# CHAPTER 12

# BRAZING

**PREPARED BY A COMMITTEE CONSISTING OF:**

M. J. Lucas, Chairman
*General Electric Corporation*

R. L. Peaslee
*Wall Colmonoy Corporation*

**WELDING HANDBOOK COMMITTEE MEMBER:**
M. J. Tomsic
*Plastronic, Inc.*

## CHAPTER 12

# BRAZING

## INTRODUCTION

### DEFINITION AND GENERAL DESCRIPTION

BRAZING JOINS MATERIALS by heating them in the presence of a filler metal having a liquidus above 840°F (450°C) but below the solidus of the base metals. Heating may be provided by a variety of processes. The filler metal distributes itself between the closely fitted surfaces of the joint by capillary action. Brazing differs from soldering, in that soldering filler metals have a liquidus below 840°F (450°C).

Brazing with silver alloy filler metals is sometimes called *silver soldering*, a nonpreferred term. Silver brazing filler metals are not solders; they have liquidus temperatures above 840°F (450°C).

Brazing does not include the process known as braze welding. Braze welding is a method of welding with a brazing filler metal. In braze welding, the filler metal is melted and deposited in grooves and fillets exactly at the points where it is to be used. Capillary action is not a factor in distribution of the brazing filler metal. Indeed, limited base metal fusion may occur in braze welding. Braze welding is described in greater detail beginning on page 414.

Brazing must meet each of three criteria:

(1) The parts must be joined without melting the base metals.

(2) The filler metal must have a liquidus temperature above 840°F (450°C).

(3) The filler metal must wet the base metal surfaces and be drawn into or held in the joint by capillary action.

To achieve a good joint using any of the various brazing processes described in this chapter, the parts must be properly cleaned and must be protected by either flux or atmosphere during the heating process to prevent excessive oxidation. The parts must be designed to afford a capillary for the filler metal when properly aligned, and a heating process must be selected that will provide the proper brazing temperature and heat distribution.

### APPLICATIONS

THE BRAZING PROCESS is used to join together various materials for numerous reasons. By using the proper joint design, the resulting braze can function better than the base metals being joined. In many instances it is desireable to join different materials to obtain the maximum benefit of both materials and have the most cost- or weight-effective joint. Applications of brazing cover the entire manufacturing arena from inexpensive toys to highest quality aircraft engines and aerospace vehicles. Brazing is used because it can produce results which are not always available with other joining processes. Advantages of brazing to join components include:

(1) Economical for complex assemblies
(2) Simple way to join large joint areas
(3) Excellent stress and heat distribution
(4) Ability to preserve coatings and claddings
(5) Ability to join dissimilar materials
(6) Ability to join nonmetals to metals
(7) Ability to join widely different thicknesses
(8) Capability of joining precision parts
(9) Joints require little or no finishing
(10) Can do many parts at one time (batch processing)

Throughout this chapter, examples of brazing illustrate when to select brazing and how to design the joint and select braze materials best suited for the individual application.

### PROCESS ADVANTAGES AND DISADVANTAGES

LIKE ANY JOINING process, brazing has both advantages and disadvantages. The advantages vary with the heating method employed, but in general, brazing will be very economical when done in large batches. A major benefit of brazing is the ability to take brazed joints apart at a later time. It can also join dissimilar metals without melting the base metals as required by other joining methods. In many instances, several hundred parts with many feet of braze joints can be brazed at one time. When protective atmosphere brazing is used, parts are kept clean and the heat treatment cycle may be employed as part of the brazing cycle.

Since the brazing process uses a molten metal to flow between the materials to be joined, there is the possibility of liquid metal interactions which are unfavorable. Depending on the material combinations involved and the thickness of the base sheets, base metal erosion may occur. In many cases, the erosion may be of little consequence, but when brazing heavily loaded or thin materials, the erosion can weaken the joint and make it unsatisfactory for its intended application. Also, the formation of brittle intermetallics or other phases can make the resulting joint too brittle to be acceptable.

A disadvantage with some of the manual brazing processes is that highly skilled technicians are required to perform the operation. This is especially true for gas torch brazing using a high melting point brazing filler metal.

Nevertheless, with the proper joint design, brazing filler metal, and process selection, a satisfactory brazing technique can be developed for most joining applications where it is not feasible to join the materials with a fusion welding process because of strength or economic considerations.

### PRINCIPLES OF OPERATION

CAPILLARY FLOW IS the dominant physical principle that assures good brazements whenever both faying surfaces to be joined are wet by the molten filler metal. The joint must be spaced to permit efficient capillary action and resulting coalescence. More specifically, capillarity is a result of surface tension between base metal(s) and filler metal, protected by a flux or atmosphere, and promoted by the contact angle between base metal and filler metal. In actual practice, brazing filler metal flow is influenced by dynamic considerations involving fluidity, viscosity, vapor pressure, gravity, and especially the effects of metallurgical reactions between filler metal and base metal.

The typical brazed joint has a relatively large area and very small gap. In the simplest brazing application, the surfaces to be joined are cleaned to remove contaminants and oxides. Next, they are coated with flux. A flux is a material which is capable of dissolving solid metal oxides and also preventing new oxidation. The joint area is then heated until the flux melts and cleans the base metals, which are protected against further oxidation by the layer of liquid flux.

Brazing filler metal is then melted at some point on the surface of the joint area. Capillary attraction between the base metal and the filler metal is much higher than that between the base metal and the flux. Accordingly, the flux is displaced by the filler metal. The joint, upon cooling to room temperature, will be filled with solid filler metal, and the solid flux will be found on the joint periphery.

Joints to be brazed are usually made with clearances of 0.001 to 0.010 in. (0.025 to 0.25 mm). The fluidity of the filler metal, therefore, is an important factor. High fluidity is a desirable characteristic of brazing filler metal since capillary action may be insufficient to draw a viscous filler metal into closely fitted joints.

Brazing is sometimes done under an active gas, such as hydrogen, or in an inert gas or vacuum. Atmosphere brazing eliminates the necessity for post cleaning and insures absence of corrosive mineral flux residue. Carbon steels, stainless steels, and superalloy components are widely processed in atmospheres of reacted gases, dry hydrogen, dissociated ammonia, argon, or vacuum. Large vacuum furnaces are used to braze zirconium, titanium, stainless steels, and the refractory metals. With good processing procedures, aluminum alloys can also be vacuum furnace brazed with excellent results.

Brazing is economically attractive for the production of high strength metallurgical bonds while preserving desired base metal properties.

## BRAZING PROCESSES

BRAZING PROCESSES ARE customarily designated according to the sources or methods of heating. Industrial methods currently significant are the following:

(1) Torch brazing
(2) Furnace brazing
(3) Induction brazing
(4) Resistance brazing
(5) Dip brazing
(6) Infrared brazing

Whatever the process used, the filler metal has a melting point above 840°F (450°C), but below that of the base metal, and it spreads within the joint by capillary action.

### TORCH BRAZING

TORCH BRAZING IS accomplished by heating with one or more gas torches.[1] Depending upon the temperature and

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[1] Chapter 11 contains information on gas torches used for welding and brazing.

the amount of heat required, the fuel gas (acetylene, propane, city gas, etc.) may be burned with air, compressed air, or oxygen. Manual torch brazing is shown in Figure 12.1.

Air-natural gas torches provide the lowest flame temperature as well as the least heat. Acetylene under pressure is used in the air-acetylene torch with air at atmospheric pressure. Both air-natural gas and air-acetylene torches can be used to advantage on small parts and thin sections.

Torches which employ oxygen with natural gas, or other cylinder gases (propane, butane) have higher flame temperatures. When properly applied as a neutral or slightly reducing flame, excellent results are obtainable with many brazing applications.

Oxyhydrogen torches are often used for brazing aluminum and nonferrous alloys. The lower temperature reduces the possibility of overheating the assembly during brazing. An excess of hydrogen provides the joint with additional cleaning and protection.

Specially designed torches having multiple tips or multiple flames can be used to an advantage to increase the rate of heat input. Care must be exercised to avoid local overheating by constantly moving the torch with respect to the work.

For manual torch brazing, the torch may be equipped with a single tip, either single- or multiple-flame. Manual torch brazing is particularly useful on assemblies involving sections of unequal mass. Machine operations can be set up, where the rate of production warrants, using one or more torches equipped with single or multiple-flame tips. The machine may be designed to move either the work or the torches, or both. For premixed city gas and air flames, a refractory type burner is used.

**Figure 12.1–Manual Torch Brazing**

Torch heating for brazing is limited in use to filler metals supplied with flux or self-fluxing. The list includes aluminum-silicon, silver, copper-phosphorus, copper-zinc, and nickel. With the exception of the copper-phosphorus filler metals, they all require fluxes. For certain applications even the self-fluxing copper-phosphorus filler metals require added flux, as shown in Table 12.1.

The filler metal can be preplaced on the joint and fluxed before heating, or it may be face- fed. Heat is applied to the joint, first melting the flux, then continuing until the brazing filler metal melts and flows into the joint. Overheating of the base metal and brazing filler metal should be avoided because rapid diffusion and "drop through" of the metal may result. Natural gas is well suited for torch brazing because its relatively low flame temperature reduces the danger of overheating.

Brazing filler metal may be preplaced at the joint in the forms of rings, washers, strips, slugs, or powder, or it may be fed from hand-held filler metal, usually in the form of wire or rod. In any case, proper cleaning and fluxing are essential.

Torch brazing techniques differ from those used for oxyfuel gas welding. Operators experienced only in welding techniques may require instruction in brazing techniques. It is good practice, for example, to prevent the inner cone of the flame from coming in contact with the joint except during preheating, since melting of the base metal and dilution with the filler metal may increase its liquidus temperature and make the flow more sluggish. In addition, the flux may be overheated and thus lose its ability to promote capillary flow, and low melting constituents of the filler metal may evaporate.

## FURNACE BRAZING

FURNACE BRAZING, AS illustrated in Figure 12.2, is used extensively when (1) the parts to be brazed can be preassembled or jigged to hold them in the correct position, (2) the brazing filler metal can be placed in contact with the joint, (3) multiple brazed joints are to be formed simultaneously on a completed assembly, (4) many similar assemblies are to be joined, and (5) complex parts must be heated uniformly to prevent the distortion that would result from local heating of the joint area.

Electric, gas, or oil heated furnaces with automatic temperature control capable of holding the temperature within ±10°F (±6°C) should be used for furnace brazing. Fluxes or specially controlled atmospheres that perform fluxing functions must be provided.

Parts to be brazed should be assembled with the filler metal and flux, if used, located in or around the joints. The

### Table 12.1
### Classification of Brazing Fluxes with Brazing or Braze Welding Filler Metals

| Classification* | Form | Filler Metal Type | Activity Temperature Range °F | Activity Temperature Range °C |
|---|---|---|---|---|
| FB1-A | Powder | BA1Si | 1080-1140 | 580-615 |
| FB1-B | Powder | BA1Si | 1040-1140 | 560-615 |
| FB1-C | Powder | BA1Si | 1000-1140 | 540-615 |
| FB2-A | Powder | BMg | 900-1150 | 480-620 |
| FB3-A | Paste | BAg and BCuP | 1050-1600 | 565-870 |
| FB3-C | Paste | BAg and BCuP | 1050-1700 | 565-925 |
| FB3-D | Paste | BAg, BCu, BNi, BAu and RBCuZn | 1400-2200 | 760-1205 |
| FB3-E | Liquid | BAg and BCup | 1050-1600 | 565-870 |
| FB3F | Powder | BAg and BCuP | 1200-1600 | 650-870 |
| FB3G | Slurry | BAg and BCuP | 1050-1600 | 565-870 |
| FB3-H | Slurry | BAg | 1050-1700 | 565-925 |
| FB3-I | Slurry | BAg, BCu, BNi, BAu and RBCuZn | 1400-2200 | 760-1205 |
| FB3-J | Powder | BAg, BCu, BNi, BAu and RBCuZn | 1400-2200 | 760-1205 |
| FB3-K | Liquid | BAg and RBCuZn | 1400-2200 | 760-1205 |
| FB4-A | Paste | BAg and BCuP | 1100-1600 | 595-870 |

* Flux 3B shown in the Brazing Manual, 3rd Edition, 1976 has been discontinued. Type 3B has been divided into types FB3C and FB3D.

Note: The selection of a flux designation for a specific type of work may be based on the form, the filler metal type, and the description above, but the information here is generally not adequate for flux selection. Refer to the latest issue of the Brazing Manual for further assistance.

preplaced filler metal may be in the form of wire, foil, filings, slugs, powder, paste, or tape. The assembly is heated in the furnace until the parts reach brazing temperature and brazing takes place. The assembly is then removed. These steps are shown in Figure 12.2. A laboratory setup for induction brazing in vacuum is shown in Figure 12.3. Many commercial fluxes are available for both general and specific brazing operations. Satisfactory results are obtained if dry powdered flux is sprinkled along the joint. Flux paste is satisfactory in most cases, but in some cases it retards the flow of brazing alloy. Flux pastes containing water can be dried by heating the assembly at 350 to 400°F (175 to 200°C) for 5 to 15 minutes in drying ovens or circulating air furnaces.

Brazing time will depend somewhat on the thickness of the parts and the amount of fixturing necessary to position them. The brazing time should be restricted to that necessary for the filler metal to flow through the joint to avoid excessive interaction between the filler metal and base metal. Normally, one or two minutes at the brazing temperature is sufficient to make the braze. A longer time at the brazing temperature will be beneficial where the filler metal remelt temperature is to be increased and where diffusion will improve joint ductility and strength. Times of 30 to 60 minutes at the brazing temperature are often used to increase the braze remelt temperature.

Furnaces used for brazing are classified as (1) batch type with either air or controlled atmosphere, (2) continuous type with either air or controlled atmosphere, (3) retort type with controlled atmosphere, or (4) vacuum. A high temperature, high vacuum brazing furnace with control panel and charging carriage is shown in Figure 12.3. Most brazing furnaces have a temperature control of the potentiometer type connected to thermocouples and gas control valves or contactors. The majority of furnaces are heated by electrical resistance using silicon-carbide, nickel-chromium, or refractory metal (Mo, Ta, W) heating elements. When a gas or oil flame is used for heating, the flame must not impinge directly on the parts.

With controlled atmosphere furnaces, a continuous flow of the atmosphere gas is maintained in the work zone to avoid contamination from outgassing of the metal parts and dissociation of oxides. If the controlled atmosphere is flammable or toxic, adequate venting of the work area and protection against explosion are necessary.

Batch type furnaces heat each workload separately. They may be top loading (pit type), side loading, or bottom loading. When a furnace is lowered over the work, it is called a *bell furnace*. Gas or oil fired batch type furnaces without retorts require that flux be used on the parts for brazing. Electrically heated batch type furnaces are often equipped for controlled atmosphere brazing, since the heating elements can usually be operated in the controlled atmosphere.

Continuous furnaces receive a steady flow of incoming assemblies. The heat source may be gas or oil flames, or

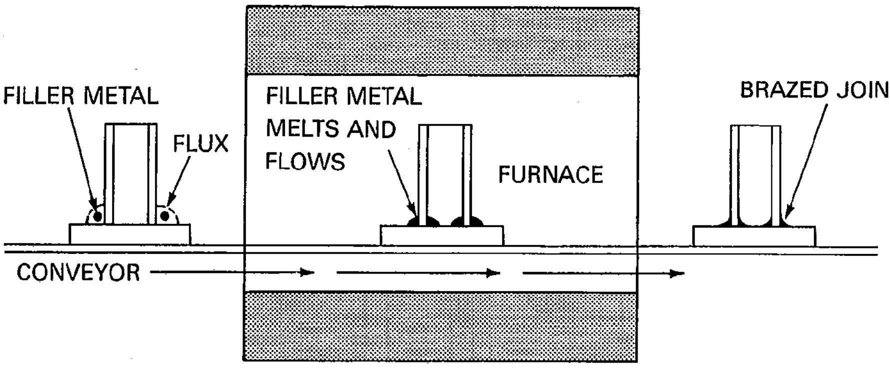

**Figure 12.2–Illustration of Furnace Brazing Operation**

electrical heating elements. The parts move through the furnace either singly or in trays or baskets. Conveyor types (mesh belts or roller hearth), shaker hearth, pusher, or slot type continuous furnaces are commonly used for high production brazing. Continuous furnaces usually contain a preheat or purging area which the parts enter first. In this area, the parts are slowly brought to a temperature below the brazing temperature. If brazing atmosphere gas is used in the brazing zone it also flows over and around the parts in the preheat zone, under positive pressure. The gas flow removes any entrapped air and starts the reduction of surface oxides. Atmosphere gas trails the parts into the cooling zone.

Retort type furnaces are batch furnaces in which the assemblies are placed in a sealed retort for brazing. The air in the retort is purged by controlled atmosphere gas and the retort is placed in the furnace. After the parts have been brazed, the retort is removed from the furnace, cooled, and its controlled atmosphere is purged. The retort is opened, and the brazed assemblies are removed. A protective atmosphere is sometimes used within a high temperature furnace to reduce external scaling of the retort.

Vacuum furnace brazing is widely used in the aerospace and nuclear fields, where reactive metals are joined or where entrapped fluxes would be intolerable. If the vacuum atmosphere is maintained by continuous pumping, it will remove volatile constituents liberated during brazing.

Vacuum brazing equipment is currently used to a large extent to braze stainless steels, superalloys, aluminum alloys, titanium alloys, and metals containing refractory or reactive elements. Vacuum is a relatively economical "atmosphere" which prevents oxidation by removing air from around the assembly. Surface cleanliness is nevertheless required for good wetting and flow. Base metals containing chromium and silicon can be vacuum brazed. Base metals that can generally be brazed only in vacuum are those containing more than a few percent of aluminum, titanium, zirconium, or other elements with particularly stable oxides. However, a nickel plated barrier is still preferred to obtain optimum quality.

Vacuum brazing furnaces are of three types:

(1) *Hot retort, or single pumped retort furnace.* This is a sealed retort, usually of fairly thick metal. The retort with work loaded inside is sealed, evacuated, and heated from the outside by a furnace. Most brazing work requires vacuum pumping continuously throughout the heat cycle to remove gases being given off by the workload. The furnaces are gas fired or electrical. The retort size and its maximum operating temperature are limited by the ability of the retort to withstand the collapsing force of atmospheric pressure at brazing temperature. Top temperature for vacuum brazing furnaces of this type is about 2100°F (1150°C).

Argon, nitrogen, or other gas is often introduced into the retort to accelerate cooling after brazing.

(2) *Double pumped or double wall hot retort vacuum furnace.* The typical furnace of this type has an inner retort containing the work, within an outer wall or vacuum chamber. Also within the outer wall are the thermal insulation and electrical heating elements. A moderately reduced pressure, typically 1.0 to 0.1 torr (133 to 13.3 Pa), is maintained within the outer wall, and a much lower pressure, below $10^{-2}$ torr (1.3 Pa), within the inner retort. Again most brazing requires continuous vacuum pumping of the inner retort throughout the heat cycle to remove gases given off by the workload.

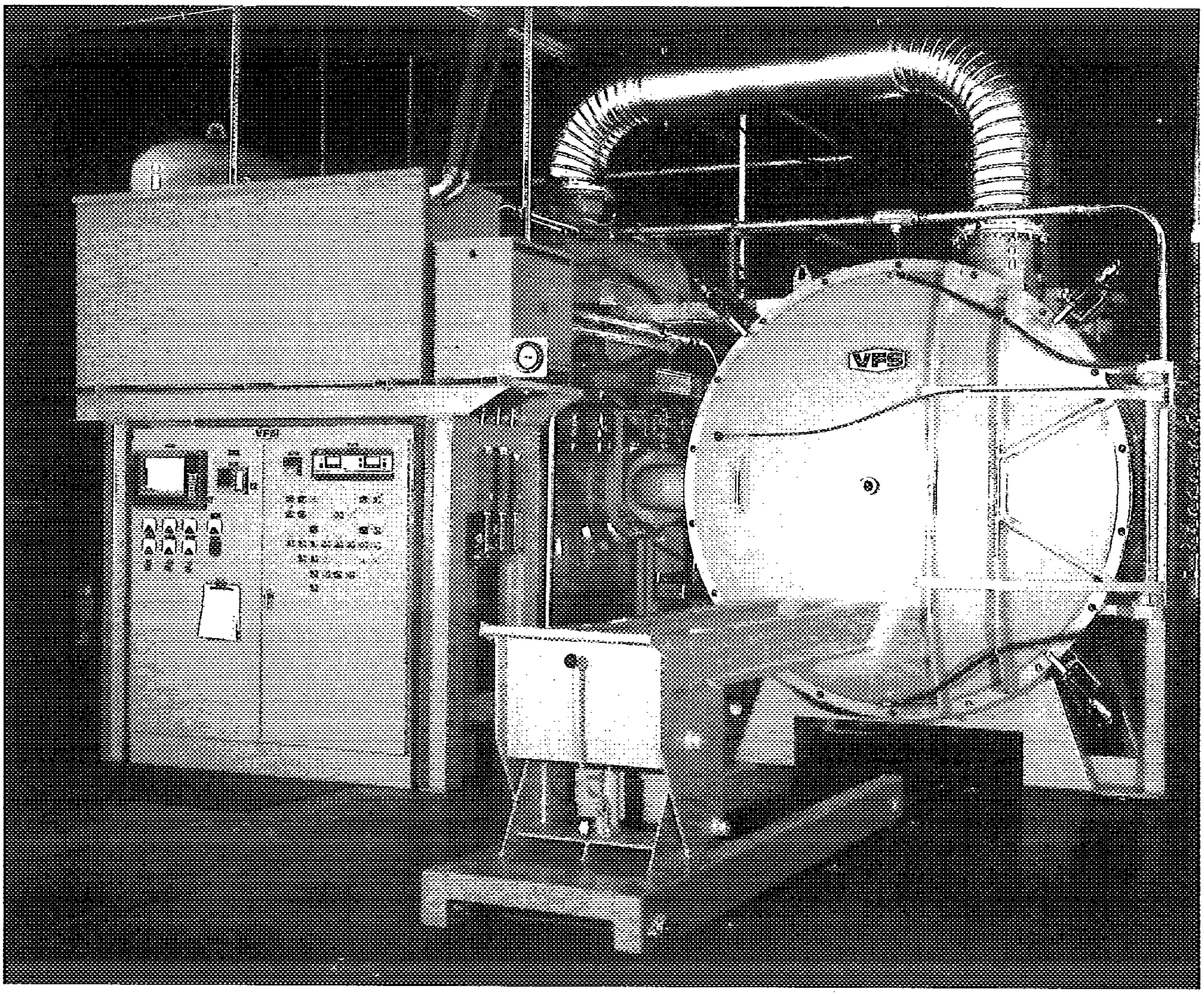

**Figure 12.3—A High Temperature, High Vacuum Brazing Furnace with Control Panel and Charging Dolly**

In this type of furnace, the heating elements and the thermal insulation are not subjected to the high vacuum. Heating elements are typically of nickel-chromium alloy, graphite, stainless steel, or silicon carbide materials. Thermal insulation is usually silica or alumina brick, or castable or fiber materials.

(3) *Cold wall vacuum furnace.* A typical cold wall vacuum furnace has a single vacuum chamber, with thermal insulation and electrical heating elements located inside the chamber. The vacuum chamber is usually water cooled. The maximum operating temperature is determined by the materials used for the thermal insulation (the heat shield) and the heating elements, which are subjected to the high vacuum as well as the operating temperature of the furnace.

Heating elements for cold wall furnaces are usually made of high temperature, low vapor pressure materials, such as molybdenum, tungsten, graphite, or tantalum. Heat shields are typically made of multiple layers of molybdenum, tantalum, nickel, or stainless steel. Thermal insulation may be high purity alumina brick, graphite, or alumina fibers sheathed in stainless steel. The maximum operating temperature and vacuum obtainable with cold wall vacuum furnaces depends on the heating element material and the thermal insulation or heat shields. Temperatures up to 4000°F (2200°C) and pressures as low as $10^{-6}$ torr ($1.33 \times 10^{-4}$ Pa) are obtainable.

Configurations for all three types of furnaces include side loading (horizontal), bottom loading, and top loading (pit type). Work zones are usually rectangular for side loading furnaces, and circular for bottom and top loading types.

Vacuum pumps for brazing furnaces may be oil sealed mechanical types for pressures from 0.1 to 10 torr (13 to 1300 Pa). Brazing of base metals containing chromium, silicon, or other rather strong oxide formers usually requires pressures of $10^{-2}$ to $10^{-3}$ torr (1.3 to 0.13 Pa), which are best obtained with a high-speed, dry Roots, or turbo-mechanical type pump. Vacuum pumps of this type are not capable of exhausting directly to atmosphere and require a roughing vacuum pump.

Brazing of base materials containing more than a few percent of aluminum, titanium, zirconium, which form very stable oxides, requires vacuum of $10^{-3}$ torr (0.13 Pa) or lower. Vacuum furnaces for such brazing usually require a diffusion pump that will obtain pressures of $10^{-2}$ to $10^{-6}$ torr (1.3 to 0.0001 Pa). The diffusion pump is backed by a mechanical vacuum pump or by both a Roots-type pump and a mechanical pump.

## INDUCTION BRAZING

THE HEAT FOR brazing with this process is obtained from an electric current induced in the parts to be brazed, hence the name *induction brazing.* For induction brazing, the parts are placed in or near a water-cooled coil carrying alternating current. They do not form a part of the electrical circuit. Parts to be heated act as the short circuited secondary of a transformer where the work coil, which is connected to the power source, is the primary. On both magnetic and nonmagnetic parts, heating is obtained from the resistance of the parts to currents induced in them by the transformer action. See Figure 12.4.

The brazing filler metal is preplaced. Careful design of the joint and the coil setup are necessary to assure that the surfaces of all members of the joint reach the brazing temperature at the same time. Flux is employed except when an atmosphere is specifically introduced to perform the same function.

Frequencies for induction brazing generally vary from 10 KHz to 450 khz. The lower frequencies are obtained with solid-state generators and the higher frequencies with vacuum tube oscillators. Induction generators are manufactured in sizes from one kilowatt to several hundred kilowatts output. Various induction brazing coil designs are illustrated in Figure 12.5. One generator may be used to energize several individual workstations in sequence, using a transfer switch, or assemblies in holding fixtures may be indexed or continuously processed through a conveyor-type coil for heating to brazing temperature.

Induction brazing is used when very rapid heating is required. Time for processing is usually in the range of seconds when large numbers of parts are handled automatically. Induction brazing has been used extensively to produce consumer and industrial products; structural assemblies; electrical and electronic products; mining, machine, and hand tools; military and ordnance equipment; and aerospace assemblies. An aerospace application of vacuum induction brazing is shown in Figure 12.6.

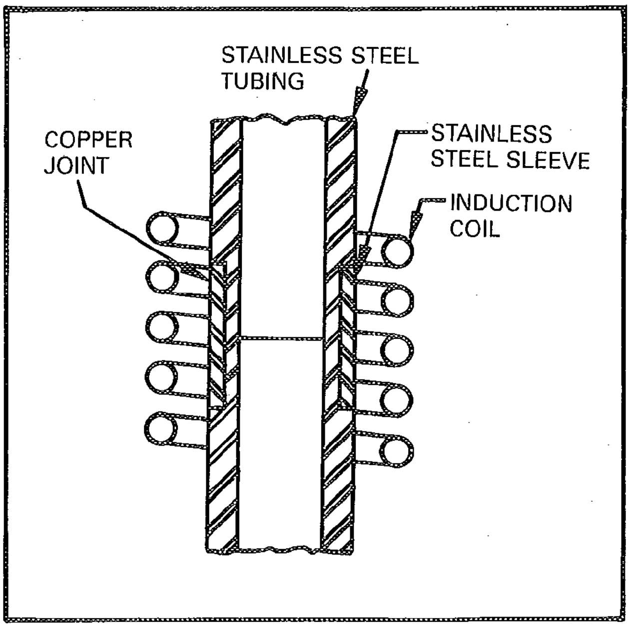

**Figure 12.4—Joint in Stainless Steel Tubing Induction Brazed in a Controlled Atmosphere. Note Placement of Joint in Induction Coil.**

Assemblies may be induction brazed in a controlled atmosphere by placing the components and coil in a nonmetallic chamber, or by placing the chamber and work inside the coil. The chamber can be quartz Vycor or tempered glass. A dual station bell jar fixture of this type is shown in Figure 12.7.

## RESISTANCE BRAZING

THE HEAT NECESSARY for resistance brazing is obtained from the flow of an electric current through the electrodes and the joint to be brazed. The parts comprising the joint become part of the electric circuit. The brazing filler metal, in some convenient form, is preplaced or face-fed. Fluxing is done with due attention to the conductivity of the fluxes. (Most fluxes are insulators when dry.) Flux is employed except when an atmosphere is specifically introduced to perform the same function. The parts to be brazed are held between two electrodes, and proper pressure and current are applied. The pressure

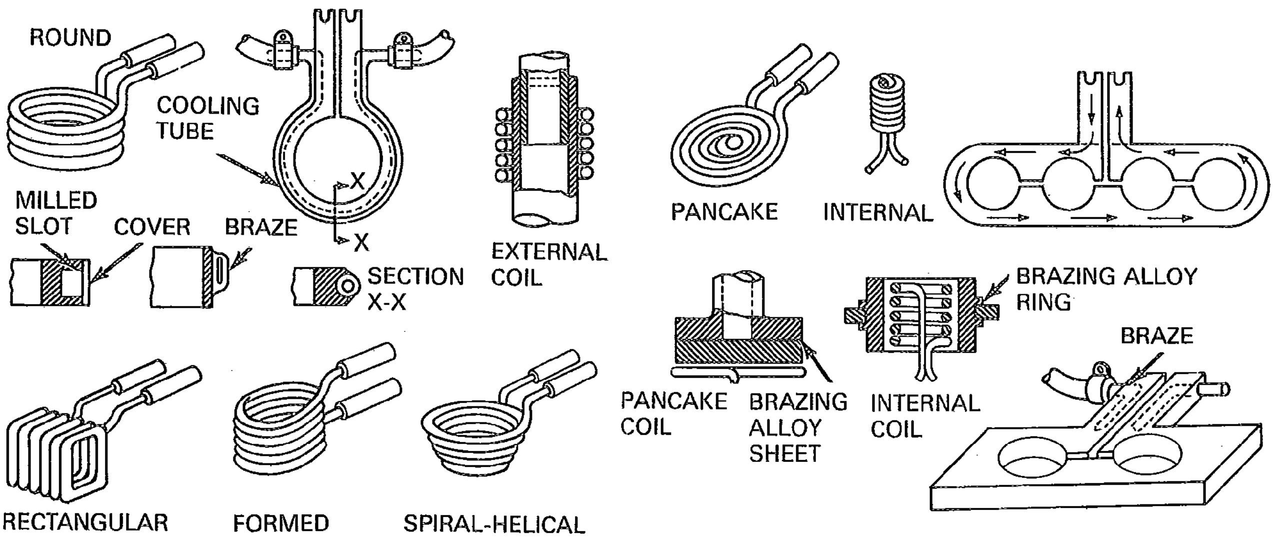

**Figure 12.5—Typical Induction Brazing Coils and Plates**

should be maintained until the joint has solidified. In some cases, both electrodes may be located on the same side of the joint with a suitable backing to maintain the required pressure.

Brazing filler metal is used in the form of preplaced wire, shims, washers, rings, powder, or paste. In a few instances, face feeding is possible. For copper and copper alloys, the copper-phosphorus filler metals are most satisfactory since they are self-fluxing. Silver base filler metals may be used, but a flux or atmosphere is necessary. A wet flux is usually applied as a very thin mixture just before the assembly is placed in the brazing fixture. Dry fluxes are not used because they are insulators and will not permit sufficient current to flow.

The parts to be brazed must be clean. The parts, brazing filler metal, and flux are assembled and placed in the fixture and pressure applied. As current flows, the electrodes become heated, frequently to incandescence, and the flux and filler metal melt and flow. The current should be adjusted to obtain uniform rapid heating in the parts. Overheating risks oxidizing or melting the work, and the electrodes will deteriorate. Too little current lengthens the time of brazing. Experimenting with electrode compositions, geometry, and voltage will give the best combination of rapid heating with reasonable electrode life.

Quenching the parts from an elevated temperature will help flux removal. The assembly first must cool sufficiently to permit the braze to hold the parts together. When brazing insulated conductors it may be advisable to quench the parts rapidly while they are still in the electrodes to prevent overheating of the adjacent insulation. Water-cooled clamps prevent damage to the insulation.

Resistance brazing is most applicable to joints which have a relatively simple configuration. It is difficult to obtain uniform current distribution, and therefore uniform heating, if the area to be brazed is large or discontinuous or is much longer in one dimension. Parts to be resistance brazed should be so designed that pressure may be applied to them without causing distortion at brazing temperature. Wherever possible, the parts should be designed to be self-nesting, which eliminates the need for dimensional features in the fixtures. Parts should also be free to move as the filler metal melts and flows in the joint.

The equipment consists of tongs or clamps with the electrodes attached at the end of each arm. The tongs should preferably be water cooled to avoid overheating. The arms are current-carrying conductors attached by leads to a transformer.

One common source of current for resistance brazing is a stepdown transformer whose secondary circuit can furnish sufficient current at low voltage (2-25 V). The current will range from about 50 A for small, delicate jobs to many thousands of amperes for larger jobs. Commercial equipment is available for resistance brazing.

Electrodes for resistance brazing are made of high resistance electrical conductors, such as carbon or graphite blocks, tungsten or molybdenum rods, or even steel in some instances. The heat for brazing is mainly generated in the electrodes and flows into the work by conduction. It is generally unsatisfactory to attempt to use the resistance of the workpieces alone as a source of heat.

The pressure applied by a spot welding machine, clamps, pliers, or other means must be sufficient to maintain good electrical contact and to hold the pieces firmly together as

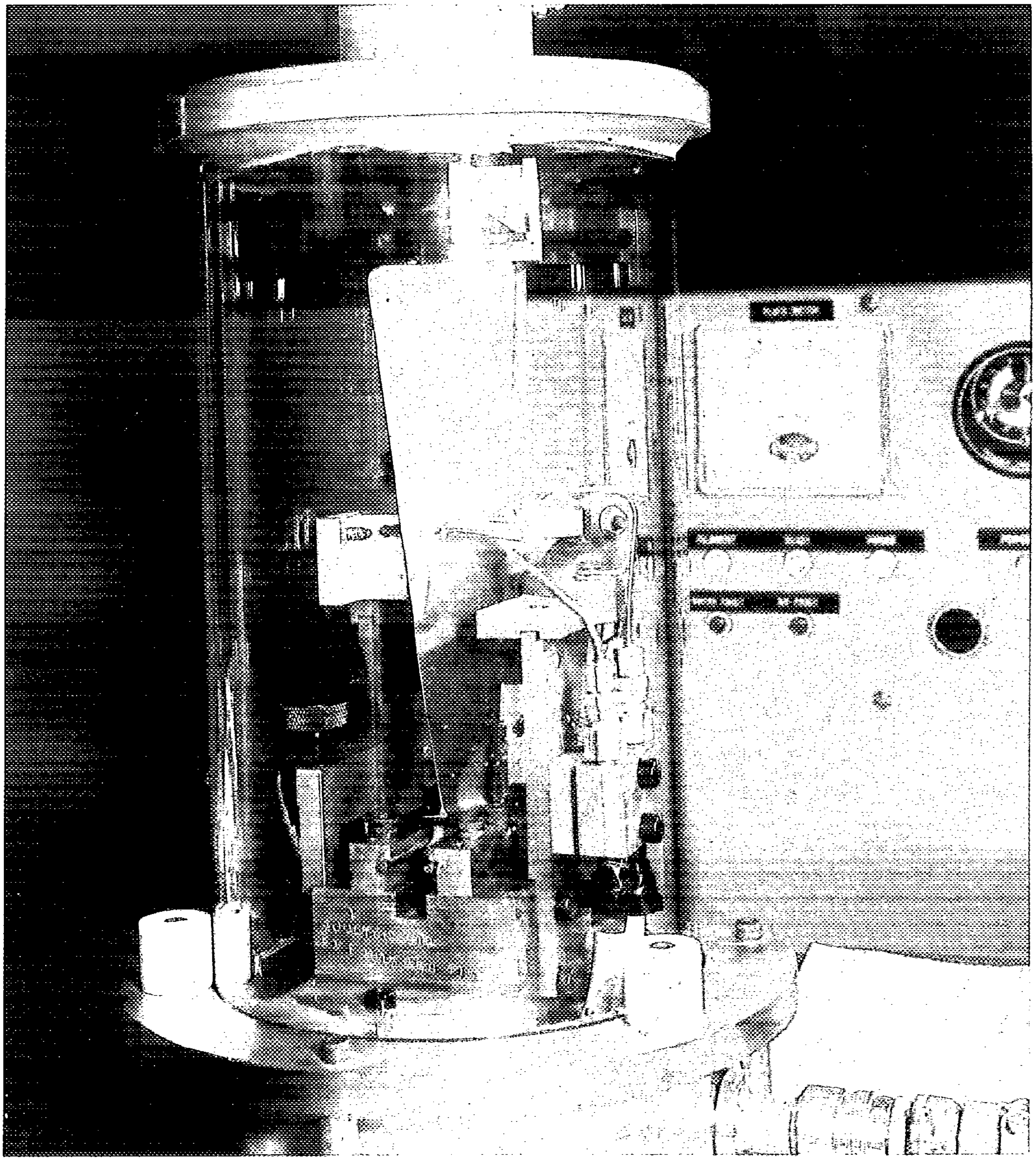

**Figure 12.6—Example of Vacuum Induction Brazing. A Tungsten Carbide Wear Pad is Being Brazing to A Titanium Compressor Blade**

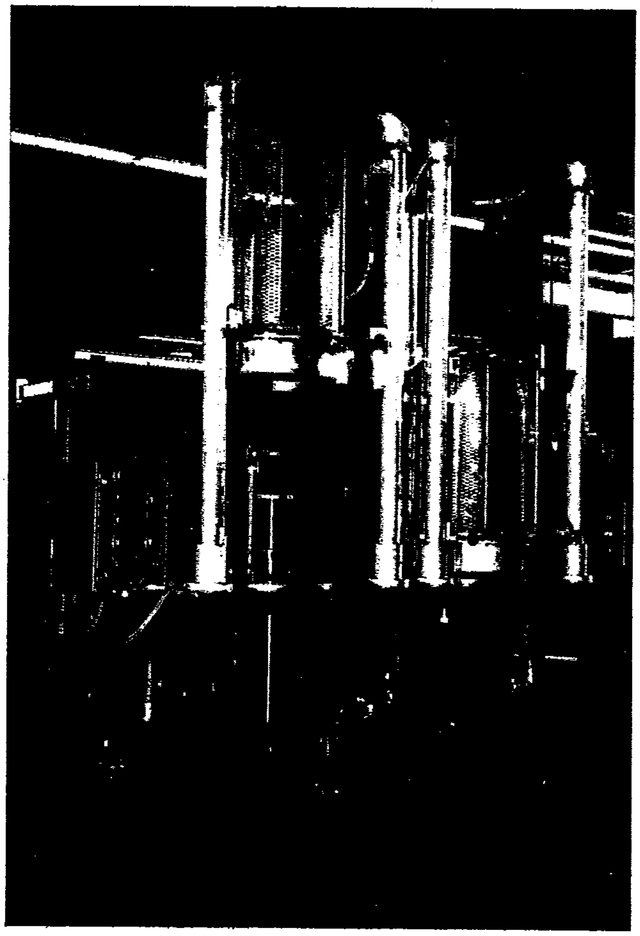

**Figure 12.7–Production Arrangement for Induction Brazing in Controlled Atmosphere or Vacuum Showing Dual Station Bell Jar Fixture, Induction Generator, Movable Stand, Generator and Gas Controls, and Supports to Facilitate Up and Down Movement of Bell Jar**

the filler metal melts. The pressure must be maintained during the time of current flow and after the current is shut off until the joint solidifies. The time of current flow will vary from about one second for small, delicate work to several minutes for larger work. This time is usually controlled manually by the operator, who determines when brazing has occurred by the temperature and the extent of filler metal flow.

## DIP BRAZING

TWO METHODS OF dip brazing are molten metal bath dip brazing and molten chemical (flux) bath dip brazing.

### Molten Metal Bath Method

THIS METHOD IS usually limited to the brazing of small assemblies, such as wire connections or metal strips. A crucible, usually made of graphite, is heated externally to the required temperature to maintain the brazing filler metal in fluid form. A cover of flux is maintained over the molten filler metal. The size of the molten bath (crucible) and the heating method must be such that the immersion of parts in the bath will not lower the bath temperature below brazing temperature. Parts should be clean and protected with flux prior to their introduction into the bath. The ends of the wires or parts must be held firmly together when they are removed from the bath until the brazing filler metal has fully solidfied.

### Molten Chemical (Flux) Bath Method

THIS BRAZING METHOD requires either a metal or ceramic container for the flux and a method of heating the flux to the brazing temperature. Heat may be applied externally with a torch or internally with an electrical resistance heating unit. A third method involves electrical resistance heating of the flux itself; in that case, the flux must be initially melted by external heating. Suitable controls are provided to maintain the flux within the brazing temperature range. The size of the bath must be such that immersion of parts for brazing will not cool the flux below the brazing temperature. See Figure 12.8.

Parts should be cleaned, assembled, and preferably held in jigs prior to immersion into the bath. Brazing filler metal is preplaced as rings, washers, slugs, paste, or as a cladding on the base metal. Preheat may be necessary to assure dryness of parts and to prevent the freezing of flux on parts which may cause selective melting of flux and brazing filler metal. Preheat temperatures are usually close to the melt-

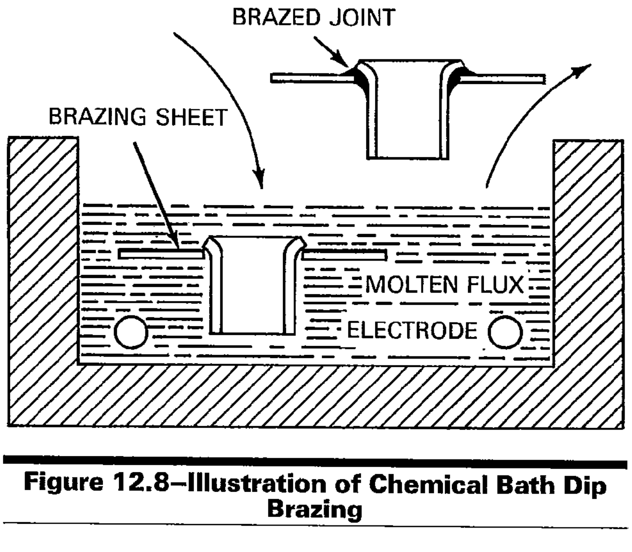

**Figure 12.8–Illustration of Chemical Bath Dip Brazing**

ing temperature of the flux. A certain amount of flux adheres to the assembly after brazing. Molten flux must be drained off while the parts are hot. Flux remaining on cold parts must be removed by water or by chemical means.

## INFRARED BRAZING

INFRARED BRAZING MAY be considered a form of furnace brazing with heat supplied by long-wave light radiation. Heating is by invisible radiation from high intensity quartz lamps capable of delivering up to 5000 watts of radiant energy. Heat input varies inversely as the square of the distance from the source, but the lamps are not usually shaped to follow the contour of the part to be heated. Concentrating reflectors focus the radiation on the parts.

For vacuum brazing or inert-gas protection, the assembly and the lamps are placed in a bell jar or retort that can be evacuated or filled with inert gas. The assembly is then heated to a controlled temperature, as indicated by thermocouples. Figure 12.9 shows an infrared brazing arrangement. The part is moved to the cooling platens after brazing.

## SPECIAL PROCESSES

### Blanket Brazing

BLANKET BRAZING USES a blanket that is resistance heated; the heat is transferred to the parts by conduction and radiation, but mostly by radiation.

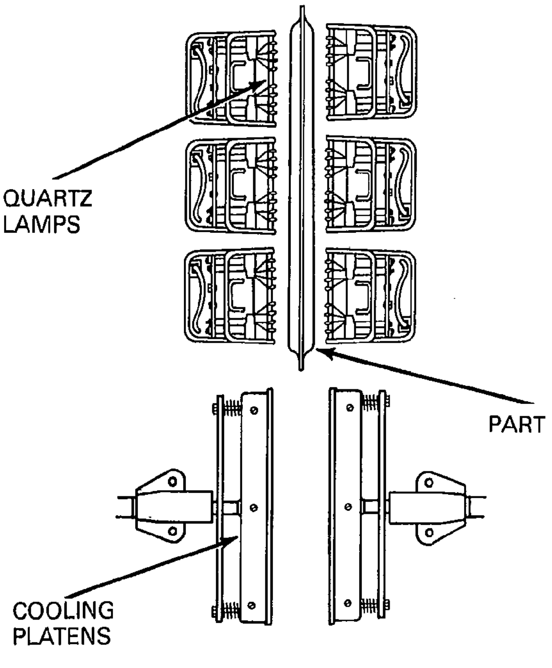

**Figure 12.9–Infrared Brazing Apparatus**

## EXOTHERMIC BRAZING

EXOTHERMIC BRAZING IS a special process which heats a commercial filler metal by a solid-state exothermic chemical reaction. An exothermic chemical reaction generates heat released as the free energy of the reactants. Nature has provided countless numbers of such reactions; those solid-state or nearly solid-state metal-metal oxide reactions are suitable for use in exothermic brazing units.

Exothermic brazing uses simplified tooling and equipment. The reaction heat brings adjoining metal interfaces to a temperature at which preplaced brazing filler metal melts and wets the base metal interface surfaces. Several commercially available brazing filler metals have a suitable flow temperature. The process is limited only by the thickness of the base metal and the effect of brazing heat, or any previous heat treatment, on the metal properties.

## BRAZING AUTOMATION

THE IMPORTANT VARIABLES involved in brazing are the temperature, time at temperature, filler metal, and brazing atmosphere. Other variables are joint fit-up, amount of filler metal, and rate and mode of heating. All of these features may be automated.

Heating by welding torches may be automated. So may furnace brazing (e.g., vacuum and atmosphere), resistance brazing, induction brazing, dip brazing, and infrared brazing. Generally, the amount of heat supplied to the joint is automated by controlling temperature and time at temperature.

Brazing filler metal may be preplaced at the joints during assembly of components, or automatically fed into the joints while at brazing temperature. So also may fluxing be provided.

Further automation may include in-line inspection and cleaning (flux removal), simultaneous brazing of multiple joints in an assembly, and continuous brazing operations.

Generally, the more automated a process becomes, the more rigorous must be its economic justification. Usually the increased cost of automation is justified by increased productivity. In the case of brazing, further justification may well be found in the energy saved with efficient joint heating.

Basically, the major advantages of automatic brazing are these:

(1) High production rates
(2) High productivity per worker
(3) Filler metal savings
(4) Consistency of results
(5) Energy savings
(6) Adaptability and flexibility

Manual torch brazing, totally unautomated, represents the simplest brazing technique, but it has economic justification. First, the braze joint is visible to the operator, who adjusts the process based on observation. Second, heat is directed only to the joint area. Whenever energy costs represent a large fraction of the cost of a braze joint, this is an important consideration.

Nevertheless, torch brazing is labor intensive and low in productivity. A continuous belt furnace increases production but loses in-line inspection and lowers energy efficiency because the entire assembly is heated.

Automatic brazing machines improve torch brazing. Typically, heat is directed just to the joint area by one or more torches. Similar effects can be obtained by induction heating. A typical machine has provisions for assembly and fixturing, automatic fluxing, preheating (if needed), brazing, air or water quenching, part removal, and inspection.

# BRAZING FILLER METALS

## CHARACTERISTICS

BRAZING FILLER METALS must have the following properties:

(1) Ability to form brazed joints with mechanical and physical properties suitable for the intended service application

(2) Melting point or melting range compatible with the base metals being joined, and sufficient fluidity at brazing temperature to flow and distribute themselves into properly prepared joints by capillary action

(3) Composition of sufficient homogeneity and stability to minimize separation of constituents (liquation) during brazing

(4) Ability to wet surfaces of base metals and form a strong, sound bond

(5) Depending on requirements, ability to produce or avoid filler-metal interactions with base metals

## MELTING AND FLUIDITY

PURE METALS MELT at a constant temperature and are generally very fluid. Binary compositions (two metals) have differing characteristics, depending upon the relative contents of the two metals. Figure 12.10 is the equilibrium diagram for the silver-copper binary system. The solidus line, ADCEB, traces the start-of-melting temperature of the alloys, while the liquidus line, ACB, shows the temperatures at which the alloys become completely liquid. At point C the two lines meet (72 percent silver-28 percent copper), indicating that that particular alloy melts at that fixed temperature (the eutectic temperature). This alloy is the eutectic composition; it is as fluid as a pure metal, while the other alloy combinations are mushy between their solidus and liquidus temperatures. The wider that temperature spread, the more sluggish are the alloys with respect to flow in a capillary joint.

The α region is a solid solution of copper in silver, the β region is a solid solution of silver in copper. The central solid zone consists of an intimate mixture of α and β solid solutions. Above the liquidus line, the silver and copper atoms are thoroughly interspersed as a liquid solution.

## LIQUATION

BECAUSE THE SOLID and liquid alloy phases of a brazing filler metal generally differ, the composition of the melt will gradually change as the temperature increases from the solidus to the liquidus. If the portion that melts first is allowed to flow out, the remaining solid may not melt and so may remain behind as a residue or "skull." Filler metals with narrow melting ranges do not tend to separate, so they flow quite freely into joints with extremely narrow clearance. Filler metals with wide melting ranges need rapid heating or delayed application to the joint until the base metal reaches brazing temperature, to minimize separation, which is called *liquation*. Filler metals subject to liquation have a sluggish flow, require wide joint clearances, and form large fillets at joint extremities.

## WETTING AND BONDING

TO BE EFFECTIVE, a brazing filler metal must alloy with the surface of the base metal without (1) undesirable diffusion into the base metal, (2) dilution with the base metal, (3) base metal erosion, and (4) formation of brittle com-

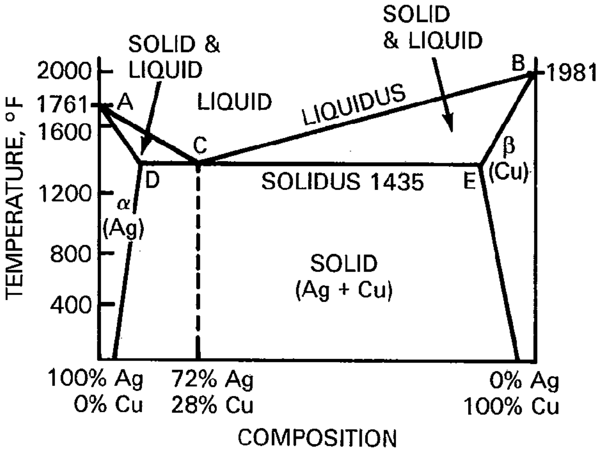

**Figure 12.10–Silver-Copper Constitutional Diagram**

pounds. Effects (1), (2), and (3) depend upon the mutual solubility between the brazing filler metal and the base metal, the amount of brazing filler metal present, and the temperature and time duration of the brazing cycle.

Some filler metals diffuse excessively, changing the base metal properties. To control diffusion, select a suitable filler metal, apply the minimum quantity of filler metal, and follow the appropriate brazing cycle. If the filler metal wets the base metal, capillary flow is enhanced. In long capillaries between the metal parts, mutual solubility can change the filler metal composition by alloying. This will usually raise its liquidus temperature and cause it to solidify before completely filling the joint.

Base metal erosion (3) occurs if the base metal and the brazing filler metal are mutually soluble. Sometimes such alloying produces brittle intermetallic compounds (4) that reduce the joint ductility.

Compositions of brazing filler metals are adjusted to control the above factors and to provide desirable characteristics, such as corrosion resistance in specific media, favorable brazing temperatures, or material economies. Thus, to overcome the limited alloying ability (wettability) of silver-copper alloys used to braze iron and steel, those filler metals contain zinc or cadmium, or both, to lower the liquidus and solidus temperatures. Tin is added in place of zinc or cadmium when constituents with high vapor pressure would be objectionable.

Similarly, silicon is used to lower the liquidus and solidus temperatures of aluminum and nickel-base brazing filler metals. Other brazing filler metals contain elements such as lithium, phosphorus, or boron, which reduce surface oxides on base metal and form compounds with melting temperatures below the brazing temperature. Those molten oxides then flow out of the joint, leaving a clean metal surface for brazing. These filler metals are essentially self-fluxing.

## FILLER METAL SELECTION

FOUR FACTORS SHOULD be considered when selecting a brazing filler metal:

(1) Compatibility with base metal and joint design

(2) Service requirements for the brazed assembly

Compositions should be selected to suit operating requirements, such as service temperature (high versus cryogenic), thermal cycling, life expectancy, stress loading, corrosive conditions, radiation stability, and vacuum operation.

(3) Brazing temperature required

Low brazing temperatures are usually preferred to economize on heat energy, minimize heat effects on base metal (annealing, grain growth, warpage), minimize base metal-filler metal interaction, and increase the life of fixtures and other tools.

High brazing temperatures are used in order to take advantage of a higher melting, but more economical, brazing filler metal; to combine annealing, stress relief, or heat treatment of the base metal with brazing; to permit subsequent processing at elevated temperatures; to promote base metal-filler metal interactions to increase the joint remelt temperature; or to promote removal of certain refractory oxides by vacuum or an atmosphere.

(4) Method of heating

Filler metals with narrow melting ranges—less than 50°F (28°C) between solidus and liquidus—can be used with any heating method, and the brazing filler metal may be preplaced in the joint area in the form of rings, washers, formed wires, shims, powder, or paste.

Alternatively, such alloys may be manually or automatically face-fed into the joint after the base metal is heated. Filler metals that tend to liquate should be used with heating methods that bring the joint to brazing temperature quickly, or the brazing filler metal should be introduced after the base metal reaches the brazing temperature.

To simplify filler metal selection, ANSI/AWS A5.8, *Specification for Brazing Filler Metal*, divides filler metals into seven categories and various classifications within each category. The specification lists products which are common, commercially available filler metals. Suggested base metal-filler metal combinations are given in Table 12.2. Other brazing filler metals not currently covered by the specification are available for special applications.

## ALUMINUM-SILICON FILLER METALS

THIS GROUP IS used for joining aluminum grades 1060, 1100, 1350, 3003, 3004, 3005, 5005, 5050, 6053, 6061, 6951, and cast alloys A712.0 and C711.0. All types are suited for furnace and dip brazing, while some types are also suited for torch brazing, using lap joints rather than butt joints.

Brazing sheet or tubing is a convenient source of aluminum filler metal. It consists of a core of aluminum alloy and a coating of lower melting filler metal. The coatings are aluminum-silicon alloys, applied to one or both sides of the sheet. Brazing sheet is frequently used as one member of an assembly, with the mating piece made of an unclad brazeable alloy. The coating on the brazing sheet or tubing melts at brazing temperature and flows by capillary attraction and gravity to fill the joints.

## MAGNESIUM FILLER METALS

MAGNESIUM FILLER METAL (BMg-1) is used to join AZ10A, K1A, and M1A magnesium alloys by torch, dip, or furnace brazing processes. Heating must be closely controlled to prevent melting of the base metal. Joint clearances of 0.004 to 0.010 in (0.10 to 0.25 mm) are best for most applications. Corrosion resistance is good if the flux is completely removed after brazing. Brazed assemblies are generally suited for continuous service up to 250°F (120°C) or intermittent service to 300°F (150°C), subject to the usual limitations of the actual operating environment.

## Table 12.2
## Base Metal-Filler Metal Combinations

| | Al & Al Alloys | Mg & Mg Alloys | Cu & Cu Alloys | Carbon & Low Alloy Steels | Cast Iron | Stainless Steel | Ni & Ni Alloys | Ti & Ti Alloys | Be, Zr, & Alloys (Reactive Metals) | W, Mo, Ta, Cb & Alloys (Refractory Metals) | Tool Steels |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Al & Al alloys | BAlSi | | | | | | | | | | |
| Mg & Mg alloys | X | BMg | | | | | | | | | |
| Cu & Cu alloys | X | X | BAg, BAu, BCuP, RBCuZn | BNi | | | | | | | |
| Carbon & low alloy steels | BAlSi | X | BAg, BAu, RBCuZN, BNi | BAg, BAu, BCu, RBCuZn, BNi | | | | | | | |
| Cast iron | X | X | BAg, BAu, RBCuZN, BNi | BAg, RBCuZn, BNi | BAg, RBCuZn, BNi | | | | | | |
| Stainless steel | BAlSi | X | BAg, BAu | BAg, BAu, BCu, BNi | BAg, BAu, BCu, BNi | BAg, BAu, BCu, BNi | | | | | |
| Ni & Ni alloys | X | X | BAg, BAu, RBCuZn, BNi | BAg, BAu, BCu, RBCuZn, BNi | BAg, BCu, RBCuZn | BAg, BAu, BCu, BNi | BAg, BAu, BCu, BNi | | | | |
| Ti & Ti alloys | BAlSi | X | BAg | BAg | BAg | BAg | BAg | Y | | | |
| Be, Zi & alloys (reactive metals) | X<br>BAlSi(Be) | X | BAg | BAg, BNi* | BAg, BNi* | BAg, BNi* | BAg, BNi* | Y | Y | | |
| W, Mo, Ta, Cb & alloys (refractory metals) | X | X | BAg, BNi | BAg, BCu, BNi* | BAg, BCu, BNi* | BAg, BCu, BNi* | BAg, BCu, BNi* | Y | Y | Y | |
| Tool steels | X | X | BAg, BAu, RBCuZn, BNi | BAg, BAu, BCu, RBCuZn, BNi | BAg, BAu, RBCuZn, BNi | BAg, BAu, BCu, BNi | BAg, BAu, BCu, RBCuZn, BNi | X | X | X | BAg, BAu, BCu, RBCuZn, BNi |

Note: Refer to AWS Specification A5.8 for information on the specific compositions within each classification.
X—Not recommended; however, special techniques may be practicable for certain dissimilar metal combinations.
Y—Generalizations on these combinations cannot be made. Refer to the Brazing Handbook for usable filler metals.
*—Special brazing filler metals are available and are used successfully for specific metal combinations.

Filler Metals:
BAlsi—Aluminum
BAg—Silver base
BAu—Gold base
BCu—Copper
BCuP—Copper phosphorus
RBCuZn—Copper zinc
BMg—Magnesium base
BNi—Nickel base

## COPPER AND COPPER-ZINC FILLER METALS

THESE BRAZING FILLER metals are used to join ferrous metals and nonferrous metals. The corrosion resistance of the copper-zinc alloy filler metals is generally inadequate for joining copper, silicon bronze, copper-nickel alloys, or stainless steel.

The essentially pure copper brazing filler metals are used to join ferrous metals, nickel-base alloys, and copper-nickel alloys. They are free flowing and often used in furnace brazing with a combusted gas, hydrogen, or dissociated ammonia atmosphere without flux. Copper filler metals are available in wrought and powder forms.

One copper filler metal is a copper oxide to be suspended in an organic vehicle.

Copper-zinc filler metals are used on steel, copper, copper alloys, nickel and nickel-base alloys, and stainless steel where corrosion resistance is not a requirement. They are used with the torch, furnace, and induction brazing processes. Fluxing is required, and a borax-boric acid flux is commonly used.

## COPPER-PHOSPHORUS FILLER METALS

THESE FILLER METALS are primarily used to join copper and copper alloys. They have some limited use for joining silver, tungsten, and molybdenum. They should not be used on ferrous or nickel-base alloys, nor on copper-nickel alloys with more than 10 percent nickel. These filler metals are suited for all brazing processes and have self-fluxing properties when used on copper. They tend to liquate if heated slowly.

## SILVER FILLER METALS

THESE FILLER METALS are used to join most ferrous and nonferrous metals, except aluminum and magnesium, with all methods of heating. They may be preplaced in the joint or fed into the joint area after heating.

Silver-copper alloys high in silver do not wet steel well when brazing is done in air with a flux. Copper forms alloys with cobalt and nickel much more readily than silver does. Thus, copper wets many of these metals and their alloys satisfactorily, where silver does not. When brazing in certain protective atmospheres without flux, silver-copper alloys will wet and flow freely on most steels at the proper temperature.

Zinc is commonly used to lower the melting and flow temperatures of silver-copper alloys. It is by far the most helpful wetting agent when joining alloys based on iron, cobalt, or nickel. Alone, or in combination with cadmium or tin, zinc produces alloys that wet the iron group metals but do not alloy with them to any appreciable depth.

Cadmium is incorporated in some silver-copper-zinc filler metals alloys to further lower the melting and flow temperatures, and to increase the fluidity and wetting action on a variety of base metals. Since cadmium oxide fumes are a health hazard, cadmium-bearing filler metals should be used with caution.

Tin has a low vapor pressure at normal brazing temperatures. It is present in silver brazing filler metals in place of zinc or cadmium when volatile constituents are objectionable, such as when brazing is done without flux in atmosphere or vacuum furnaces, or when the brazed assemblies will be used in high vacuum at elevated temperatures. Silver-copper filler metals with tin additions have wide melting ranges. Fillers containing zinc wet ferrous metals more effectively than those containing tin, and where zinc is tolerable, they are preferred to fillers with tin.

Stellites, cemented carbides, and other molybdenum- and tungsten-rich refractory alloys are brazed with filler metals with added manganese, nickel, and, infrequently, cobalt to increase wettability.

When stainless steels and alloys that form refractory oxides are brazed in reducing or inert atmospheres without flux, silver brazing filler metals containing lithium as the wetting agent are quite effective. The heat of formation of $Li_2O$ is high, so lithium metal reduces adherent oxides on the base metal. The resultant lithium oxide is readily displaced by the brazing filler metal.

## GOLD FILLER METALS

GOLD FILLER METALS are used to join parts in electron tube assemblies where volatile components are undesirable. They are used to braze iron, nickel, and cobalt-base metals where resistance to oxidation or corrosion is required. They are commonly used on thin sections because of their low rate of interaction with the base metal.

## NICKEL FILLER METALS

NICKEL BRAZING FILLER metals are generally used on 300 and 400 series stainless steels, nickel and cobalt-base alloys, even carbon steel, low alloy steels, and copper when specific properties are desired. They exhibit good corrosion and heat resistance properties. They are normally applied as powders, pastes, rod, foil, or in the form of sheet or rope with plastic binders.

Nickel filler metals have the very low vapor pressure needed in vacuum systems and vacuum tube applications at elevated temperatures.

The phosphorus-containing filler metals suffer from low ductility because they form nickel phosphides. The boron-containing filler metals must be carefully controlled when used to braze thin sections, to prevent erosion.

## COBALT FILLER METAL

THIS FILLER METAL is used for its high temperature properties and its compatibility with cobalt-base metals. Brazing in a high quality atmosphere or diffusion brazing gives optimum results. Special high temperature fluxes are available for torch brazing.

## FILLER METALS FOR REFRACTORY METALS

BRAZING IS EXCELLENT for fabricating assemblies of refractory metals, in particular those involving thin sections. However, only a few filler metals have been specifically designed for both high temperature and high corrosion applications.

Those filler metals and pure metals used to braze refractory metals are given in Table 12.3. Low melting filler metals, such as silver-copper-zinc, copper-phosphorus, and copper, are used to join tungsten for electrical contact applications, but these filler metals cannot operate at high temperatures. The use of higher melting rare metals, such as tantalum and columbium, is warranted in those cases.

Nickel-base and precious-metal-base filler metals may also be used to join tungsten.

Various brazing filler metals will join molybdenum. The effect of brazing temperature on base metal recrystallization must be considered. When brazing above the recrystallization temperature, brazing time must be kept short. If high temperature service is not required, copper and silver-base filler metals may be used.

Columbium and tantalum are brazed with a number of refractory or reactive-metal-base filler metals. The metal systems Ti-Zr-Be and Zr-Cb-Be are typical, also platinum, palladium, platinum-iridium, platinum-rhodium, titanium, and nickel-base filler metals (such as nickel-chromium-silicon alloys). Copper-gold alloys containing gold in amounts between 46 and 90 percent form age hardening compounds which are brittle. Silver-base filler metals are not recommended because they may embrittle the base metals.

**Table 12.3**
**Brazing Filler Metals for Refractory Metals[a]**

| | Liquidus Temperature | | | Liquidus Temperature | |
|---|---|---|---|---|---|
| **Brazing Filler Metal** | **°F** | **°C** | **Brazing Filler Metal** | **°F** | **°C** |
| Cb | 4380 | 2416 | Mn-Ni-Co | 1870 | 1021 |
| Ta | 5425 | 2997 | | | |
| Ag | 1760 | 960 | Co-Cr-Si-Ni | 3450 | 1899 |
| Cu | 1980 | 1082 | Co-Cr-W-Ni | 2600 | 1427 |
| Ni | 2650 | 1454 | Mo-Ru | 3450 | 1899 |
| Ti | 3300 | 1816 | Mo-B | 3450 | 1899 |
| Pd-Mo | 2860 | 1571 | Cu-Mn | 1600 | 871 |
| Pt-Mo | 3225 | 1774 | Cb-Ni | 2175 | 1190 |
| Pt-30W | 4170 | 2299 | | | |
| Pt-50Rh | 3720 | 2049 | Pd-Ag-Mo | 2400 | 1306 |
| | | | Pd-Al | 2150 | 1177 |
| Ag-Cu-Zn-Cd-Mo | 1145-1295 | 619-701 | Pd-Ni | 2200 | 1205 |
| Ag-Cu-Zn-Mo | 1324-1450 | 718-788 | Pd-Cu | 2200 | 1205 |
| Ag-Cu-Mo | 1435 | 780 | Pd-Ag | 2400 | 1306 |
| Ag-Mn | 1780 | 971 | Pd-Fe | 2400 | 1306 |
| | | | Au-Cu | 1625 | 885 |
| Ni-Cr-B | 1950 | 1066 | Au-Ni | 1740 | 949 |
| Ni-Cr-Fe-Si-C | 1950 | 1066 | Au-Ni-Cr | 1900 | 1038 |
| Ni-Cr-Mo-Mn-Si | 2100 | 1149 | Ta-Ti-Zr | 3800 | 2094 |
| Ni-Ti | 2350 | 1288 | | | |
| Ni-Cr-Mo-Fe-W | 2380 | 1305 | Ti-V-Cr-Al | 3000 | 1649 |
| Ni-Cu | 2460 | 1349 | Ti-Cr | 2700 | 1481 |
| Ni-Cr-Fe | 2600 | 1427 | Ti-Si | 2600 | 1427 |
| Ni-Cr-Si | 2050 | 1121 | Ti-Zr-Be[b] | 1830 | 999 |
| | | | Zr-Cb-Be[b] | 1920 | 1049 |
| | | | Ti-V-Be[b] | 2280 | 1249 |
| | | | Ta-V-Cb[b] | 3300-3500 | 1816-1927 |
| | | | Ta-V-Ti[b] | 3200-3350 | 1760-1843 |

[a] Not all the filler metals listed are commercially available.

[b] Depends on the specific composition.

# FLUXES AND ATMOSPHERES

METALS AND ALLOYS may react with the atmosphere to which they are exposed, more so as the temperature is raised. The common reaction is oxidation, but nitrides and carbides are sometimes formed.

Fluxes, gas atmospheres, and vacuum are used to prevent undesirable reactions during brazing. Some fluxes and atmospheres may also reduce oxides already present.

Titanium, zirconium, columbium (niobium), and tantalum become permanently embrittled when brazed in any atmosphere containing hydrogen, oxygen, or nitrogen. Hydrogen will embrittle copper that has not been thoroughly deoxidized.

The use of flux or atmosphere does not eliminate the need to clean parts prior to brazing. Recommended cleaning procedures are contained in Chapter 7 of the *AWS Brazing Manual*, 3rd edition, 1976. The functions of individual fluxing ingredients are discussed in Chapter 4 of that Manual.

Since the purpose of a braze filler is to flow over the base material and into capillaries, it also may flow over portions of the piece being joined. This may be undesirable from a cosmetic viewpoint or there may be holes or features on the part that must not be filled or plugged for the device to function properly. When extraneous flow must be prevented, the brazer applies a "stopoff" material to retard the flow of the filler material. Great care must be exercised to prevent the stopoff material from getting into the actual braze joint because this would produce an unbonded condition. Stopoff materials are generally oxides applied by brush, tape, spray, or a hypodermic needle system. The common stopoffs are oxides of titanium, calcium, aluminum, or magnesium.

Stopoffs retard braze flow by intentionally putting oxides on the surface of the materials being joined. This works quite well when furnace brazing without flux. However, when flux is used, the cleaning action of the flux may counteract the stopoff effect. After brazing, the stopoff material can be removed by washing with hot water or by chemical or mechanical stripping.

# APPLICATIONS

## SELECTION OF BASE METALS

THE EFFECT OF brazing on the mechanical properties of the metal in a brazement and the final joint strength must be considered. Base metals strengthened by cold working will be annealed by brazing process temperatures and times in the annealing range of the base metal being processed. "When brazed, "hot-cold worked", heat-resistant base metals will also exhibit only the annealed physical properties. The brazing cycle by its very nature will usually anneal cold worked base metal unless the brazing temperature is very low and the time at temperature is very short.

It is not practical to cold work the base metal after the brazing operation.

When a brazement must have strength after brazing that will be above the annealed properties of the base metal, a heat treatable base metal should be selected. The base metal can be an oil-quench type, an air-quench type that can be brazed and hardened in the same or a separate operation, or a precipitation-hardening type that can be brazed and solution treated in a combined cycle. Parts already hardened may be brazed with a low temperature filler metal using short times at temperature to maintain the mechanical properties.

## ALUMINUM AND ALUMINUM ALLOYS

THE NONHEAT TREATABLE wrought aluminum alloys that are brazed most successfully are the ASTM 1XXX and 3XXX series, and low magnesium alloys of the ASTM 5XXX series. Available filler metals melt below the solidus temperatures of all commercial wrought, nonheat treatable alloys.

The heat treatable wrought alloys most commonly brazed are the ASTM 6XXX series. The ASTM 2XXX and 7XXX series of aluminum alloys are low melting and, therefore, not normally brazeable, with the exception of 7072 and 7005 alloys.

Aluminum sand and permanent mold casting alloys most commonly brazed are ASTM 443.0, 356.0, and 712.0 alloys. Aluminum die castings are generally not brazed because of blistering from their high gas content.

Table 12.4 lists the common aluminum base metals that can be brazed.

Most aluminum brazing is done by torch, dip, or furnace processes. Furnace brazing may be done in air or controlled atmosphere, including vacuum.

Additional information on brazing aluminum and aluminum alloys is contained in Chapter 12, *Brazing Manual*, 3rd Edition.

## MAGNESIUM AND MAGNESIUM ALLOYS

BRAZING TECHNIQUES SIMILAR to those used for aluminum are used for magnesium alloys. Furnace, torch, and dip brazing can be employed, although the latter process is the most widely used.

Magnesium alloys that are considered brazeable are given in Table 12.5. Furnace and torch brazing experience

## Table 12.4
## Nominal Composition and Melting Range of Common Brazeable Aluminum Alloys

| Commercial Designation | ASTM Alloy | Brazeability Rating[b] | Nominal Composition[a] Cu | Si | Mn | Mg | Zn | Cr | Approximate Melting Range °F | °C |
|---|---|---|---|---|---|---|---|---|---|---|
| EC | EC | A | | Al 99.45% min | | | | | 1195-1215 | 646-657 |
| 1100 | 1100 | A | | Al 99% min | | | | | 1190-1215 | 643-657 |
| 3003 | 3003 | A | -- | -- | 1.2 | -- | -- | -- | 1190-1210 | 643-654 |
| 3004 | 3004 | B | -- | -- | 1.2 | 1.0 | -- | -- | 1165-1205 | 629-651 |
| 3005 | 3005 | A | 0.3 | 0.6 | 1.2 | 0.4 | 0.25 | 0.1 | 1180-1215 | 638-657 |
| 5005 | 5005 | B | -- | -- | -- | 0.8 | -- | -- | 1170-1210 | 632-654 |
| 5050 | 5050 | B | -- | -- | -- | 1.2 | -- | -- | 1090-1200 | 588-649 |
| 5052 | 5052 | C | -- | -- | -- | 2.5 | -- | -- | 1100-1200 | 593-649 |
| 6151 | 6151 | C | -- | 1.0 | -- | 0.6 | -- | 0.25 | 1190-1200 | 643-649 |
| 6951 | 6951 | A | 0.25 | 0.35 | -- | 0.65 | -- | -- | 1140-1210 | 615-654 |
| 6053 | 6053 | A | -- | 0.7 | -- | 1.3 | -- | -- | 1105-1205 | 596-651 |
| 6061 | 6061 | A | 0.25 | 0.6 | -- | 1.0 | -- | 0.25 | 1100-1205 | 593-651 |
| 6063 | 6063 | A | -- | 0.4 | -- | 0.7 | -- | -- | 1140-1205 | 615-651 |
| 7005 | 7005 | B | 0.1 | 0.35 | 0.45 | 1.4 | 4.5 | 0.13 | 1125-1195 | 607-646 |
| 7072 | 7072 | A | -- | -- | -- | -- | 1.0 | -- | 1125-1195 | 607-646 |
| Cast 43 | Cast 443.0 | A | -- | 5.0 | -- | -- | -- | -- | 1065-1170 | 629-632 |
| Cast 356 | Cast 356.0 | C | -- | 7.0 | -- | 0.3 | -- | -- | 1035-1135 | 557-613 |
| Cast 406 | Cast 406 | A | | Al 99% min | | | | | 1190-1215 | 643-657 |
| Cast A612 | Cast A712.0 | B | -- | -- | -- | 0.7 | 6.5 | -- | 1105-1195 | 596-646 |
| Cast C612 | Cast C712.0 | A | -- | -- | -- | 0.35 | 6.5 | -- | 1120-1190 | 604-643 |

a. Percent of alloying elements: aluminum and normal impurities constitute remainder.

b. Brazeability ratings: A = Alloys readily brazed by all commercial methods and procedures.
B = Alloys that can be brazed by all techniques with a little care.
C = Alloys that require special care to braze.

is limited to M1A alloy. Dip brazing can be used for AZ10A, AZ31B, AZ61A, K1A, M1A, ZE10A, ZK21A, and ZK60A alloys.

The filler metals used for brazing magnesium are also summarized in Table 12.5. BMg-1 brazing filler metal is suitable for the torch, dip, or furnace brazing process. The BMg-2a alloy is usually preferred in most brazing applications because of its lower melting range. A zinc base filler metal known as GA432 is an even lower melting composition suitable only for dip brazing use.

## BERYLLIUM

BRAZING IS THE preferred method for metallurgically joining beryllium.[2] Suitable brazing filler metal systems and their temperature ranges include:

(1) Zinc: 800-850°F (427-454°C)
(2) Aluminum-silicon: 1050-1250°F (566-677°C)
(3) Silver-copper: 1200-1660°F (649-904°C)
(4) Silver: 1620-1750°F (882-954°C)

Zinc melts below 840°F, the temperature defined by AWS for brazing filler metal. Nevertheless, it is generally accepted as the lowest melting filler metal for brazing beryllium.

Aluminum-silicon filler metals can be used in high-strength, wrought beryllium assemblies because the brazing temperature is well below the base metal recrystallization temperature. BAlSi-4 type filler metal brazes well with fluxes. Fluxless brazing requires stringent control. Aluminum-base filler metals have less metallurgical interaction with the base metal than silver-base fillers. This is a significant advantage when thin beryllium sections or foils are to be joined.

Silver and silver-base brazing filler metals find use in structures exposed to elevated temperatures. Atmosphere brazing with these alloy systems is straight forward and may be performed in purified atmospheres or vacuum.

## COPPER AND COPPER ALLOYS

THE COPPER ALLOY base metals include copper-zinc alloys (brass), copper-silicon alloys (silicon bronze), copper-aluminum alloys (aluminum bronze), copper-tin alloys (phosphor bronze), copper-nickel alloys, and several others. The brazing of copper and copper alloys and appropriate filler

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[2] Beryllium and its compounds are toxic. Proper handling and identification of beryllium metal is required by federal regulations.

**Table 12.5**
**Brazeable Magnesium Alloys and Filler Metals**

| AWS A5.8 Classification | ASTM Alloy Designation | Avail. Forms | Solidus | | Liquidus | | Brazing Range | | Suitable Filler | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | °F | °C | °F | °C | °F | °C | BMg-1 | BMG-2a |
| | | | | | **Base Metal** | | | | | |
| — | AZ10A | E | 1170 | 632 | 1190 | 643 | 1080-1140 | 582-616 | X | X |
| — | AZ31B | E. S | 1050 | 566 | 1160 | 627 | 1080-1100 | 582-593 | | X |
| — | K1A | C | 1200 | 649 | 1202 | 650 | 1080-1140 | 582-616 | X | X |
| — | M1A | E. S | 1198 | 648 | 1202 | 650 | 1080-1140 | 582-616 | X | X |
| — | ZE10A | S | 1100 | 593 | 1195 | 646 | 1080-1100 | 582-593 | | X |
| — | ZK21A | E | 1159 | 626 | 1187 | 642 | 1080-1140 | 582-616 | X | X |
| | | | | | **Filler Metal** | | | | | |
| BMg-1 | AZ92A | W. R.<br>ST. P | 830 | 443 | 1110 | 599 | 1120-1140 | 604-616 | — | — |

E = Extruded shapes and structural sections
S = Sheet and plate
C = Castings
W = Wire
R = Rod
ST = Strip
P = Powder

metals are discussed in detail in Chapter 14, *Brazing Manual*, 3rd Edition.

## LOW CARBON AND LOW ALLOY STEELS

LOW CARBON AND low alloy steels are brazed without difficulty. They are frequently brazed at temperatures above 1980°F (1080°C) with copper filler metal in a controlled atmosphere, or at lower temperatures with silver base filler metals.

For alloy steels, the filler metal should have a solidus well above any heat-treating temperature to avoid damage to joints that will be heat-treated after brazing. In some cases, air hardening steels can be brazed and then hardened by quenching from the brazing temperature.

A filler metal with brazing temperature lower than the critical temperature of the steel can be used when no change in the metallurgical properties of the base metal is wanted.

## HIGH-CARBON AND HIGH-SPEED TOOL STEELS

HIGH-CARBON STEELS contain more than 0.45 percent carbon. High-carbon tool steels usually contain 0.60 to 1.40 percent carbon.

Brazing of high-carbon steels is best accomplished prior to or during the hardening operation. Hardening temperatures for carbon steels range from 1400 to 1500°F (760 to 820°C). Filler metals having brazing temperatures above 1500°F (820°C) should be used. When brazing and hardening are done in one operation, the filler metal should have a solidus at or below the austenitizing temperature.

Tempering and brazing can be combined for high-speed tool steels and high-carbon, high-chromium alloy tool steels which have tempering temperatures in the range of 1000 to 1200°F (540°C to 650°C). Filler metals with brazing temperatures in that range are used. The part is removed from the tempering furnace, brazed by localized heating methods, and then returned to the furnace for completion of the tempering cycle.

## CAST IRONS

CAST IRONS GENERALLY require special brazing considerations. The types of cast iron include white, gray, malleable, and ductile. White cast iron is seldom brazed.

Prior to brazing, faying surfaces generally are cleaned electrochemically or chemically, seared with an oxidizing flame, or grit blasted. When low-melting silver brazing filler metals are used, wetting by the brazing filler metal is easiest. Ductile and malleable cast irons should be brazed below 1400°F (760°C).

When high carbon cast iron is brazed with copper, the brazing temperature should be low to avoid melting of localized areas of the cast iron, particularly in light sections.

## STAINLESS STEELS

ALL OF THE stainless steel alloys are difficult to braze because of their high chromium content. Brazing of these alloys is best accomplished in purified (dry) hydrogen or in a vacuum. Dew points below -60°F (-51°C) must be maintained because wetting becomes difficult following the formation of chromium oxide. Torch brazing requires fluxing to reduce any chromium oxides present.

Most of the silver alloy, copper, and copper-zinc filler metals are used for brazing stainless steels. Silver alloys containing nickel are generally best for corrosion resistance. Filler metals containing phosphorus should not be used on highly stressed parts because brittle nickel and iron phosphides may be formed at the joint interface.

Boron-containing nickel filler metals are generally best for stainless steels containing titanium or aluminum, or both, because boron has a mild fluxing action which aids in wetting these base metals. Diffusion brazing produces joints with improved physical properties.

Brazing of the austenitic chromium-nickel stainless steels is discussed further in Chapter 18, *Brazing Manual*, 3rd Edition.

### Chromium Irons and Steels

THE MARTENSITIC STAINLESS steels (403, 410, 414, 416, 420, and 431) air harden upon cooling from brazing, which occurs above their austenitizing temperature range. Therefore, they must be annealed after brazing or during the brazing operation. These steels are also subject to stress cracking with certain brazing filler metals.

The ferritic stainless steels (405, 406, and 430) cannot be hardened and their grain structure cannot be refined by heat treatment. These alloys degrade in properties when brazed at temperatures above 1800°F (980°C), because of excessive grain growth. They lose ductility after long heating times between 650 and 1100°F (340 and 600°C). However, some of the ductility can be recovered by heating the brazement to approximately 1450°F (790°C) for a suitable time.

### Precipitation-Hardening Stainless Steels

THESE STEELS ARE basically stainless steels with additions of one or more of the elements copper, molybdenum, aluminum, and titanium. Such alloying additions make it possible to strengthen the alloys by precipitation hardening heat treatments. When alloys of this type are brazed, the brazing cycle and temperature must match the heat treatment cycle of the alloy. Manufacturers of these alloys have developed recommended brazing procedures for their particular steels.

## NICKEL AND HIGH-NICKEL ALLOYS

NICKEL AND THE high nickel alloys are embrittled by sulfur and low-melting metals present in brazing alloys, such as zinc, lead, bismuth, and antimony. Base metal surfaces must be thoroughly cleaned prior to brazing to remove any substances that may contain these elements. Sulfur and sulfur compounds must also be excluded from the brazing atmosphere.

Nickel and its alloys are subject to stress cracking in the presence of molten brazing filler metals. Parts should be annealed prior to brazing to remove residual stresses, or carefully stress relieved during the braze cycle.

Silver brazing filler metals are commonly used. In corrosive environments, high silver brazing alloys are preferred. Cadmium-free brazing filler metals are chosen to avoid stress corrosion cracking.

Nickel-base brazing filler metals offer the greatest corrosion and oxidation resistance and elevated temperature strength.

Brazing is a preferred method for joining dispersion-strengthened nickel alloys that must function at elevated temperatures. High strength brazements have been made with special nickel-base brazing filler metals and then tested up to 2400°F (1300°C).

## HEAT-RESISTANT ALLOYS

HEAT-RESISTANT ALLOYS are generally brazed in a hydrogen atmosphere or high temperature vacuum furnaces using nickel-base or special filler metals.

The cobalt-base alloys are the easiest of the super alloys to braze because most of them do not contain titanium or aluminum. Alloys that are high in titanium or aluminum are difficult to braze in dry hydrogen because titanium and aluminum oxides are not reduced at brazing temperatures.

## TITANIUM AND ZIRCONIUM

TITANIUM AND ZIRCONIUM combine readily with oxygen, and react to form brittle intermetallic compounds with many metals and with hydrogen and nitrogen. Parts must be cleaned before brazing and brazed immediately after cleaning.

Silver and silver-based filler metals were used in early brazing of titanium, but brittle intermetallics were formed and crevice corrosion resulted. Type 3003 aluminum foil will join thin, lightweight structures, such as complex honeycomb sandwich panels. Electroplating various elements on the base metal faying surfaces will let them react in situ with the titanium during brazing to form a titanium alloy eutectic. That transient liquid phase flows well and forms fillets, then solidifies due to interdiffusion.

Other brazing filler metals with high service capability and corrosion resistance include Ti-Zr-Ni-Be, Ti-Zr-Ni-Cu, and Ti-Ni-Cu alloys. The best braze processing is obtained in high vacuum furnaces using closely controlled temperatures in the range of 1650 to 1750° (900 to 955°C).

## CARBIDES AND CERMETS

CARBIDES OF THE refractory metals tungsten, titanium, and tantalum that are bonded with cobalt are used for cutting tools and dies. Closely related materials called *cermets* are ceramic particles bonded with various metals.

Brazing carbides and cermets is more difficult than brazing metals. Torch, induction, or furnace brazing is used, often with a sandwich brazing technique: a layer of weak, ductile metal (pure nickel or pure copper) is interposed between the carbide or cermet and a hard metal support. The cooling stresses cause the soft metal to deform instead of cracking the ceramic.

Silver-base brazing alloys, copper-zinc alloys, and copper are often used on carbide tools. Silver alloys containing nickel are preferred for their better wettability. The nickel base alloys containing boron and a 60% Pd - 40% Ni alloy may be satisfactory for brazing nickel- and cobalt-bonded cermets of tungsten carbide, titanium carbide, and columbium carbide.

## CERAMICS

ALUMINA, ZIRCONIA, MAGNESIA, forsterite ($Mg_2SiO_4$), beryllia, and thoria are ceramic materials which can be joined by brazing. They are inherently difficult to wet with conventional filler metals. Differences in thermal expansion, heat conduction, and ductility result in cracking and crack propagation at relatively low stresses.

If the ceramic is premetallized to facilitate wetting, copper, silver-copper, and gold-nickel filler metals are used. Titanium or zirconium hydride can be decomposed at the ceramic-metal interface to form an intimate bond.

Nonmetallized ceramics are brazed with silver-copper-clad or nickel-clad titanium wires. Useful titanium and zirconium alloys are Ti-Zr-Be, Ti-V-Zr, Zr-V-Cb, Ti-V-Be, and Ti-V-Cr.

## PRECIOUS METALS

THE PRECIOUS METALS silver, gold, platinum, and palladium present few brazing difficulties. Their thin oxide films are readily removed by fluxes and reducing atmospheres.

Resistance or furnace brazing is common for electrical contacts. Silver (BAg) and precious metal (BAu) filler metals braze contacts to holders.

## REFRACTORY METALS

TUNGSTEN, MOLYBDENUM, TANTALUM, and columbium brazing is still in the developmental stages.

### Tungsten

TUNGSTEN CAN BE brazed to itself and to other metals and nonmetals with nickel-base filler metals, but interaction between tungsten and nickel will recrystallize the base metal. The tungsten should be stress relieved by heat treatment prior to brazing, and the brazing cycle should be short to limit interaction with the filler metal.

### Molybdenum

MOLYBDENUM AND ITS alloys are brazed with palladium-base filler metals and molybdenum-base metals (Mo-0.5Ti) with high recrystallization temperatures. Chromium plating, as a barrier layer, prevents formation of intermetallic compounds. Most high-temperature brazing filler metals are suitable for oxidation resistant service for coating applications.

### Tantalum and Columbium

TANTALUM AND COLUMBIUM require special techniques to be satisfactorily brazed. All reactive gases must be removed from the brazing atmosphere. These include oxygen, nitrogen, carbon monoxide, ammonia, and hydrogen. Tantalum forms oxides, nitrides, carbides, and hydrides very readily, leading to a loss of ductility. For oxidation protection at high temperatures, tantalum and columbium are often electroplated with copper or nickel. The brazing filler metal must be compatible with any plating used.

## DISSIMILAR METAL COMBINATIONS

MANY DISSIMILAR METAL combinations may be brazed, even those with metallurgical incompatibility that precludes welding.

Important criteria to be considered start with differences in thermal expansion. If a metal with high thermal expansion surrounds a low expansion metal, clearances at room temperature which are satisfactory for capillary flow will be too great at brazing temperature. Conversely, if a low expansion metal surrounds a high expansion metal, no clearance may exist at brazing temperature. For example, when brazing a molybdenum plug in a copper block, the parts must be a press fit at room temperature; if a copper plug is to be brazed in a molybdenum block, a properly centered loose fit at room temperature is required.

In brazing tube-and-socket type joints between dissimilar base metals, the tube should be the low expansion metal and the socket the high expansion metal. At brazing temperature, the clearance will be maximum and the capillary will fill with brazing alloy. When the joint cools to room temperature, the brazed joint and the tube will be in compression.

A tongue-in-groove joint should place the groove in the low expansion material. The fit at room temperature should be designed to give capillary joint clearances on both sides of the tongue at brazing temperature. Longitudinal shear stresses in the braze metal are limited by making overlap distances small.

"Sandwich brazing" is commonly used to manufacture carbide-tipped metal cutting tools. A relatively ductile metal is coated on both sides with brazing filler metal, and the composite is used in the joint. This places a third material in that joint which will deform during cooling and reduce the stresses caused by differential contraction of the parts brazed together.

The filler metal used to braze dissimilar metals must be compatible with both base metals. It should have corrosion or oxidation resistance at least equal to the poorer of the two metals being brazed. It should not form galvanic couples which could promote crevice corrosion in the braze area. Brazing filler metals form low melting phases with many base metals, requiring adaption of the brazing cycle, quantity and placement of filler metal, and joint design.

Metallurgical reactions between the brazing filler metal and dissimilar base metals may be objectionable. One example is the brazing of aluminum to copper. Copper reacts with aluminum to form a low melting brittle compound. Such problems can be overcome by coating one of the base metals with a metal which is compatible with the brazing filler metal. To braze aluminum to copper, the copper is plated with silver, or a high silver alloy. The joint is then brazed at 1500°F (816°C) with a standard aluminum brazing filler metal. Nickel plating would also form a suitable diffusion barrier.

# JOINT DESIGN

BASICALLY TWO TYPES of joints are used in brazing: the lap joint and, the butt joint. These joints are shown in Figure 12.11.

The lap joint may be made as strong as the weaker member, even when using a low strength filler metal or in the presence of small defects in the joint, by using an overlap at least three times the thickness of the thinner member. Lap joints feature high joint efficiency and ease of fabrication; they have the disadvantage that the increased metal thickness at the joint creates a stress concentration at those abrupt changes in cross section.

Butt joints are used where the lap joint thickness would be objectionable, and where the strength of a brazed butt joint will satisfactorily meet service requirements. The joint strength depends only partly on the filler metal strength.

The scarf joint is a variation of the butt joint. As shown in Figure 12.12, the cross-sectional area of this joint is increased without an increase in metal thickness. Two disadvantages which limit its use: the sections are difficult to align, and the joint is difficult to prepare, particularly in thin members. Since the joint is at an angle to the axis of tensile loading, the load-carrying capacity is that of a lap joint.

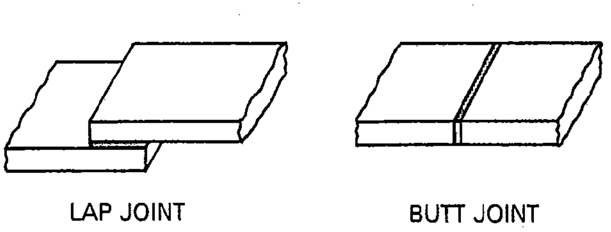

**Figure 12.11–Basic Lap and Butt Joints for Brazing**

## JOINT CLEARANCE

JOINT CLEARANCE HAS a major effect on the mechanical performance of a brazed joint. This applies to all types of loading, such as static, fatigue, and impact, and to all joint designs. Several effects of joint clearance on mechanical performance are (1) the purely mechanical effect of restraint to plastic flow of the filler metal by a higher strength base metal, (2) the possibility of slag entrapment, (3) the possibility of voids, (4) the relationship between joint clearance and capillary force which accounts for filler metal distribution, and (5) the amount of filler metal that must be diffused with the base metal when diffusion brazing.

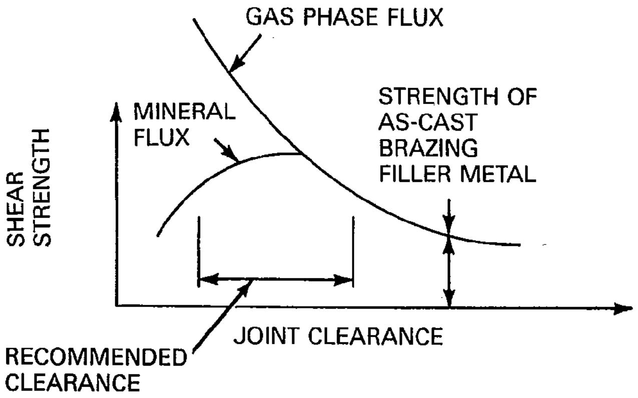

**Figure 12.12–Relationship Between Joint Clearance and Shear Strength for two Fluxing Methods**

If the brazed joint is free of defects (no flux inclusions, voids, unbrazed areas, pores, or porosity), its strength in shear depends upon the joint thickness, as illustrated in Figure 12.13. This figure indicates the change in joint shear strength with joint clearance. Table 12.6 may be used as a guide for clearances at brazing temperature when designing brazed joints for maximum strength.

Some specific clearance versus strength data for silver brazed butt joints in steel are shown in Figures 12.14 and 12.15.[3] Figure 12.14 shows the optimum shear values obtained with joints in 0.5 in. (12.7 mm) round drill rod using pure silver. The rods were butt brazed by induction heating in a dry 10 percent hydrogen-90 percent nitrogen atmosphere. Figure 12.15 relates tensile strength to joint thickness for butt brazed joints of the same size. Note how the strength decreased at extremely small clearances.

Preplaced filler is brazing filler metal placed in the joint, such as foil placed between two plates. In this application, the clearances noted in Table 12.6 generally do not apply. In applications using preplaced filler metal, the members being joined should be preloaded so that the joint clearance will decrease during the brazing operation. That forces the filler metal into voids created by the normal roughness of the faying surfaces. In some applications, additional filler metal is made available by extending the filler metal shim out beyond the joint edges.

The type of fluxing will have an important bearing on the joint clearance to used to accomplish a given brazement.

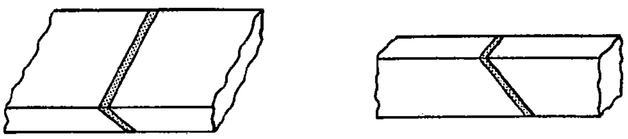

Figure 12.13–Typical Scarf Joint Designs

A mineral flux must melt at a temperature below the melting range of the brazing filler metal, and it must flow into the joint ahead of the filler metal. When the joint clearance is too small, the mineral flux may be held in the joint and not be displaced by the molten filler metal. This will produce joint defects. When the clearance is too large, the molten filler metal will flow around pockets of flux, causing excessive flux inclusions.

The joint clearance at the brazing temperature of a joint between dissimilar base metals must be calculated from thermal expansion data. Figure 12.16 shows thermal expansion data for some materials. Figure 12.17 can be used to find the diametral clearance at brazing temperature between dissimilar metals.

### Table 12.6
### Recommended Joint Clearance at Brazing Temperature

| Filler Metal AWS Classification[a] | in. | mm | Joint Clearance[b] |
|---|---|---|---|
| BA1Si Group | 0.006-0.010 | 0.15-0.25 | For length at lap less than 1/4 in. (6.35 mm) |
| | 0.010-0.025 | 0.25-0.61 | For length at lap greater than 1/4 in. (6.35 mm) |
| BCuP Group | 0.001-0.005 | 0.03-0.12 | |
| BAg Group | 0.002-0.005 | 0.05-0.12 | Flux brazing (mineral fluxes) |
| | 0.001-0.002[c] | 0.03-0.05 | Atmosphere brazing (gas phase fluxes) |
| BAu Group | 0.002-0.005 | 0.05-0.12 | Flux brazing (mineral fluxes) |
| | 0.000-0.002[c] | 0.00-0.05 | Atmosphere brazing (gas phase fluxes) |
| BCu Group | 0.000-0.002[c] | 0.00-0.05 | Atmosphere brazing (gas phase fluxes) |
| BCuZn Group | 0.002-0.005 | 0.05-0.12 | Flux brazing (mineral fluxes) |
| BMg Group | 0.004-0.010 | 0.10-0.25 | Flux brazing (mineral fluxes) |
| BNi Group | 0.002-0.005 | 0.05-0.12 | General applications (flux or atmosphere) |
| | 0.000-0.002 | 0.00-0.05 | Free flowing types, atmosphere brazing |

a. See Table 12.2 for an explanation of filler metals.

b. Clearance on the radius when rings, plugs, or tubular members are involved. On some applications it may be necessary to use the recommended clearance on the diameter to assure not having excessive clearance when all the clearance is on one side. An excessive clearance will produce voids. This is particularly true when brazing is accomplished in a high quality atmosphere (gas phase fluxing).

c. For maximum strength, a press fit of 0.001 mm/mm or in./in. of diameter should be used.

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[3] The data in Figures 12.14 and 12.15 were obtained with nonstandard test specimens.

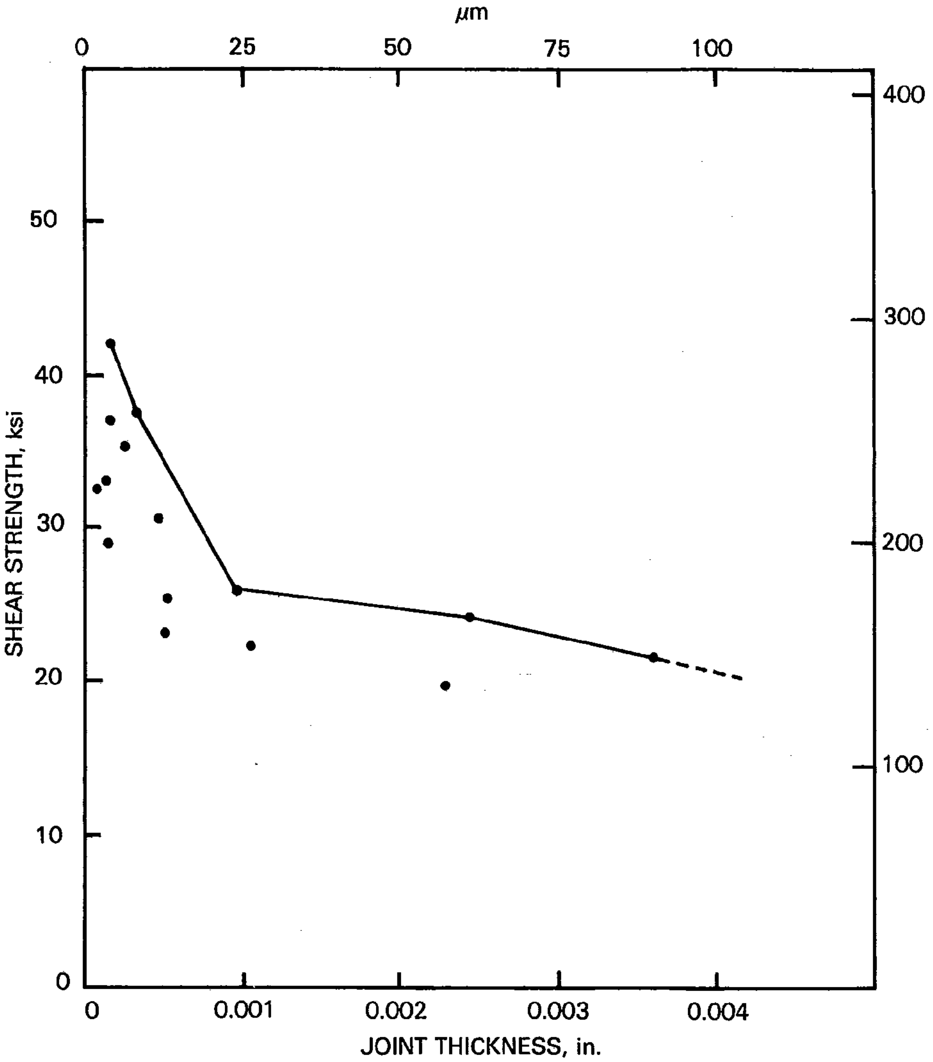


**Figure 12.14–Relationship of Shear Strength to Brazed Joint Thickness for Pure Silver Joints in 0.5 in. (12.7 mm) Diameter Steel Drill Rod**

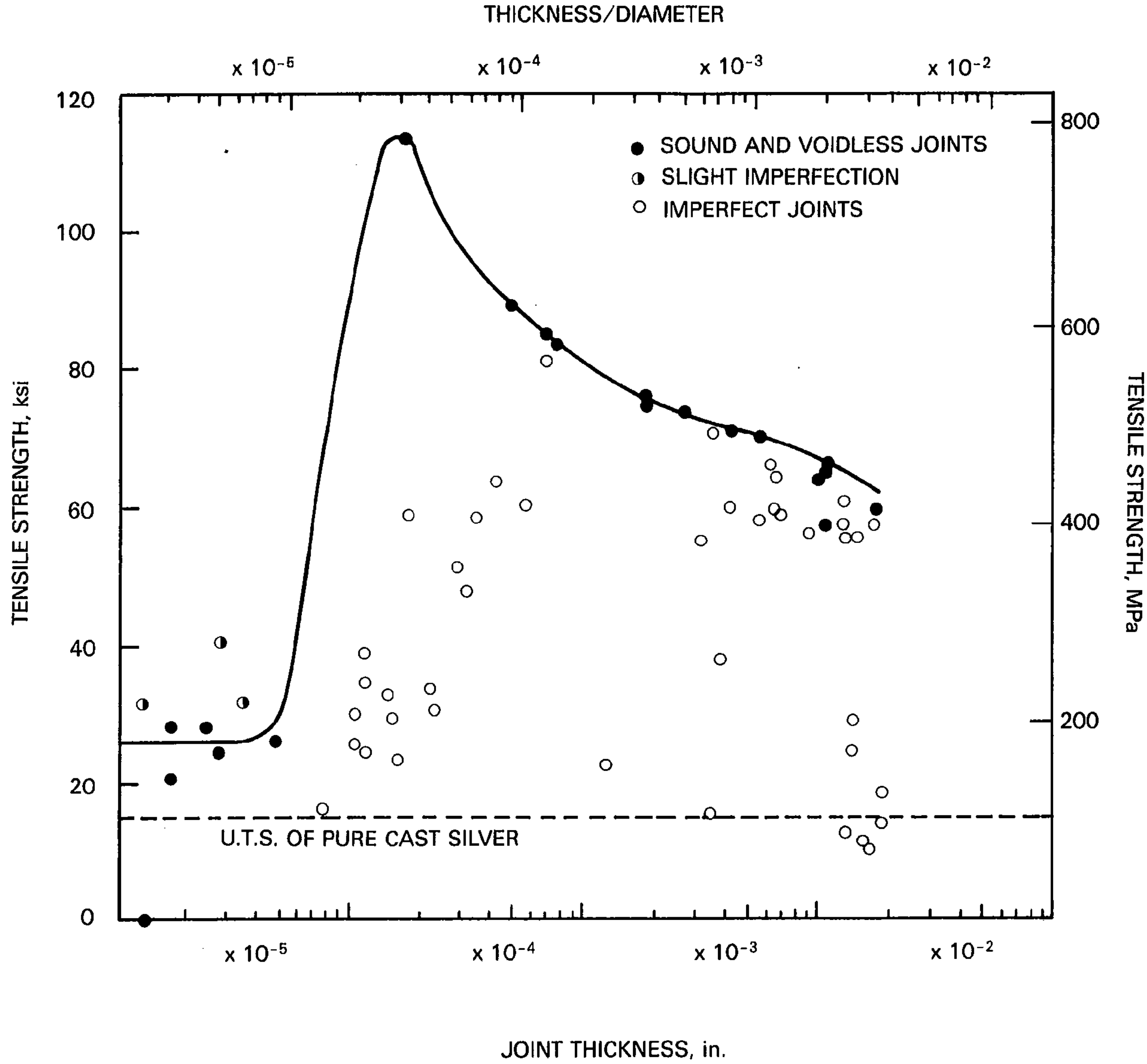


**Figure 12.15–Relationship of Tensile Strength to Brazed Joint Thickness of 0.5 in. (12.7 mm) Diameter Silver Brazed Butt Joints in 4340 Steel**

To withstand high differential thermal expansion of two metals being brazed, the brazing filler metal must be strong enough to resist fracture and the base metal must yield during cooling. Some residual stress will remain in the final brazement. Thermal cycling of such a brazement during its service life will repeatedly stress the joint area, which may shorten the service life. Dissimilar metal brazements should be designed so that residual stresses do not add to the stress imposed during service.

## STRESS DISTRIBUTION

HIGH-STRENGTH BRAZEMENTS ARE designed to fail in the base metal. In brazements where joints will be lightly loaded, it is economical to use simplified joint designs which may break in the brazed joint if overstressed in testing or in service.

A good brazement design will incorporate joints that avoid high-stress concentration at the edges of the braze

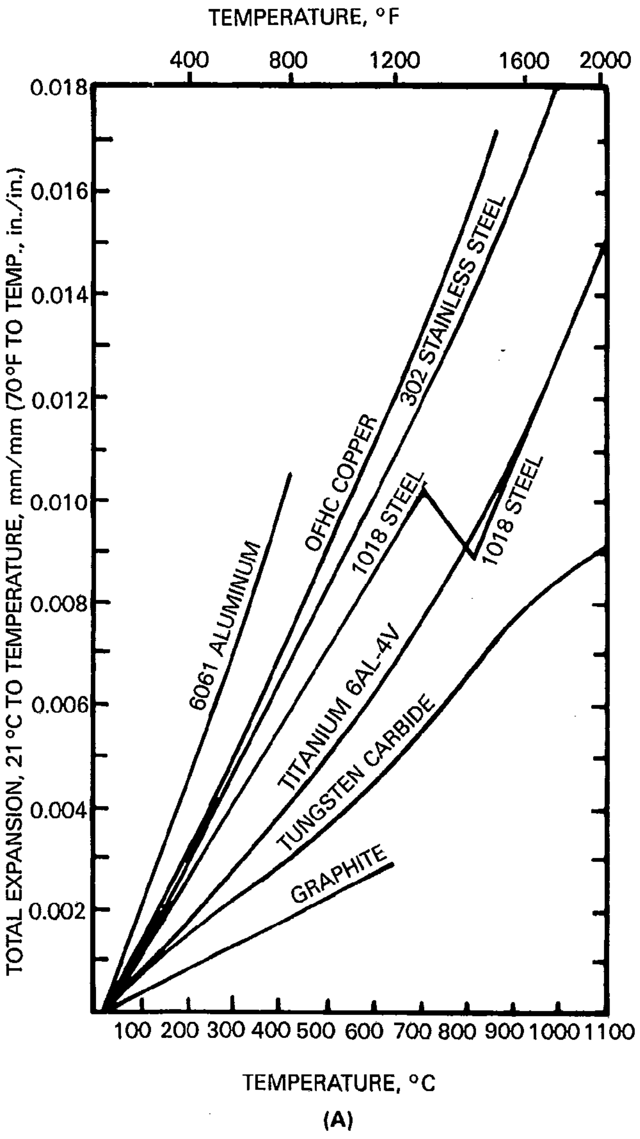


**Figure 12.16–Thermal Expansion Curves for Some Common Materials**

and will distribute the stresses uniformly into the base metal. Typical designs are shown in Figures 12.18 through 12.21.

A fillet of brazing filler metal is not good brazing design. It is seldom possible to make the brazing filler metal consistently form a desired fillet size and contour. When the fillets become too large, shrinkage or piping porosity will act as a stress concentration.

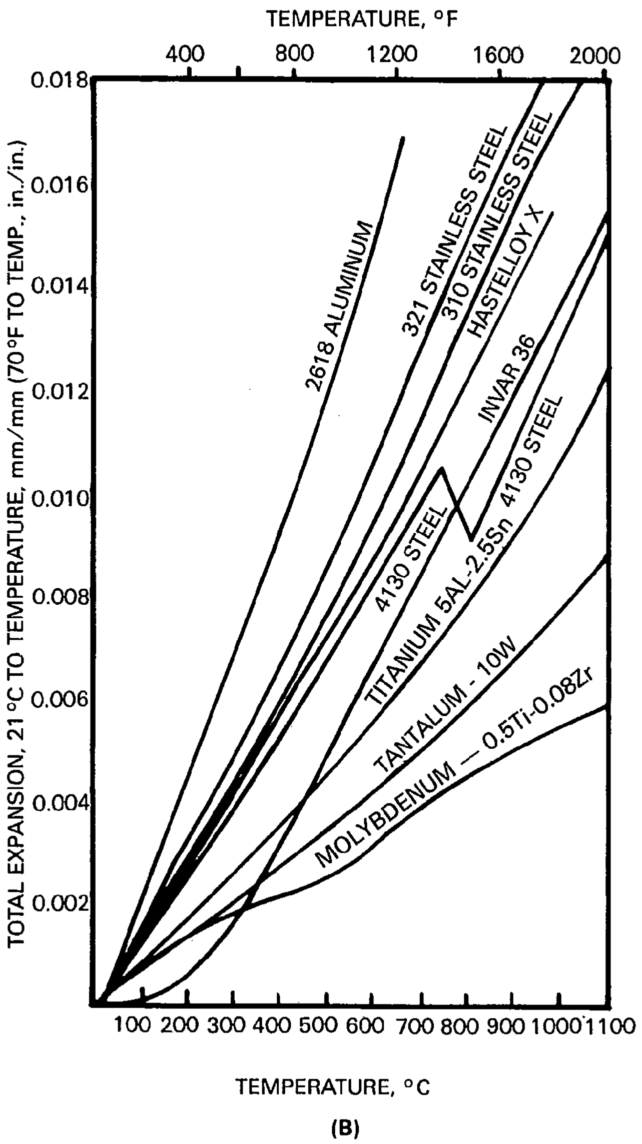
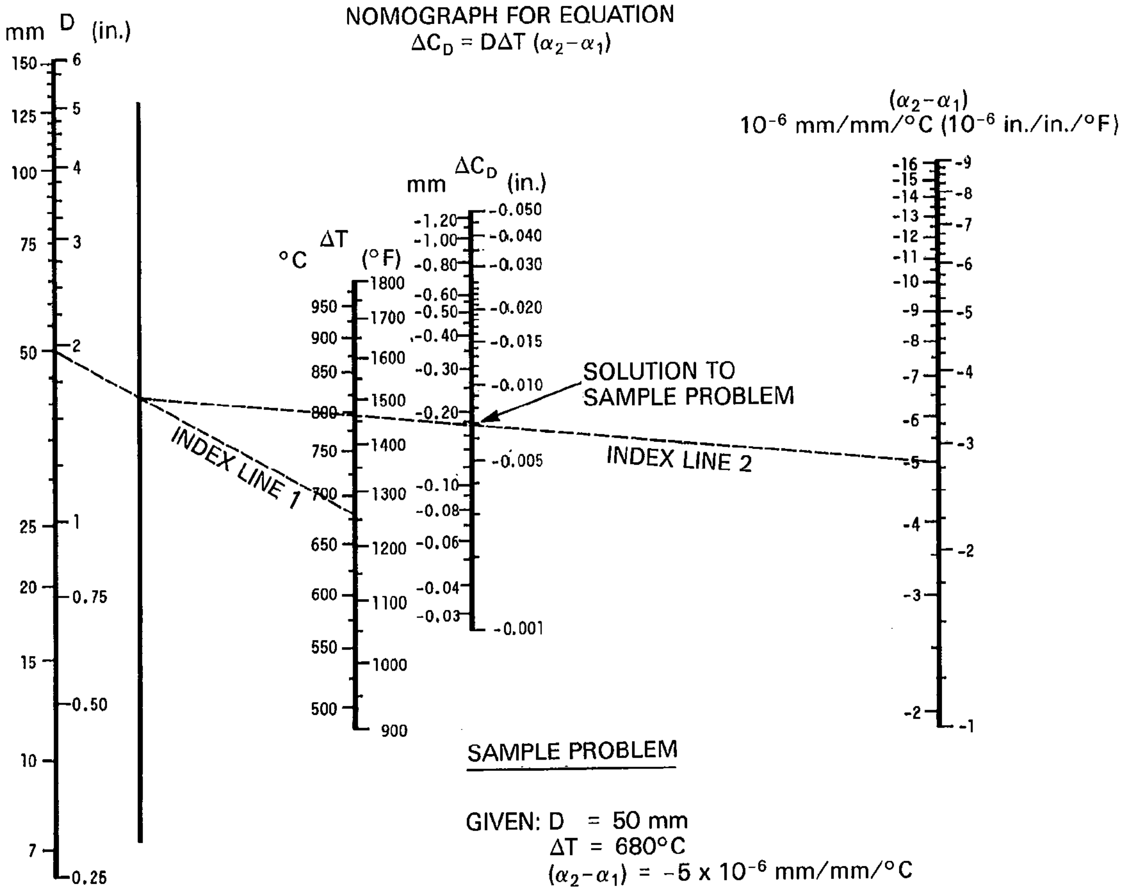


**Figure 12.16 (Continued)–Thermal Expansion Curves for Some Common Materials**

## ELECTRICAL CONDUCTIVITY

BRAZING FILLER METALS in general have low electrical conductivity compared to copper. However, a braze joint will not add appreciable resistance to the circuit when properly designed.

With butt joints, the brazed joint thickness (resistance) is very small compared to the length-wise resistance of the conductor, even though the unit resistivity of the filler metal is much higher than that of the base metal. Never-



NOMOGRAPH FOR EQUATION
$\Delta C_D = D\Delta T\,(\alpha_2-\alpha_1)$

SAMPLE PROBLEM

GIVEN: D = 50 mm
$\Delta T$ = 680°C
$(\alpha_2-\alpha_1) = -5 \times 10^{-6}$ mm/mm/°C

SOLUTION: $\Delta C_D$ = -0.17 mm

NOTES:

1. This nomograph gives change in diameter caused by heating. Clearance to promote brazing filler metal flow must be provided at brazing termperature.
2. D = nominal diameter of joint, mm (in.)
$\Delta C_D$ = change in clearance, mm (in.)
$\Delta T$ = brazing temperature minus room temperature, °C (°F)
$\alpha 1$ = mean coefficient of thermal expansion, male member, mm/mm/°C (in./in./°F)
$\alpha 2$ = mean coefficient of thermal expansion, female member, mm/mm/°C (in./in./°F)
3. This nomograph assumes a case where $\alpha_1$ exceeds $\alpha_2$ so that scale value for $(\alpha_1-\alpha_2)$ is negative. Resultant values for $\Delta C_D$ are therefore also negative, signifying that the joint gap reduces upon heating. Where $(\alpha_2-\alpha_1)$ is positive, values of $\Delta C_D$ are read as positive, signifying enlargement of the joint gap upon heating.

**Figure 12.17–Nomograph for Finding the Change in Diametral Clearance in Dissimilar Metal Joints**

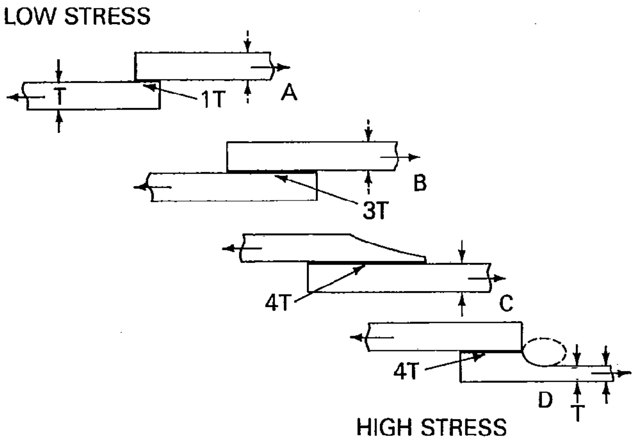


**Figure 12.18–Brazed Lap Joint Designs for use at Low and High Stresses—Flexure of Right Member in C and D will Distribute the Load Through the Base Metal**

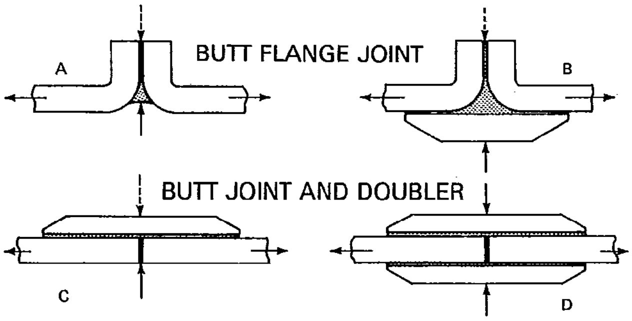


**Figure 12.20–Butt Joing Designs for Sheet Metal Brazements—The Loading in Joint A cannot be Symmetrical**

theless, a filler metal with low resistivity should be used, provided it will meet all other requirements of the project.

Since voids in the brazed joint will reduce the effective area of the electrical path, lap joints are recommended. A lap length at least 1-1/2 times the thickness of the thinner member will have a joint resistance approximately equal to the same length in solid copper.

## TESTING OF BRAZED JOINTS

STANDARDIZING TESTING TO evaluate the strength of brazed joints must be adopted. Different designs of test specimens yield different results. Note in Figure 12.22 that the "apparent joint strength" measured for a low overlap distance is high in comparison to the long overlap strength. Two laboratories that each test only one overlap distance may be testing at opposite ends of the curve, with widely different conclusions. The entire usable overlap range of the curve must be sampled to obtain adequate data.

The load-carrying capacity of the joint is best revealed in the right-hand portion of the base metal curve. The brazement should be designed to fail in the base metal without an excessive overlap.

For further information, refer to the latest edition of AWS C3.2, *Standard Method for Evaluating the Strength of Brazed Joints in Shear.*

## BRAZING METALLURGY

BRAZING TEMPERATURES ARE below the solidus of the metal(s) being joined. Metallurgical changes that accom-

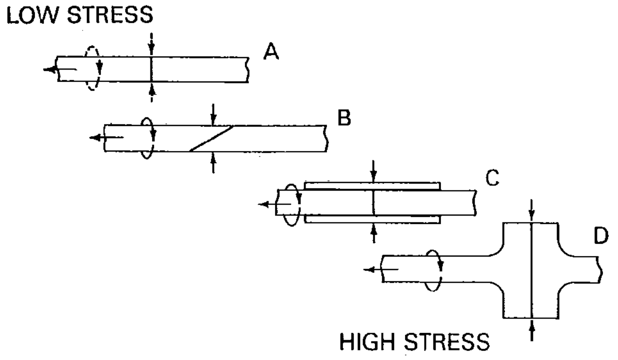


**Figure 12.19–Brazed Butt Joint Designs to Increase Capacity of Joint for High Stress and Dynamic Loading**

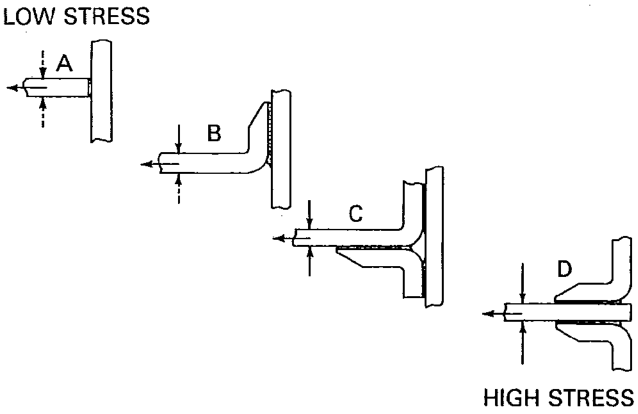


**Figure 12.21–T-joint Designs for Sheet Metal Brazements**

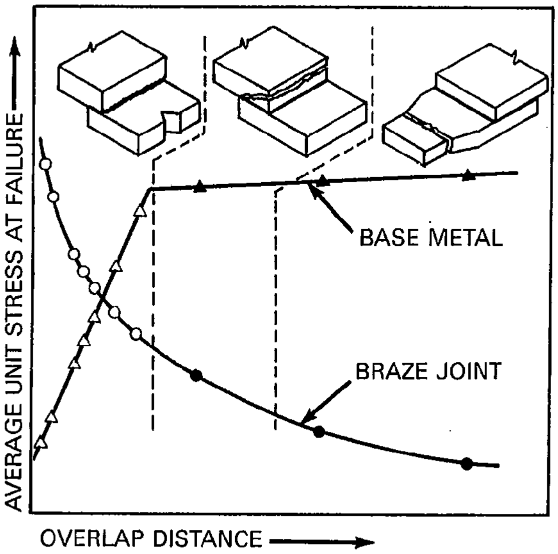


**Figure 12.22–Average Unit Shear Stress in the Brazed Lap Joint and Average Unit Tensile Strength in the Base Metal as Functions of Overlap Distance—(Open Symbols Represent Failures in the Filler Metal; Filled Symbols Represent Failures in the Base Metal)**

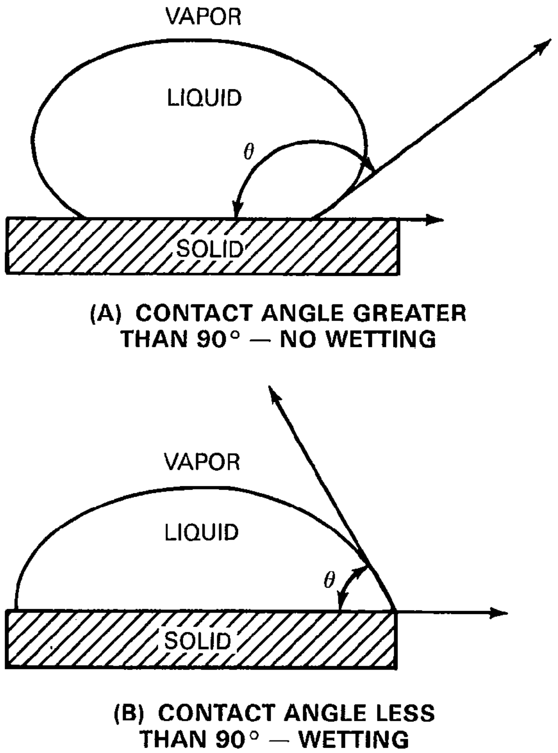
pany brazing are restricted to solid-state reactions in the base metal, solidification and interface reactions between the brazing filler metal and base metal, reactions within the solid filler metal.

The capillary flow of brazing metal depends upon its surface tension, wetting characteristics, and physical and metallurgical reactions with the base material, flux or atmosphere, and oxides on the base metal surface. The flow is further controlled by hydrostatic pressure within the joint. Figure 12.23 is an idealized presentation of the wetting concept.

A contact angle less than 90 degrees measured between the solid and liquid usually identifies a positive wetting characteristic. Contact angles greater than 90 degrees indicate no wetting (dewetting).

In some brazing processes, wetting and spreading are assisted by the addition of flux. In vacuum brazing, flow and wetting depend entirely upon surface interactions between the liquid metal and base metal. Most oxides are readily displaced or removed by flux. Oxides of chromium, aluminum, titanium, and manganese require special treatments.

At peak temperature in the brazing cycle, when liquid filler metal is present in the joint, erosion can occur in the base metal. The rate of dissolution of the base metal by the filler metal depends on the mutual solubility limits, the quantity of brazing filler metal available to the joint, the brazing temperature, and the potential formation of lower temperature eutectics.



(A) CONTACT ANGLE GREATER THAN 90° — NO WETTING

(B) CONTACT ANGLE LESS THAN 90° — WETTING

**Figure 12.23–Wetting Angles of Brazing Filler Metals**

Sometimes an interlayer of intermetallic compound may form between the filler metal and the base metal during the joining operation. Phase diagrams are used to predict intermetallic compound formation.

Once the filler metal has solidified to form the joint, subsequent effects may be controlled by diffusion phenomena. When joining super alloys with a nickel-base filler metal containing boron, subsequent thermal cycles diffuse the boron into the base metal. This method of metallurgical joining is called *liquid-activated diffusion welding*, but actually, it is an extension of the joining mechanism in brazing.

Liquid filler metal penetration between base metal grain boundaries may occur. Base metals in a stressed state are particularly susceptible to liquid metal penetration. Copper-based filler metals used on high iron-nickel alloys under stress fail rapidly. Alloying elements diffuse more rapidly into grain boundaries than into a crystal lattice.

If a eutectic is formed, being low-melting it may fill any grain-boundary crack as it separates; then little damage may be done. This is known as an *intrusion*.

The dynamic characteristics of the brazing process are receiving increasing recognition, and careful consideration is being given to the subsequent diffusion and metallurgical changes that can occur in service. At elevated temperatures, changes may occur in the solid-state as a direct result of diffusion, oxidation, or corrosion. This means that the metallurgical and mechanical properties of these joints may change in service and must be evaluated as part of the joint qualification procedure.

# BRAZING PROCEDURES

## PRECLEANING AND SURFACE PREPARATION

CLEAN, OXIDE-FREE SURFACES are essential to ensure sound brazed joints of uniform quality. Grease, oil, dirt, and oxides prevent the uniform flow and bonding of the brazing filler metal, and they impair fluxing action resulting in voids and inclusions. With the refractory oxides or critical atmosphere brazing applications, precleaning must be more thorough and the cleaned components must be preserved and protected from contamination.

The length of time that cleaning remains effective depends upon the metals involved, the atmospheric conditions, the amount of handling the parts may receive, the manner of storage, and similar factors. It is recommended that brazing be done as soon as possible after the parts have been cleaned.

Degreasing is generally done first. The following degreasing methods are commonly used, and their action may be enhanced by mechanical agitation or by applying ultrasonic vibrations to the bath:

(1) Solvent cleaning: petroleum solvents or chlorinated hydrocarbons
(2) Vapor degreasing: stabilized trichloroethylene or stabilized perchloroethylene
(3) Alkaline cleaning: commercial mixtures of silicates, phosphates, carbonates, detergents, soaps, wetting agents and, in some cases, hydroxides
(4) Emulsion cleaning: mixtures of hydrocarbons, fatty acids, wetting agents, and surface activators
(5) Electrolytic cleaning: both anodic and cathodic

Scale and oxide removal can be accomplished mechanically or chemically. Prior degreasing allows intimate contact of the pickling solution with the parts, and vibration aids in descaling with any of the following solutions:

(1) Acid cleaning: phosphate type acid cleaners
(2) Acid pickling: sulfuric, nitric, and hydrochloric acid
(3) Salt bath pickling: electrolytic and nonelectrolytic

The selection of chemical cleaning agent will depend on the nature of the contaminant, the base metal, the surface condition, and the joint design. For example, base metals containing copper and silver should not be pickled with nitric acid. In all cases, the chemical residue must be removed by thorough rinsing to prevent formation of other equally undesirable films on the joint surfaces, or subsequent chemical attack of the base metal.

Mechanical cleaning removes oxide and scale and also roughens the mating surfaces to enhance capillary flow and wetting by the brazing filler metal. Grinding, filing, machining, and wire brushing can be used. Grit blasting can be done with clean blasting material such as silica sand, alumina, and other nonmetallics. They must not leave any deposit on the surfaces that would impair brazing.

## FLUXING AND STOPOFF

WHEN A FLUX is selected for use, it must be applied as an even coating, completely covering the joint surfaces of the parts. Fluxes are most commonly applied in the form of pastes or liquids. Dry powdered flux may be sprinkled on the joint or applied by dipping the heated end of the filler metal rod into the flux container. The particles should be small and thoroughly mixed to improve metal coverage and fluxing action. The areas surrounding the joints may be kept free from discoloration and oxidation by applying flux to a wide area on each side of the joint.

The paste and liquid flux should adhere to clean metal surfaces. If the metal surfaces are not clean, the flux will ball up and leave bare spots. Thick paste fluxes can be applied by brushing. Less viscous consistencies can be applied by dipping, hand squirting, or automatic dispensing. The proper consistency depends upon the types of oxides present, as well as the heating cycle. For example, ferrous oxides formed during fast heating of the base metal are soft and easy to remove, and only limited fluxing action is required. However, when joining copper or stainless steel or when the heating cycle is long, a concentrated flux is required. Flux reacts with oxygen, and once it becomes saturated, it loses all its effectiveness. The viscosity of the flux may be reduced without dilution by heating it to 120 to 140°F (50 to 60°C), preferably in a ceramic-lined flux or glue pot with a thermostat control. Warm flux has low surface tension and adheres to the metal more readily.

When filler metal flow must be restricted to definite areas, "stopoffs" are employed to outline the areas that are not to be brazed. Some commercial stopoff preparations are a slurry in water or an organic binder of oxides of aluminum, chromium, titanium, or magnesium. Others are called *parting compounds* and *surface reaction stopoffs*.

## BRAZING FILLER METAL PLACEMENT

WHEN DESIGNING A brazed joint, the brazing process to be used and the manner in which the filler metal will be placed in the joint should be established. In most manually brazed joints, the filler metal is simply fed from the face side of the joint. For furnace brazing and high production brazing, the filler metal is preplaced at the joint. Automatic dispensing equipment may perform this operation.

Brazing filler metal is available in the form of wire, shims, strip, powder, and paste. Figures 12.24 and 12.25 illustrate methods of preplacing brazing filler metal in wire and sheet forms. When the base metal is grooved to accept preplaced filler metal, the groove should be cut in the heavier section. When computing the strength of the intended joint, the groove area should be subtracted from the joint area, since the brazing filler metal will flow out of the groove and into the joint interfaces, as shown in Figure 12.26.

Powdered filler metal can be applied in any of the locations indicated in Figure 12.24. It can be applied dry to the joint area and then wet down with binder, or it can be premixed with the binder and applied to the joint. The density of powder is usually only 50 to 70 percent of a solid metal, so the groove volume must be larger for powder.

Where preplaced shims are used, the sections being brazed should be free to move together when the shims melt. Some type of loading may be necessary to move them together and force excess filler metal and flux out of the joint.

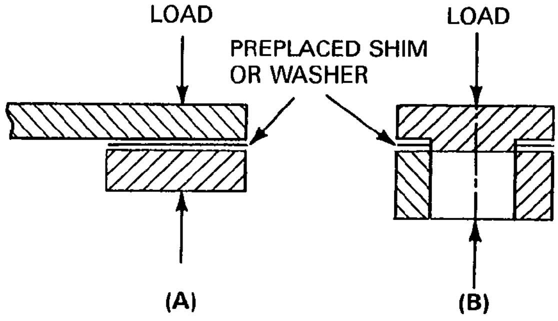


Figure 12.25–Preplacement of Brazing Filler Shims

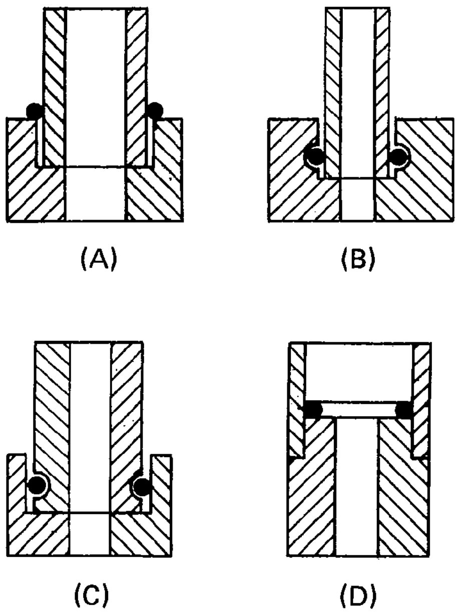


Figure 12.24–Methods of Preplacing Brazing Filler Wire

## ASSEMBLY

THE PARTS TO be brazed should be assembled immediately after fluxing, before the flux has time to dry and flake off. Assemblies designed to be self-locating and self-supporting are the most economical.

When fixtures are needed to maintain alignment or dimensions, the mass of a fixture should be minimized. It should have pinpoint or knife-edge contact with the parts, away from the joint area. Sharp contacts minimize heat loss through conduction to the fixture. The fixture material must have adequate strength at brazing temperature to support the brazement. It must not readily alloy at elevated temperatures with the work at the points of contact. In torch brazing, extra clearance will be needed to access the joint with the torch flame as well as the brazing filler metal. In induction brazing, fixtures are generally made of ceramic materials to avoid putting extraneous metal in the field of the induction coil. Ceramic fixtures may be designed to serve as a heat shield or a heat absorber.

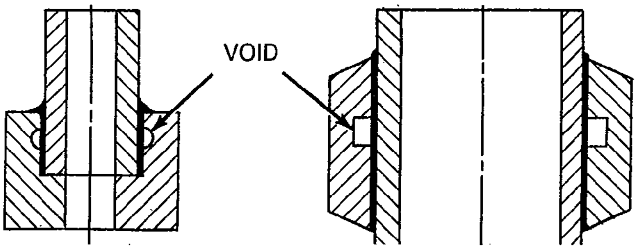


Figure 12.26–Brazed Joints with Grooves for Preplacement of Filler Metal; After the Brazing Cycle the Grooves are Void of Filler Metal

### Flux Removal

FOR ALL PROCESSES, all traces of flux should be removed from the brazement. Flux residues usually may be removed by rinsing with hot water. Oxide-saturated flux is glass-like and more difficult to remove. If the metal and joint design can withstand quenching, saturated flux can be removed by quenching the brazement from an elevated temperature. This treatment cracks off the flux coating. In stubborn cases, it may be necessary to use a warm acid solution, such as 10 percent sulfuric acid, or one of the proprietary cleaning compounds which are available commercially. Nitric acid should not be used on alloys containing copper or silver.

Fluxes used for brazing aluminum are not readily soluble in cold water. They are usually rinsed in very hot water, above 180°F (82°C), with a subsequent immersion in nitric acid, hydrofluoric acid, or a combination of those acids. A thorough water after-rinse is then necessary.

Oxidized areas adjacent to the joint may be restored by chemical cleaning or by mechanical methods, such as wire brushing or blast cleaning.

### Stopoff Removal

STOPOFF MATERIALS OF the "parting-compound" type can be easily removed mechanically by wire brushing, air blasting, or water flushing. The "surface-reaction" type used on corrosion and heat resistant base metals can best be removed by pickling in hot nitric acid-hydrofluoric acid, except in assemblies containing copper and silver. Sodium hydroxide (caustic soda) or ammonium bifluoride solutions can be used in all applications, including copper and silver, because they will not attack base metals or filler metals. A few stop off materials can readily be removed by dipping in 5 to 10 percent nitric or hydrochloric acid.

# INSPECTION

INSPECTION OF BRAZEMENTS should always be required to protect the ultimate user, but it's often specified by regulatory codes and by the fabricator. Inspection of brazed joints may be conducted on test specimens or by tests of the finished brazed assembly. The tests may be nondestructive or destructive.

Generally, brazing discontinuities are of three general classes:

(1) Those associated with drawing or dimensional requirements
(2) Those associated with structural discontinuities in the brazed joint
(3) Those associated with the braze metal or the brazed joint

## NONDESTRUCTIVE TESTING METHODS

THE OBJECTIVES OF nondestructive inspection of brazed joints should be (1) to seek out discontinuities defined in quality standards or codes, and (2) to obtain clues to the causes of irregularities in the fabricating process.

### Visual Inspection

EVERY BRAZED JOINT should be examined visually. It is a convenient preliminary test when other test methods are to be used.

The joint should be free from foreign materials: grease, paint, oil, oxide film, flux, and stopoff. Visual examination should reveal flaws due to damage, misalignment and poor fit-up of parts, dimensional inaccuracies, inadequate flow of brazing filler metals, exposed voids in the joint, surface flaws such as cracks or porosity, and heat damage to base metal.

Visual inspection will not detect internal flaws, such as flux entrapment in the joint or incomplete filler metal flow between the faying surfaces.

### Proof Testing

PROOF TESTING IS a method of inspection that subjects the completed joint to loads slightly in excess of those that will be experienced during its subsequent service life. These loads can be applied by hydrostatic methods, by tensile loading, by spin testing, or by numerous other methods. Occasionally, it is not possible to assure a serviceable part by any of the other nondestructive methods of inspection, and proof testing then becomes the most satisfactory method.

### Leak Testing

PRESSURE TESTING DETERMINES the gas or liquid tightness of a closed vessel. It may be used as a screening method to find gross leaks before adopting sensitive test methods. A low pressure air or gas test may be done by one of three methods (sometimes used in conjunction with a pneumatic proof test): (1) submerging the pressurized vessel in water and noting any signs of leakage by rising air bubbles; (2) pressurizing the assembly, closing the air or gas inlet source, and then noting any change in internal pressure over a period of time (corrections for temperature may be necessary); or (3) pressurizing the assembly and checking for leaks by brushing the joint area with a soap solution or a commercially available liquid and noting any bubbles and their source.

A method sometimes used in conjunction with a hydrostatic proof test is to examine the brazed joints visually for indications of the hydrostatic fluid escaping through the joint.

The leak testing of brazed assemblies with freon is extremely sensitive. The part under test is pressurized using either pure freon gas, or a gas such as nitrogen containing a tracer, usually Freon 12. Areas are sniffed or probed with a sampling device which is sensitive to the halide ion. The detection of a leak is indicated by a meter or an audible alarm. A leak may be measured quantitatively by this method. Precaution must be taken to avoid contaminating the surrounding air with freon which will decrease the sensitivity of the method.

A less sensitive method is to probe for leaks of the tracer gas with a butane gas torch flame. The presence of Freon 12 is indicated by a change in the flame color. Flame testing must not be used near combustible material.

The mass spectrometer leak test is the most sensitive and accurate way of detecting extremely small leaks. A tracer gas, such as helium or hydrogen, is used in conjunction with a mass spectrometer in one of two ways: (1) Evacuate the brazed assembly and surround the area to be tested with the tracer gas—the mass spectrometer is coupled to the interior; or (2) Pressurize the brazed assembly with the tracer gas and sniff the exterior with the mass spectrometer probe. A sensitive-sensing device detects the tracer gas and converts it to an electrical signal.

## Liquid Penetrant Inspection

THIS NDT METHOD finds cracks, porosity, incomplete flow, and similar surface flaws in a brazed joint. Commercially colored or fluorescent penetrants penetrate surface openings by capillary action. After the surface penetrant has been removed, any penetrant in a flaw will be drawn out by a white developer that is applied to the surface. Colored penetrant is visible under ordinary light. Fluorescent penetrant flaw indications will glow under an ultraviolet (black) light source. Since penetration of minute openings is involved, interpretation is sometimes difficult because of the irregularities in braze fillets and residues of flux deposits. Inpection by another method must be used to differentiate surface irregularities from joint discontinuities.

## Radiographic Inspection

RADIOGRAPHIC INSPECTION OF brazements detects lack of bond or incomplete flow of filler metal. The joints should be uniform in thickness and the exposure made straight through the joint. The sensitivity of the method is generally limited to two percent of the joint thickness. X-ray absorption by certain filler metals, such as gold and silver, is greater than absorption by most base metals. Therefore, areas in the joint that are void of braze metal show much darker than the brazed area on the film or viewing screen.

## Ultrasonic Inspection

THE ULTRASONIC TESTING method using low energy, high frequency mechanical vibration (sound waves) readily detects, locates, or identifies discontinuities in brazed joints. The applicability to brazements of this method depends largely on the design of the joint, surface condition, material grain size, and the configuration of adjacent areas.

## Thermal Heat Transfer Inspection

INSPECTION BY HEAT transfer will detect lack of bond in such brazed assemblies as honeycomb and covered skin panel surfaces. With one technique, the surfaces are coated with a developer which is a low melting point powder. The developer melts and migrates to cool areas upon the application of heat from an infrared lamp. The bonded areas act as heat sinks, resulting in a thermal gradient to which the developer will react. Sophisticated techniques use phosphors, liquid crystals, and temperature-sensitive materials.

Infrared-sensitive electronic devices with some form of readout are available to monitor temperature differences less than 2°F (1°C) which indicate variations in braze quality.

# DESTRUCTIVE TESTING METHODS

DESTRUCTIVE METHODS OF inspection clearly show whether a brazement design will meet the requirements of intended service conditions. Destructive methods must be restricted to partial sampling. It is used to verify the nondestructive methods of inspection, by sampling production material at suitable intervals.

## Metallographic Inspection

THIS METHOD REQUIRES the removal of sections from the brazed joints and preparing them for macroscopic or microscopic examination. This method detects flaws (especially porosity), poor flow of brazing filler metal, excessive base metal erosion, the diffusion of brazing filler metal, improper fit-up of the joint, and it will reveal the microstructure of the brazed joint.

## Peel Tests

PEEL TESTS ARE frequently employed to evaluate lap type joints. One member of the brazed specimen is clamped rigidly in a vise, and the free member is peeled away from the joint. The broken parts reveal the general quality of the bond and the presence of voids and flux inclusions in the joint. The permissible number, size, and distribution of these discontinuities should be defined in the job contract, specification, or code.

### Tension and Shear Tests

THESE TESTS DETERMINE quantitatively the strength of the brazed joint, or verify the relative strengths of the joint and base metal. This method is widely used when developing a brazing procedure. Random sampling of brazed joints is used for quality control and verification of brazing performance.

### Torsion Tests

THE TORSION TEST evaluates brazed joints with a stud, screw, or tubular member brazed to a base member. The base member is clamped rigidly and the stud, screw, or tube is rotated to failure which will occur in either the base metal or the brazing alloy.

## COMMON IMPERFECTIONS IN BRAZED JOINTS

NONDESTRUCTIVE AND DESTRUCTIVE inspections identify the following types of brazing imperfections. The limits of acceptability should be specifically defined.

### Lack of Fill (Voids, Porosity)

LACK OF FILL can be the result of improper cleaning, excessive clearances, insufficient filler metal, entrapped gas, and movement of the mating parts caused by improper fixturing. The filler metal is vulnerable when in the liquid or partially liquid state. Lack of fill reduces the strength of the joint by reducing the load-carrying area, and it may provide a path for leakage.

### Flux Entrapment

ENTRAPPED FLUX MAY be found in any brazing operation where a flux is added to prevent and remove oxidation during the heating cycle. Flux trapped in the joint prevents flow of the filler into that area, thus reducing the joint strength. It may also falsify leak- and proof-test indications. Entrapped corrosive flux may reduce service life.

### Noncontinuous Fillets

MISSING FILLETS ARE usually noted during visual inspection. Whether their omissions can be waived depends upon the job contract.

### Base Metal Erosion

EROSION RESULTS WHEN the brazing filler metal alloys with the base metal. It may result in undercuts or the disappearance of the mating surface. Erosion reduces the strength of the joint by changing the composition of the materials and by reducing the base metal cross-sectional area.

### Unsatisfactory Surface Appearance

UNSATISFACTORY BRAZING FILLER metal appearance, including excessive spreading and roughness, is objectionable for more than aesthetic reasons. Appearance defects may act as stress concentrations, corrosion sites, or may interfere with inspection of the brazement.

### Cracks

CRACKS REDUCE BOTH strength and service life. They act as stress raisers, lowering the mechanical strength of the brazement and causing premature fatigue failure.

# TROUBLESHOOTING

POOR BRAZING IS usually the result of the following failures:

(1) No wetting - no capillary flow, which leaves voids

(2) Excessive wetting - too much filler metal where it is not desired, e.g., in holes, or on machined surfaces

(3) Erosion - attack on the base metal by the brazing filler metal, which reduces the thickness of parent metal areas

If the basic cause of each of these failures can be identified, the solution of the brazing problem will be at hand. Table 12.7 lists items to consider for each of these failure problems.

### Table 12.7
### Solutions to Typical Brazing Problems

PROBLEM —No Flow, No Wetting

CAUSES:
—Braze filler—different lot or wrong one
—Low temp—poor technique, thermocouple/controller error
—Time—too short
—Dirty parts—not cleaned properly
—Poor atmosphere—too little flux, wrong flux, bad gas or vacuum
—No Ni-plate—allowing oxidation of base metal
—Gap too large—poor fitup control

PROBLEM —Excess Flow or Wetting—Causes Hole Plugging, Brazing Wrong Joints

CAUSES:
—Temperature too high—poor technique, furnace error
—Time—too long
—Too much filler metal—poor technique, different gap size
—Braze filler—different lot or wrong one
—No stopoff used

PROBLEM Erosion—Braze Filler Metal Eats Away Parent Metal

CAUSES:
—Temperature too high—poor technique, furnace error
—Time at temperature too long—poor technique, controller error
—Excessive braze filler metal—poor technique, change in gap, parts in different attitude
—Cold worked parts—highly susceptible—change in part manufacturer—not stress relieved
—Braze filler metals are too high above liquidus or high concentration of melting point depressants.

# BRAZE WELDING

## INTRODUCTION

BRAZE WELDING IS accomplished using a brazing filler metal having a liquidus above 840°F (450°C) but below the solidus of the base metals to be welded. As noted on the first page of this chapter, braze welding differs from brazing in that the filler metal is not distributed in the joint by capillary attraction. The filler metal is added to the joint as welding rod or is deposited from an arc welding electrode.[4] The base metals are not melted, only the filler metal melts. Bonding takes place between the deposited filler metal and the hot unmelted base metals in the same manner as conventional brazing, but without intentional capillary flow. Joint designs for braze welding are similar to those used for oxyacetylene welding.

Braze welding was originally developed to repair cracked or broken cast iron parts. Fusion welding of cast iron requires extensive preheating and slow cooling, to minimize the development of cracks and the formation of hard cementite. With braze welding, cracks and cementite are easier to avoid, and fewer expansion and contraction problems are encountered.

Most braze welding is done with an oxyfuel gas welding torch, a copper alloy brazing rod, and a suitable flux. Braze welding also is done with carbon arc, gas tungsten arc, and plasma arc torches, without flux. The carbon arc torch is used to weld galvanized sheet steel. The GTAW and PAW torches, which use inert gas shielding, braze weld with filler metals that have relatively high melting temperatures.

Braze welding has the following advantages over conventional fusion welding processes:

(1) Less heat is required to accomplish bonding, which permits faster joining and lower fuel consumption. The process produces little distortion from thermal expansion and contraction.

(2) The deposited filler metal is relatively soft and ductile, readily machinable, and under low residual stress.

(3) Welds have strength adequate for many applications.

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[4] Braze welding of cast iron is sometimes done by the shielded metal arc welding process. See Chapter 2.

(4) The equipment is simple and easy to use.

(5) Metals that are brittle, such as gray cast iron, can be braze welded without extensive preheat.

(6) The process provides a convenient way to join dissimilar metals, for example copper to steel and cast iron, and nickel-copper alloys to cast iron and steel.

Braze welding does have these disadvantages:

(1) Weld strength is limited to that of the filler metal.

(2) Permissible performance temperatures of the product are lower than those of fusion welds because of the lower melting temperature of the filler metal. With copper alloy filler metal, service is limited to 500°F (260°C) or lower.

(3) The braze welded joint may be subject to galvanic corrosion and differential chemical attack.

(4) The brazing filler metal color may not match the base metal color.

## EQUIPMENT

CONVENTIONAL BRAZE WELDING is done using an oxyfuel gas welding torch and the associated equipment described in Chapter 11. In some applications, an oxyfuel preheating torch may be needed. Special applications use carbon arc, gas tungsten arc, or plasma arc welding equipment described in other chapters of the Handbook.

Clamping and fixturing equipment may also be needed to hold the parts in place and align the joint.

## MATERIALS

### Base Metals

BRAZE WELDING IS generally used to join cast iron and steel. It can also be used to join copper, nickel, and nickel alloys. Other metals can be braze welded with suitable filler metals that wet and form a strong metallurgical bond with them.

Dissimilar metal weldments between many of the above metals are possible with braze welding if suitable filler metals are used.

### Filler Metals

COMMERCIAL BRAZE WELDING filler metals are the brasses containing approximately 60 percent copper and 40 percent zinc. Brazing alloys with small additions of tin, iron, manganese, and silicon have improved flow characteristics, decreased volatilization of the zinc, and they scavenge oxygen and increase the weld strength and hardness. Filler metal with added nickel (10 percent) has a whiter color and higher weld metal strength.

Chemical compositions and properties of three standard copper-zinc welding rods used for braze welding are given in Table 12.8. The minimum joint tensile strength will be approximately 40 to 60 ksi (275 to 413 MPa). The joint strength decreases rapidly when the weldment is above 500°F (260°C).

Because a braze weld is a bimetal joint, corrosion must be considered in its application. The completed joint will be subject to galvanic corrosion in certain environments, and the filler metal may be less resistant to certain chemical solutions than the base metal.

### Fluxes

FLUXES FOR BRAZE welding are proprietary compounds developed for braze welding of stated base metals with brass filler metal rods. They are designed for use at temperatures higher than met in brazing operations, and so they remain active for longer times at temperature than similar fluxes used for capillary brazing. The following types of flux are in general use for braze welding of iron and steels:

(1) A basic flux that cleans the base metal and weld beads and assists in the precoating (tinning) of the base metal. It is used for steel and malleable iron.

(2) A flux that performs the same functions as the basic flux and also suppresses the formation of zinc oxide fumes.

(3) A flux that is formulated specifically for braze welding of gray or malleable cast iron. It contains iron oxide or manganese dioxide to combine with free carbon on the cast iron surface and so remove it.

Flux may be applied by one of the following four methods:

**Table 12.8**
**Copper-Zinc Welding Rods for Braze Welding**

| AWS Classification* | Approximate Chemical Composition, % | | | | | Min Tensile Strength | | Liquidus Temperature | |
|---|---|---|---|---|---|---|---|---|---|
| | Copper | Zinc | Tin | Iron | Nickel | ksi | MPa | °F | °C |
| RBCuZn-A | 60 | 39 | 1 | | | 40 | 275 | 1650 | 900 |
| RBCuZn-C | 60 | 38 | 1 | 1 | | 50 | 344 | 1630 | 890 |
| RBCuZn-D | 50 | 40 | | | 10 | 60 | 413 | 1714 | 935 |

* See AWS Specifications A5.7 and A5.8 for additional information.

(1) The heated filler rod may be dipped into the flux and transferred to the joint during braze welding.

(2) The flux may be brushed on the joint prior to brazing.

(3) The filler rod may be precoated with flux.

(4) The flux may be introduced through the oxyfuel gas flame.

## METALLURGICAL CONSIDERATIONS

THE BOND BETWEEN filler metal and base metal in braze welding is the same bonding that occurs with conventional brazing. The clean base metal is heated to a temperature at which its surface is wet by the molten filler metal, producing a metallurgical bond between them. Cleanliness is prerequisite. The presence of dirt, oil, grease, oxide film, or carbon will inhibit wetting.

Following wetting, atomic diffusion takes place between the brazing filler metal and the base metal in a narrow zone at the interface. Indeed, with some base metals the brazing filler metal may slightly penetrate the grain boundaries of the base metal, further contributing to bond strength.

Braze welding filler materials are alloys that have sufficient ductility as-cast to let them flow plastically during solidification and subsequent cooling. The alloys thereby accommodate shrinkage stresses. Two-phase alloys that have a low-melting grain boundary constituent are not useable—those boundaries crack open during solidification and cooling.

## GENERAL PROCESS APPLICATIONS

THE GREATEST USE of braze welding is the repair of broken or defective steel and cast iron parts. Since large components can be repaired in place, significant cost savings result. Braze welding also rapidly joins thin-gage mild steel sheet and tubing where fusion welding would be difficult.

Galvanized steel duct work is braze welded using a carbon arc heat source. The brazing temperature is held to below the vaporization temperature of the zinc. This minimizes the loss of the protective zinc coating from the steel surfaces, but it exposes the welder to a significant amount of zinc fumes, requiring exhaust ventilation.

The thicknesses of metals that can be braze welded range from thin gage sheet to very thick cast iron sections. Fillet and groove welds are used to make butt, corner, lap, and T-joints.

## BRAZE WELDING PROCEDURE

### Fixturing

ADEQUATE FIXTURING IS usually required to hold parts in their proper location and alignment for braze welding. In repairing cracks and defects in cast iron parts, fixturing may not be necessary unless the part is broken apart.

### Joint Preparation

JOINT DESIGNS FOR braze welds are similar to those for oxyacetylene welding. For thicknesses over 3/32 in. (2 mm), single- or double-V-grooves are prepared with 90 to 120 degrees included angle, to provide large bond areas between base metal and filler metal. Square grooves may be used for thickness less than 3/32 in. (2 mm).

The prepared joint faces and adjacent surfaces of the base metal must be cleaned to remove all oxide, dirt, grease, oil, and other foreign material. On cast iron, the joint faces must also be free of graphite smears caused by prior machining. Graphite smears can be removed by quickly heating the cast iron to a dull red color and then wire brushing it after it cools to black heat. If the casting has been heavily soaked with oil, it should be heated in the range of 600 to 1200°F (320 to 650°C) to burn off the oil. The surfaces should be wire brushed to remove any residue.

In production braze welding of cast iron components, the surfaces to be joined are usually cleaned by immersion in an electrolytic molten salt bath.

### Preheating

PREHEATING MAY BE required to prevent cracking from thermally induced stresses in large cast iron parts. Preheating copper reduces the amount of heat required from the brazing torch and the time required to complete the joint.

Preheating may be local or general. The temperature should be 800 to 900°F (425 to 480°C) for cast iron. Higher temperatures can be used for copper. When braze welding is completed on cast iron parts, they should be thermally insulated for slow cooling to room temperature, to minimize the development of thermally induced stresses.

### Technique

THE JOINT TO be oxyfuel gas braze welded must be aligned and fixtured in position. Braze welding flux, when required, is applied to preheated filler rod (unless precoated) and also sprinkled on thick joints during heating with the torch. The base metal is heated until the filler metal melts, wets the base metal, and flows onto the joint faces (precoating). The braze welding operation then progresses along the joint, precoating the faces, then filling the groove with one or more passes using operating techniques similar to oxyfuel gas welding. With an oxyacetylene flame, the inner cone should not be directed on copper-zinc alloy filler metals nor on iron or steel base metal.

With electric arc torches the technique is similar to oxyfuel gas braze welding, except that flux is not generally used.

## TYPES OF WELDS

GROOVE, FILLET, AND edge welds are used to braze weld assemblies made from sheet and plate, pipe and tubing, rods and bars, castings, and forgings. To obtain good joint strength, adequate bond area between the brazing filler metal and the base metal is required. Weld groove geometry should provide adequate groove face area so that the joint will not fail along the interfaces.

# SAFE PRACTICES IN BRAZING

HAZARDS ENCOUNTERED WITH brazing operations are similar to those associated with welding and cutting. At brazing temperatures some elements vaporize, producing toxic gases. Personnel and property need protection against hot materials, gases, fumes, electrical shock, radiation, and chemicals.

Minimum brazing safety requirements are specified in the American National Standard Z49.1, *Safety in Welding and Cutting*,[5] published by the American Welding Society, Miami, Florida. This standard applies to brazing, braze welding, and soldering, as well as other welding and cutting processes.

## GENERAL AREA SAFE PRACTICE

BRAZING EQUIPMENT, MACHINES, cables, and other apparatus should be placed so that they present no hazard to personnel in work areas, in passageways, on ladders, or on stairways. Good housekeeping should be maintained.

Precautionary signs conforming to the requirements of ANSI Z535.2, *Environment and Facility Safety Signs*, should be posted designating the applicable hazard(s) and safety requirements.

## PERSONNEL PROTECTION

### Ventilation

IT IS ESSENTIAL that adequate ventilation be provided so that personnel will not inhale gases and fumes generated while brazing. Some filler metals and base metals contain toxic materials such as cadmium, beryllium, zinc, mercury, or lead, which are vaporized during brazing. Fluxes contain chemical compounds of fluorine, chlorine, and boron, which are harmful if they are inhaled or contact the eyes or skin.

Solvents such as chlorinated hydrocarbons and cleaning compounds, such as acids and alkalies, may be toxic or flammable or cause chemical burn when present in the brazing environment.

To avoid suffocation, care must be taken with atmosphere furnaces to insure that the furnace is purged with air before personnel enter it.

### Eye and Face Protection

EYE AND FACE protection shall comply with ANSI Z87.1, *Practices for Occupational and Educational Eye and Face Protection.* Goggles or spectacles with shade number four or five filter lenses should be worn by operators and helpers for torch brazing. Operators of resistance, induction, or salt bath dip brazing equipment and their helpers should use face shields, spectacles, or goggles as appropriate, to protect their faces and eyes.

### Protective Clothing

APPROPRIATE PROTECTIVE CLOTHING for brazing should provide sufficient coverage and be made of suitable materials to minimize skin burns caused by spatter or radiation. Heavier material such as woolen or heavy cotton clothing are preferable to lighter materials because they are more difficult to ignite. All clothing shall be free from oil, grease, and combustible solvents. Brazers shall wear protective heat-resistant gloves made of leather or other suitable materials.

### Respiratory Protective Equipment

WHEN CONTROLS SUCH as ventilation fail to reduce air contaminants to allowable levels and where the implementation of such controls is not feasible, respiratory protective equipment should be used to protect personnel from hazardous concentrations of airborne contaminants. Only approved respiratory protection equipment should be used. Approvals of respiratory equipment are issued by the National Institute of Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA). Selection of the proper equipment should be in accordance with ANSI Z88.2.

## PRECAUTIONARY LABELING AND MATERIAL SAFETY DATA SHEETS

BRAZING OPERATIONS POSE potential hazard from fumes, gases, electric shock, heat, and radiation. Personnel should be warned against these hazards, where applicable, by use of adequate precautionary labeling as defined in ANSI/ASC Z49.1. Examples of labeling are shown in Figures 12.27 through 12.30.

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[5] American National Standards Institute (ANSI) 1430 Broadway, New York, NY 10018.

WARNING: PROTECT yourself and others. Read and understand this label.

FUMES AND GASES can be dangerous to your health.
ARC RAYS can injure eyes and burn skin.
ELECTRIC SHOCK can KILL.

- Before use, read and understand the manufacturer's instructions, Material Safety Data Sheets (MSDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases from your breathing zone and the general area.
- Wear correct eye, ear, and body protection.
- Do not touch live electrical parts.
- See American National Standard Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, 550 N.W. LeJeune Rd., P.O. Box 351040, Miami, Florida 33135; OSHA Safety and Health Standards, 29 CFR 1910, available from U.S. Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS LABEL.

**Figure 12.27–Warning Label for Arc Welding Processes and Equipment**

WARNING: PROTECT yourself and others. Read and understand this label.

FUMES AND GASES can be dangerous to your health.
HEAT RAYS (INFRARED RADIATION from flame or hot metal) can injure eyes.

- Before use, read and understand the manufacturer's instructions, Material Safety Data Sheets (MSDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the flame, or both, to keep fumes and gases from your breathing zone and the general area.
- Wear correct eye, ear, and body protection.
- See American National Standard Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, 550 N.W. LeJeune Rd., P.O. Box 351040, Miami, Florida 33135; OSHA Safety and Health Standards, 29 CFR 1910, available from U.S. Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS LABEL.

**Figure 12.28–Warning Label for Oxyfuel Gas Processes**

DANGER: CONTAINS CADMIUM, Protect yourself and others. Read and understand this label.

FUMES ARE POISONOUS AND CAN KILL.

- Before use, read and understand the manufacturer's instructions, Material Safety Data Sheets (MSDSs), and your employer's safety practices.
- Do not breathe fumes. Even brief exposure to high concentrations should be avoided.
- Use enough ventilation, exhaust at the work, or both, to keep fumes and gases from your breathing zone and the general area. If this cannot be done, use air supplied respirators.
- Keep children away when using.
- See American National Standard Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, 550 N.W. LeJeune Rd., P.O. Box 351040, Miami, Florida 33135; OSHA Safety and Health Standards, 29 CFR 1910, available from U.S. Government Printing Office, Washington, DC 20402.

If chest pain, shortness of breath, cough, or fever develop after use, obtain medical help immediately.

DO NOT REMOVE THIS LABEL.

**Figure 12.29–Warning Label for Brazing Filler Metals Containing Cadmium**

## Resistance and Induction Brazing Processes

AS A MINIMUM, the information shown in Figure 12.27, or its equivalent, shall be placed on stock containers of consumable materials and on major equipment such as power supplies, wire feeders, and controls used in electrical resistance or induction brazing processes. The information shall be readily visible to the worker and may be on a label, tag, or other printed form as defined in ANSI Z535.2 and ANSI Z535.4, *Product Safety Signs and Labels*.

## Oxyfuel Gas, Furnace, Dip Brazing Processes

AS A MINIMUM, the information shown in Figure 12.28, or its equivalent, should be placed on stock containers of consumable materials and on major equipment used in oxyfuel gas, furnace (except vacuum), and dip brazing processes. The information should be readily visible to the worker and may be on a label, tag, or other printed form as defined in ANSI Z535.2 and ANSI Z535.4.

## Filler Metals Containing Cadmium

AS A MINIMUM, brazing filler metals containing more cadmium than 0.1 percent by weight should carry the information shown in Figure 12.29, or its equivalent on tags, boxes, or other containers, and on any coils or wire or strip not supplied to the user in a labeled container. Label requirements should also conform to ANSI Z535.4.

## Brazing Fluxes Containing Fluorides

AS A MINIMUM, brazing fluxes and aluminum salt bath dip brazing salts containing fluorine compounds should have precautionary information as shown in Figure 12.30, or its equivalent, on tags, boxes, jars, or other containers. Labels for other fluxes should conform to the requirements of ANSI Z129.1, *Precautionary Labeling for Hazardous Industrial Chemicals*.

## Material Safety Data Sheets (MSDSs)

THE SUPPLIERS OF brazing materials shall provide Material Safety Data Sheets, or equivalent, which identify the hazardous materials, if any, present in their products. The MSDS shall be prepared and distributed to users in accordance with OSHA 29CFR 1910.1200, *Hazard Communications Standard*.

A number of potentially hazardous materials may be present in fluxes, filler metals, coatings, and atmospheres used in brazing processes. When the fumes or gases from a product contain a component whose individual limiting

WARNING: CONTAINS FLUORIDES. Protect yourself and others. Read and understand this label.

FUMES AND GASES CAN BE DANGEROUS TO YOUR HEALTH. BURNS EYES AND SKIN ON CONTACT. CAN BE FATAL IF SWALLOWED.

- Before use, read and understand the manufacturer's instructions, Material Safety Data Sheets (MSDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the work, or both, to keep fumes and gases from your breathing zone and the general area.
- Avoid contact of flux with eyes and skin.
- Do not take internally.
- Keep out of reach of children.
- See American National Standard Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, 550 N.W. LeJeune Rd., P.O. Box 351040, Miami, Florida 33135; OSHA Safety and Health Standards, 29 CFR 1910, available from U.S. Government Printing Office, Washington, DC 20402.

First Aid: If flux comes in contact with eyes, flush immediately with clean water for at least 15 minutes. If swallowed, induce vomiting. Never give anything by mouth to an unconscious person. Call a physician.

DO NOT REMOVE THIS LABEL.

**Figure 12.30–Warning Label for Brazing and Gas Welding Fluxes Containing Fluorides**

value will be exceeded before the general brazing fume limit of 5 mg/m$^3$ is reached, the component shall be identified on the MSDS. These include, but are not limited to, the low PEL materials listed earlier.

## FIRE PREVENTION AND PROTECTION

FOR DETAILED INFORMATION on fire prevention and protection in brazing processes, NFPA 51B, *Fire Protection in Use of Cutting and Welding Processes*, should be consulted.

Brazing should preferably be done in specially designated areas which have been designed and constructed to minimize fire risk. No brazing shall be done unless the atmosphere is either nonflammable or unless gases (such as hydrogen) which can become flammable when mixed with air are confined and prevented from being released into the atmosphere.

Sufficient fire extinguishing equipment shall be ready for use where brazing work is being done. The fire extinguishing equipment may be pails of water or a water hose, buckets of sand, hose, portable extinguishers, or an automatic sprinkler system, depending upon the nature and quantity of combustible material in the adjacent area.

Before brazing is begun in a location not specifically designated for such purposes, inspection and authorization by a responsible person shall be required.

When repairing containers that have held flammable or other hazardous materials, there is the possibility of explosions, fires, and the release of toxic vapors. Brazers must be fully familiar with American Welding Society ANSI/AWS F4.1, *Recommended Safe Practices for the Preparation for Welding and Cutting of Containers and Piping That Have Held Hazardous Substances*".

For more information, consult the applicable state, local, and Federal specifications, as well as the AWS *Brazing Manual.*

### Brazing Atmospheres

FLAMMABLE GASES ARE sometimes used as atmospheres for furnace brazing operations. These include combusted fuel gas, hydrogen, dissociated ammonia, and nitrogen-hydrogen mixtures. Prior to introducing such atmospheres, the furnace or retort must be purged of air by safe procedures recommended by the furnace manufacturer.

Adequate area ventilation must be provided that will exhaust and discharge to a safe place explosive or toxic gases that may emanate from furnace purging and brazing operations. Local environmental regulations should be consulted when designing the exhaust system.

### Steam Hazard From Moist Materials

IN DIP BRAZING and in dip soldering, the parts to be immersed in the bath must be completely dry. Moisture on the parts will cause an instantaneous generation of steam that may expel the contents of the dip pot explosively. Predrying the parts prevents this danger. If supplementary flux must be added, it must be dried to remove both surface moisture and also water of hydration.

## ELECTRICAL HAZARDS

ALL ELECTRICAL EQUIPMENT used for brazing should conform to ANSI/NFPA 70, *National Electric Code* (latest edition). The equipment should be installed by qualified personnel under the direction of a competent technical supervisor. Prior to production use, the equipment should be inspected by competent safety personnel to ensure that it is safe to operate.

## SUPPLEMENTARY READING LIST

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