tubing. Nickel will wet and flow acceptably on most metals. When used on copper-based alloys, nickel may diffuse into the copper, stopping its capillary flow.

**Nickel and Nickel Alloys A5.14**

Nickel and nickel alloys are increasingly used as a substitute for silver-based alloys. Nickel is generally more difficult to use than silver because it has lower wetting and flow characteristics. However, nickel has a much higher strength than silver.

Class BNi-1 is a high-strength, heat-resistant alloy that is ideal for brazing jet engine parts and for other similar applications.

Class BNi-2 is similar to BNi-1 but has a lower melting point and a better flow characteristic.

Class BNi-3 has a high flow rate that is excellent for large areas and close-fitted joints.

Class BNi-4 has a higher surface tension than the other nickel filler rods, which allows larger fillets and poor-fitted joints to be filled.
Class BNI-5 has a high oxidation resistance and high strength at elevated temperatures and can be used for nuclear applications.

Class BNI-6 is extremely free flowing and has good wetting characteristics. The high corrosion resistance gives this class an advantage when joining low chromium steels in corrosive applications.

Class BNI-7 has a high resistance to erosion and can be used for thin or honeycomb structures.

**Aluminum-Silicon**

BAlSi brazing filler metals can be used to join most aluminum sheet and cast alloys. The AWS type number 1 flux must be used when brazing aluminum. It is very easy to overheat the joint. If the flux is burned by overheating, it will obstruct wetting. Use standard torch brazing practices but guard against overheating.

**Copper and Copper Alloys A5.7**

Although pure copper (Cu) can be gas fusion welded successfully using a neutral oxyfuel flame without a flux, most copper filler metals are used to join other metals in a brazing process.

Class BCu-1 can be used to join ferrous, nickel, and copper-nickel metals with or without a flux. BCu-1 is also available as a powder that is classified as BCu-1a. This material has the same applications as BCu-1. The AWS type number 3B flux must be used with metals that are prone to rapid oxidation or with heavy oxides such as chromium, titanium, manganese, and others.

Class BCu-2 has applications similar to those for BCu-1. However, BCu-2 contains copper oxide suspended in an organic compound. Since copper oxides can cause porosity, tying up the oxides with the organic compounds reduces the porosity.

**Silver and Gold**

Silver and gold are both used in small quantities when joining metals that will be used under corrosive conditions, when high joint ductility is needed, or when low electrical resistance is important. Because of the ever-increasing price and reduced availability of these precious metals, other filler metals should first be considered. In many cases, other alloys can be used with great success. When substituting a different filler metal for one that has been used successfully, the new metal and joint should first be extensively tested.

### JOINT DESIGN

**General**

The spacing between the parts being joined greatly affects the tensile strength of the finished part. Table 19-6 lists the spacing requirements at the joining temperature for the most common alloys. As the parts are heated, the initial space may increase or decrease, depending upon the joint design and fixturing. The changes due to expansion can be calculated, but trial and error also works. The strongest joints are obtained when the parts use lap or scarf joints where the joining area is equal to three times the thickness of the thinnest joint member, Figure 19-28. The strength of a butt joint can be increased if the area being joined can be increased. Parts that are 1/4-in. (6-mm) thick should not be considered for brazing or soldering if another process will work successfully.

Some joints can be designed so that the flux and filler metal may be preplaced. When this is possible, visual checking for filler metal around the outside of the joint is easy. Evidence of filler metal around the outside is a good indication of an acceptable joint.

Joint cleaning is very important to a successful soldered or brazed part. The surface must be cleaned of all oil, dirt, paint, oxides, or any other contaminants. The surface can be mechanically cleaned by using a wire brush, sanding, sandblasting, grounding,
scraping, or filing. It can be cleaned chemically with an acid, alkaline, or salt bath.

Soldering or brazing should start as soon as possible after the parts are cleaned to prevent any additional contamination of the joint.

**EXPERIMENT 19-2**

**Fluxing Action**

In this experiment, as part of a small group, you will observe oxide removal by a flux as the flux reaches its effective temperature. For this experiment, you need a piece of copper, either tubing or sheet, rosin or C-flux, and a properly lit and adjusted torch.

Any paint, oil, or dirt must first be removed from the copper. Do not remove the oxide layer unless it is blue-black in color. Put some flux on the copper and start heating it with the torch. When the flux becomes active, the copper that is covered by the flux will suddenly change to a bright coppery color. The copper that is not covered by the flux will become darker and possibly turn blue-black, Figure 19-29. Continue heating the copper until the flux is burned off and the once clean spot quickly builds an oxide layer.

Repeat this experiment, but this time hold the torch further from the metal's surface. When the flux begins to clean the copper, flash the torch off the metal (quickly move the flame off and back onto the same spot). Try to control the heat so that the flux does not burn off.

**EXPERIMENT 19-3**

**Tinning or Phase Temperature**

In this experiment, as part of a small group, you will observe the wetting of a piece of metal by a filler metal. For this experiment, you will need one piece of 16-gauge mild steel, BRCuZn filler metal rod, powdered flux, and a properly lit and adjusted torch.

Place the sheet flat on a firebrick. Heat the end of the rod and dip it in the flux so that some flux sticks on the rod, Figure 19-30A, Figure 19-30B,
and Figure 19-30C. BRCuZn brazing rods are available as both bare rods and prefluxed, Figure 19-30D. Direct the flame onto the plate. When the sheet gets hot, hold the brazing rod in contact with the sheet, directing the flame so that a large area of the sheet is dull red and the rod starts to melt, Figure 19-31. After a molten pool of braze metal is deposited on the sheet, remove the rod and continue heating the sheet and molten pool until the braze metal flows out. Repeat this experiment until you can get the braze metal to flow out in all directions equally at the same time.
Brazing and soldering are processes that have many great advantages but are often overlooked when a joining process is being selected. For example, brazing and soldering are excellent processes for portable applications. In addition, their versatility makes them great choices for many jobs in which good joint design will result in joint strength equal to or higher than that of welding. The ability to join many different materials with a limited variety of fluxes and filler metals reduces the need for a large inventory of materials, which can result in great cost savings for a small business, home shop, or farm.

For example, solder can be used on the threads of a bolt on an off-road vehicle to act as a locknut to keep it from vibrating off. To remove the nut, one need only heat the threads, and it unscrews easily. Soldering can then be either a permanent or a temporary attaching process.

Be creative in the way you apply these processes. They can be very beneficial to you and your employer.

**REVIEW QUESTIONS**

1. What is the temperature difference between soldering and brazing?
2. Discuss three advantages of soldering and brazing over other methods of joining.
3. What is the difference between brazing and braze welding?
4. Define tensile strength.
5. What does the amount of shear strength of a brazed joint depend on?
6. Explain how ductility and fatigue resistance would be important qualities to have on the brazed joints of a mountain bike.
7. What determines the corrosion resistance of a joint?
8. List three functions flux has when used in soldering and brazing.
9. What happens if fluxes are overheated?
10. Name five methods by which heat is applied when soldering or brazing.
11. Which heating method would be best for the following situations:
   a. The temperature must be closely controlled so that the parts do not overheat.
   b. A thick section must be heated the quickest way.
   c. A large quantity of small parts must be joined.
   d. It is important that the interior of the part not be heated.
12. What factors should be considered when choosing the type of filler metal for a specific joint?
13. Where must tin-lead solder never be used?
14. What type of solder is used for plumbing and why is it used?
15. Why is silver added to cadmium-silver brazing alloys?
16. Explain what the letters represent in the American Welding Society’s classification system for brazing alloys.
17. What would a common use be for the following brazing alloys?
   a. BRCuZn-A
   b. BRCuZn-D
   c. BCuP
   d. BNi-1
   e. BAlSi
18. How much overlap should a joint have to maximize its strength?
19. What joint preparation is needed for a successful soldered or brazed part?