Module 4
Design for Assembly
Lecture 4
Design for Brazing and Soldering
Instructional objectives

By the end of this lecture, the student will learn

(a) what are the principles of brazing and soldering processes?
(b) possible applications of different variants of the brazing and soldering processes,
(c) recommended designs for the brazing and soldering to achieve good quality joints economically.

What is brazing?

Brazing is a joining process, which produces coalescence of materials by heating to a suitable temperature and by using a filler metal (often referred to as braze) having a liquidus temperature above 450°C and below the solidus temperature of the base material. The filler metal is drawn into the gap between the closely fitted surfaces of the joint by capillary action. To achieve a perfect joint, the filler and the parent materials should be metallurgically compatible and the design of the joint should incorporate a minimum gap into which the braze filler metal will be drawn. The joints must be properly cleaned and protected by the flux or protective atmosphere during the heating process to prevent excessive oxidation. There are many ways of brazing, and they all differ in the method of applying heat to the braze assembly, in particular, the joint area. These include torch brazing, furnace brazing, induction brazing, dip brazing, and resistance brazing.

Torch brazing

In torch brazing, the heating of the joint is accomplished using the flame of a single or multiple gas torches. Multiple torches are used to obtain a uniform heating throughout the joint area. The brazing filler metal may be preplaced at the joint in the form of rings, washers, strips, slugs, powder, or it may be fed manually. Torch brazing is very useful on assemblies that involve heating sections of different mass. Manual torch brazing is particularly useful for repair work. Torch brazing is used when the part to be brazed is too large, or of complex shape, or cannot be heated by the other methods.

Furnace brazing

In furnace brazing, the parent materials / parts are cleaned and placed in a furnace. The parts should be self-jigging and assembled, with the filler materials already placed near or in the joint. The brazing filler material may be in the form of wire, foil, fillings, slugs, powder, paste, tape, and so on. The furnaces are usually of electrical resistance type. Fluxing is
employed except when an atmosphere is specifically introduced in the furnace to perform the same function. Furnace brazing is often done without the use of flux by the use of special atmospheres (hydrogen and other special gases – helium and argon-) in the brazing furnace. Furnace brazing is also performed in vacuum during the fabrication of aerospace and nuclear components where entrapped fluxes are not tolerable.

*Figure 4.4.1* shows an automated furnace brazing set-up in which the parts along with the preplaced brazing filler and flux are carried inside the furnace through a conveyer belt. As the assembly travels through the furnace (or kept for the intended time inside the furnace), the filler melts and covers the joint area. As the assembly comes out of the furnace, the filler solidifies creating the brazed joint. Furnace is useful to braze the parts of uniform mass, the parts of all sizes having multiple and hidden joints. This process is particularly useful for high production brazing.

![Illustration of furnace brazing operation](image)

**Induction brazing**

In induction brazing, the heat necessary for brazing is obtained by the induction heating principle. The components to be brazed are placed in the magnetic field of a water cooled coil carrying a high frequency current. This current induces eddy currents in the components. The induced current flow in the surface skin of the body and are concentrated in the area closest to the coil. The depth of the heating depends on the current frequency used. High frequency current produces skin heating in the components while lower frequency current results in deeper heating and is thus recommended for brazing heavier sections. The heating effect is given by the equation

$$H = I^2 R$$  \hspace{1cm} (4.4.1)
where H, I and R refer to heat produced, induced current and electrical resistance of the material, respectively. In induction brazing, fluxing may or may not be employed and the filler metal is usually preplaced at the joint.

*Figure 4.4.2* shows the typical coil designs used in the induction brazing process. The primary advantage of the induction brazing over other brazing processes is its localized heating which minimizes oxidation, distortion and the metallurgical changes like softening of cold worked or heat treated metal. Controlled heat input along with rapid heating rates and automatic mode makes it a high production rate process which can be used in air.

**Dip brazing**

Dip brazing is accomplished by immersing clean and assembled parts into a molten bath contained in a suitable pot. Dip brazing is classified into chemical bath dip brazing and molten metal bath dip brazing. In chemical bath dip brazing the filler metal, in a suitable form, is preplaced and the assembly is dipped in a bath of molten salt, as shown in *Figure 4.4.3*. The salt bath provides the required heat and necessary protection from oxidation. The salt bath is contained in a suitable pot, also called the furnace, which is heated by electrical resistance. In molten bath dip brazing the parts are immersed in a bath of molten brazing filler metal contained in a furnace. The molten brazing metal flows into the joint by capillary action.

![Brazing Coils and Plates](image)
Dip brazing is preferred for brazing small to medium sized parts with multiple or hidden joints. It is also useful to braze parts of irregular shapes. This process is best suited for moderate to high production runs.

Resistance brazing

In resistance brazing, the heat to melt the filler material is obtained by Joule’s heating (i.e. resistive heating against the flow of an electrical current through the parts being brazed). The parts become a part of the electrical circuit through electrodes made of copper alloys or carbon-graphite. The parts to be brazed are held between two electrodes, and proper pressure and current are applied. The pressure is maintained until the joint has solidified. In some cases both the electrode are located on the same side of the joint with a suitable backing to maintain the required pressure. Resistance brazing is normally used for low volume production where heating is localized at the area to be brazed.

Selection of Filler metal

The following factors must be considered when selecting a brazing filler metal.

[2] Service requirement for the brazed assembly. Compositions should be selected to suit operating requirements, such as service temperature, thermal cycling, stress loading, corrosive conditions and so on.
[3] Filler metals with narrow melting ranges less than 28°C between solidus to liquidus can be used with any heating method.
AWS (American Welding Society) A5.8 standard explains the selection of the suitable base metal-filler metal combinations in a great detail. Table 4.4.1 gives the base metal and the filler metals widely used for brazing operation.

<table>
<thead>
<tr>
<th>Base metal</th>
<th>Carbon and alloy steels, cast iron, stainless steel, copper and copper alloys, magnesium and magnesium alloys, aluminium, cast iron, nickel and nickel alloys, titanium and zirconium, ceramics, precious metals and refractory metals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filler metal</td>
<td>Aluminum-silicon, magnesium, copper and copper-zinc, copper-phosphorus, silver, gold, nickel, cobalt.</td>
</tr>
</tbody>
</table>

Protective atmosphere in brazing [3]

Even though flux is required to control the formation of oxides during brazing, a controlled atmosphere still may be desired to extend the useful life of a flux and to minimize the cleaning of the joint area after the brazing process. In controlled atmosphere applications, the post-braze cleaning is not necessary. Hence controlled atmosphere brazing is extremely help in the cases where the cleaning of the flux entrapment is difficult, such as heat exchangers, thrust chambers, and honeycomb sandwich structures. Controlled atmospheres are used in furnace, induction and resistance brazing processes. The controlled atmospheres are of three types

- Reducing atmosphere
- Inert atmosphere
- Vacuum atmosphere

Reducing atmosphere

Reduced atmosphere consists of gases like carbon dioxide, carbon monoxide, nitrogen and hydrogen. The components of this atmosphere have individual characteristics which affect their suitability for brazing various metals and alloys. Copper, brass, low carbon steels, medium carbon steels, high carbon steels, nickel, nickel alloys, and monel are few metals that can be brazed in reduced atmosphere. The detailed explanation about the composition of the reduced atmosphere recommended for brazing various kind of metals are usually well documented in openly available standard literature or handbooks [3].
Inert atmosphere

Argon and helium are the commonly used gases in inert atmosphere. This type of atmosphere can be used to braze most metals, particularly in brazing base metals whose properties are adversely affected by exposure to hydrogen. For example, alloys of titanium, zirconium, niobium, and tantalum are extremely sensitive to the presence of minute quantities of hydrogen and become embrittled. These metals can also be brazed equally well in a vacuum atmosphere.

Vacuum atmosphere

Brazing in vacuum atmosphere is well suited for joining heat resistant nickel and iron base alloys that contain aluminium and/or titanium, reactive metals, and refractory metals. Vacuum conditions are especially suited for brazing very large, continuous areas where solid or liquid fluxes cannot be removed adequately from the interfaces during brazing, and where gaseous atmospheres are not completely efficient because of their inability to purge occluded gases evolved at close fitting brazing interfaces. Vacuum atmosphere is also suitable for brazing many similar and dissimilar base metals, including titanium, zirconium, niobium, molybdenum, and tantalum.

Application of brazing in metal-ceramic joining [3,4]

Metal-ceramic joints have wide applications in reactor power system (typically in space crafts), thermonuclear power reactors, and heat exchangers. Metal-ceramic joints are produced by two methods:

- Molybdenum-Manganese/Nickel plating method
- Active filler metal brazing

Molybdenum-Manganese/Nickel plating method

Molybdenum-Manganese/Nickel plating method is also known as Moly-Manganese metallization. Figure 4.4.4 depicts various steps followed in this method to produce ceramic-metal joint. Initially a coating of molybdenum and manganese particles mixed with glass additives and volatile carriers is applied to the ceramic surface to be brazed. Next, the coating is fired in a wet hydrogen environment leaving a glassy metallic coating. Further a layer of nickel is plated over the glassy metallic coating. Next, the nickel plating is sinter-fired in a dry hydrogen atmosphere leaving a finished metallic surface that can be readily brazed using standard braze filler metals.
Active filler metal brazing

Active filler metal brazing is more famous than the Moly-Manganese metallization. The primary for this is that it is very material dependent, active filler metals display good wetting with most ceramic materials. Moreover, this method permits the use of standard brazing techniques when making metal-ceramic brazements without the need to apply any metallization to the ceramic substrate. Figure 4.4.5 depicts various steps followed in this method to produce ceramic-metal joint. The metal and the ceramic substrates are cleaned, and the active filler metal preform or paste is applied between the faying surfaces of the brazement. The brazing operation is usually performed in an inert or vacuum environment.

Figure 4.4.4  Molybdenum-Manganese/Nickel plating method [4].
What is Soldering?

Soldering is a joining process, which produce coalescence of material by heating them to the soldering temperature and by using a filler metal (solder) having liquidus temperature not exceeding 450°C and below the solidus temperature of the base metals. Similar to brazing the filler metal is drawn into the gap between the closely fitted surfaces of the joint by capillary action. Usually, a nonferrous alloy is used as solder material. There are many ways of soldering, and alike brazing, they also differ in the method of applying heat to the solder assembly, in particular, the joint area. The main soldering variants include soldering iron, torch soldering, dip soldering, wave and cascade soldering, induction soldering, resistance soldering.

Soldering iron

The soldering iron with copper tip is the traditional soldering tool. The heat required to melt the solder is generated by the electrical resistance heating of the copper tip. The other methods of heating the copper tip are by using oil, coke or gas burners. The life of the copper tip is enhanced by coating it with solder wettable metal like iron. This iron coating decreases the dissolution of copper in molten solder. Soldering iron is most often used for installation, repairs, and limited production work in electronics assembly.

Torch soldering

Similar to torch brazing, the necessary heat required to heat the joint is supplied by the flame of a gas torch. The solder is applied manually. Torch soldering is widely used in the plumbing trade for soldering copper tubing to copper fitting.
Dip soldering

In dip soldering a bath of molten solder provides adequate heat and solder to the work to produce a solder joint. The joint is obtained by dipping the parts to be joined in a molten solder bath. An entire unit comprising of any number of joints can be soldered in one operation after proper cleaning and fluxing. The operation needs the fixtures to maintain proper joint clearances during solidification of solder. It is one of the cheapest methods to solder and is extensively used in the small scale industries. Dip soldering is widely used in electronic industry exclusively for making through-hole printed circuit assemblies and surface mount.

Wave and cascade soldering

In wave and cascade soldering also a bath of molten solder provides adequate heat and solder to the work to produce a solder joint. Figure 4.4.6(a) depicts the procedure used to produce solder joint in wave soldering process. Single, double and series of waves are generated by pumping the molten solder out of a narrow slot. The soldering joint is produced by moving the parts to be joined over the generated waves [Fig. 4.4.6(a)]. Figure 4.4.6(b) shows the procedure used to generate soldering joints in cascade soldering. In this process, the molten solder flows down a trough by gravity and the parts to be joined or work to be soldered moves in the opposite direction. Further, the molten solder is returned by pump to the upper reservoir. This is a high production soldering process. Wave and cascade soldering processes are widely used in electronic industry particularly for the production of electronic circuit boards.

Induction soldering

Similar to induction brazing, the heat necessary for soldering in this process is obtained by the induction heating principle. The components to be soldered are placed in the magnetic field of a water cooled coil carrying a high frequency current. This current induces eddy currents in the components. The induced current flow in the surface skin of the body and are concentrated in the area closest to the coil. The depth of the heating depends on the current frequency used. High frequency current produces skin heating in the components while lower frequency current results in deeper heating and is thus recommended for soldering heavier sections.

The primary advantage of the induction soldering is its localized heating which minimizes oxidation, good appearance and constantly high joining quality. It is readily automated and hence leads to large sale production of solder joints of comparatively simple design.
Resistance soldering

The heating principle is similar to that of the resistance brazing. Resistance soldering is widely applied to attach lugs to welding cables, manufacturing electrical machinery involving soldering joints and soldering plumbing fittings.

Figure 4.4.6  Schematic set-ups of (a) wave soldering and (b) cascade soldering systems

Base and the filler metals (solder) for soldering

*Table 4.4.2* shows the widely used base metal and the solder used in the soldering operation. The base metals are listed in order of decreasing solubility. ASTM B32-04 explains the suitable combination of the base metal and the solder.
### Table 4.4.2  Base and the filler metals (solder) widely used for soldering operation [1, 2]

<table>
<thead>
<tr>
<th>Base metal</th>
<th>Lead, cadmium, silver, copper, brass, bronze, lead, nickel, monel, zinc, steel, inconel, stainless steel, chromium, nichrome, silicon bronze, alnico and aluminum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solder</td>
<td>Tin-lead, tin-antimony, tin-antimony-lead, tin-lead-silver, tin-silver and tin-lead-silver, tin-zinc, cadmium-silver, cadmium-zinc, zinc-aluminum and fusible alloys</td>
</tr>
</tbody>
</table>

### Design recommendations for brazing and soldering

[a] Lap joints are preferred whenever possible. The joint area (overlap) should be sufficiently large as that the joint is as strong as the weaker member of the assembly. Figure 4.4.7 shows the recommended lap joint configuration.

![Figure 4.4.7](image)

**Figure 4.4.7**  Recommended lap joint configuration [2]

[b] Butt joints are not recommended unless strength requirements are very low.

c] Table 4.4.3 depicts the recommended and not recommended joint configurations.

[d] Self jigging soldering and brazing assemblies are more economical and recommended. Table 4.4.4 explains different methods/approaches for holding the parts together in a self jigging assembly.

[e] When filler metal is used in shin form, the assembly should be such that the parts are free to move when the filler metal melts. This allows a stronger and narrow gap joint.

[f] If induction heating is used, the joint is designed to allow space for proper location of the induction coil.

[g] Dip brazed assemblies are designed so that flux from the bath is not trapped in the joint.
**Table 4.4.3**  Joint configurations for brazing and soldering [2]

<table>
<thead>
<tr>
<th>Recommended</th>
<th>Not recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Recommended Configurations" /></td>
<td><img src="image2" alt="Not Recommended Configurations" /></td>
</tr>
</tbody>
</table>

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### Table 4.4.4 Various self-jigging methods for brazed assemblies [2]

<table>
<thead>
<tr>
<th>Approach to hold the parts</th>
<th>Self jigging assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity</td>
<td>![Gravity Diagram]</td>
</tr>
<tr>
<td>Press fit</td>
<td>![Press fit Diagram]</td>
</tr>
<tr>
<td>Spot and tack welding</td>
<td>![Spot and tack Welding Diagram]</td>
</tr>
<tr>
<td>Crimping or forming</td>
<td>![Crimping or Forming Diagram]</td>
</tr>
<tr>
<td>Expanding and swaging</td>
<td>![Expanding and Swaging Diagram]</td>
</tr>
<tr>
<td>Staking and peening</td>
<td>![Staking and Peening Diagram]</td>
</tr>
<tr>
<td>Threading and riveting</td>
<td>![Threading and Riveting Diagram]</td>
</tr>
</tbody>
</table>
Exercise

1. Distinguish between brazing and soldering processes.
2. Look into the various brazing standards and find out the typical brazing fillers and fluxes that should be used for brazing of aluminum-steel, copper-steel and stainless steel-copper alloys.

References