Brazing, Soldering, Adhesive-Bonding and Mechanical-Fastening Processes

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Chapter 32

Brazing & Soldering

- Joining processes that require lower temperatures than those for fusion welding
- Filler metals are placed in or supplied to the joint
- Filler metals are melted by an external source of heat
- Solidification to form a strong joint
- Temperatures for soldering are lower than for brazing
- Soldered joint has lower strength than a brazed joint

Brazing

- A joining process in which a filler metal is placed between the faying surfaces to be joined (or at their periphery) and the temperature is raised sufficiently to melt the filler metal, but not the components (base metal)
- It is a liquid-solid state bonding process
- When filler metal cools and solidifies a strong bond is formed

FIGURE 32.1 Examples of brazed and soldered parts.
(a) Resistance-brazed light-bulb filament; (b) brazed radiator heat exchanger;
(c) soldered circuit board; (d) brazed ring housing; and
(e) brazed heat exchanger. Source: Courtesy of Edison Welding Institute.

FIGURE 32.2 An example of furnace brazing (a) before and (b) after brazing. The filler metal is a shaped wire and moves into the interfaces by capillary action with the application of heat.

FIGURE 32.3 Joint designs commonly used in brazing operations.
The clearance between the two parts being brazed is an important factor in joint strength. If the clearance is too small, the molten braze metal will not penetrate the interface fully. If it is too large, there will be insufficient capillary action for the molten metal to fill the interface.
**TABLE 32.1** Typical Filler Metals for Brazing Various Metals and Alloys

<table>
<thead>
<tr>
<th>Base metal</th>
<th>Filler metal</th>
<th>Brazing temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum and its alloys</td>
<td>Aluminum silicide</td>
<td>870-920</td>
</tr>
<tr>
<td>Magnesium alloys</td>
<td>Magnesium-chromide</td>
<td>880-925</td>
</tr>
<tr>
<td>Copper and its alloys</td>
<td>Copper-phosphide</td>
<td>700-921</td>
</tr>
<tr>
<td>Ferrous and nonferrous</td>
<td>Silver &amp; copper alloys</td>
<td>620-1150</td>
</tr>
<tr>
<td>(except aluminum and magnesium)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron, nickel, and cobalt-based alloys</td>
<td>Gold</td>
<td>900-1100</td>
</tr>
<tr>
<td>Stainless steels, nickel- and cobalt-based alloys</td>
<td>Nickel-silver</td>
<td>921-1200</td>
</tr>
</tbody>
</table>

**Filler Metals**
- Several metals are available with a range of brazing temperatures.
- Filler metals for brazing generally have a composition that is significantly different from the composition of the metals to be joined. This is different than for fusion welding.
- Filler metals are available in a variety of shapes, such as wire, rod, ring, shim stock, filings.
- Incorrect filler selection may lead to embrittlement of the joint by:
  - Grain-boundary penetration of liquid metal
  - Formation of brittle-intermetallic compounds at the joint
  - Galvanic corrosion at the joint
- Mechanical and metallurgical properties of bond may change over time by diffusion of filler metal into the base metal.

**Brazing Fluxes**
- Use of a flux is essential
  - Flux prevents oxidation and removes oxide films
- Generally made of borax, boric acid, borates, fluorides, chlorides
- Wetting agents may be used to improve:
  - Wetting characteristics of molten filler
  - Capillary action
- Surfaces must be clean; no oil, rust, other
- Remove fluxes after brazing; flush with hot water
  - Before corrosive action can start

**Brazed Joint Strength**
- Strength depends on:
  - Joint clearance
  - Joint area
  - Nature of bond at the interfaces
- With small clearances, roughness of mating surfaces becomes important
- Must clean the surfaces (mechanically or chemically) to ensure full capillary action

**Brazing Methods**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torch Brazing (TB)</td>
<td>Oxyfuel gas with carburizing flame</td>
</tr>
<tr>
<td>Furnace Brazing (FB)</td>
<td>All parts heated uniformly, batch or continuous</td>
</tr>
<tr>
<td>Induction Brazing (IB)</td>
<td>High-frequency AC current in induction coil</td>
</tr>
<tr>
<td>Resistance Brazing (RB)</td>
<td>Electrical resistance of parts being brazed, applied through electrodes</td>
</tr>
<tr>
<td>Dip Brazing (DB)</td>
<td>Assemblies dipped in molten filler-metal bath</td>
</tr>
<tr>
<td>Infrared Brazing (IRB)</td>
<td>Use high-intensity quartz lamp</td>
</tr>
<tr>
<td>Diffusion Brazing (DFB)</td>
<td>Filler metal diffuses into faying surfaces in furnace</td>
</tr>
<tr>
<td>High-energy Beams</td>
<td>Electron or laser beams</td>
</tr>
<tr>
<td>Braze Welding</td>
<td>Filler metal deposited using oxy-acetylene torch with oxidizing flame</td>
</tr>
</tbody>
</table>
Soldering

- The filler metal is called ‘solder’
- The filler metal melts at relatively low temperature
- Filler metal fills joint by capillary action (same as brazing)
- Low surface tension
- High wetting capability
- Heat supplied by:
  - Soldering irons
  - Torches
  - Ovens

Soldering

- Solders melt at a temperature that is the eutectic point of the solder alloy
- Example: Solder 61.9% Sn and 38.1% Pb
  - melts at 188°C (370°F), lower than MP for pure Sn & pure Pb.
- Fluxes used in soldering, same reason as for welding & brazing

Table 32.2: Types of Solders and Their Applications

<table>
<thead>
<tr>
<th>Types of Solders and Their Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tin-lead</td>
</tr>
<tr>
<td>Tin-zinc</td>
</tr>
<tr>
<td>Lead-silver</td>
</tr>
<tr>
<td>Cadmium-silver</td>
</tr>
<tr>
<td>Zinc-aluminum</td>
</tr>
<tr>
<td>Tin-silver</td>
</tr>
<tr>
<td>Tin-bismuth</td>
</tr>
</tbody>
</table>

Solderability

- Copper, Silver & Gold are easy to solder
- Iron & Nickel more difficult
- Aluminum & Stainless Steels difficult
- Steels, Cast Irons, Titanium, Magnesium, Ceramics, Graphite can be soldered by first coating with a metallic element to induce interfacial bonding
  - Example: Tinplate
Soldering Techniques

- Torch Soldering (TS)*
- Furnace Soldering (FS)*
- Iron Soldering (INS) (use soldering iron)
- Induction Soldering (IS)*
- Resistance Soldering (RS)*
- Dip Soldering (DS)*
- Infrared Soldering (IRS)*
- Ultrasonic Soldering
- Reflow (paste) Soldering (RS)
- Wave Soldering (WS)

* Similar to the equivalent Brazing technique

Ultrasonic Soldering

- A transducer subjects the molten solder to ultrasonic cavitation.
- Cavitation removes the oxide films from the surfaces to be joined
- Since no oxides present, then do not need a flux. ("Fluxless Soldering")

Reflow Soldering

- Solder pastes are solder-metal particles held together by flux, binding, and wetting agents
- Solder pastes are semisolid, have high viscosity, maintain shape over time
- Paste is applied over the joint
- Product is heated in furnace in controlled manner for proper soldered joint

Wave Soldering

- A common technique for attaching circuit components to boards
- Note that solder does not wet all surfaces
- A standing laminar wave of molten solder is generated by a pump
- Preheated & prefluxed boards pass over the molten solder wave
- The solder wets the exposed metal surfaces but does not adhere to polymer surfaces

FIGURE 32.7 (a) Screening solder paste onto a printed circuit board in reflow soldering. (b) Schematic illustration of the wave-soldering process. (c) SEM image of wave-soldered joint on surface-mount device. Source: (a) After V. Solberg.

FIGURE 32.8 Joint designs commonly used for soldering.
Adhesive Bonding

Forms of adhesives:
- Liquid
- Paste
- Solution
- Emulsion
- Powder
- Tape
- Film

Properties of Adhesives

- Strength
  - Shear
  - Peel
- Toughness
- Resistance to fluids & chemicals
- Resistance to environmental degradation, including heat & moisture
- Capability to wet surfaces to be bonded

Types of Adhesives

- Natural Adhesives
- Inorganic Adhesives
- Synthetic Organic Adhesives
  - Chemically reactive
  - Pressure sensitive
  - Hot melt
  - Reactive hot melt
  - Evaporative or diffusion
  - Film & Tape
  - Delayed tack
  - Electrically & Thermally conductive

Adhesive Systems
(Classified on the basis of their chemistry)

- Epoxy-based systems
- Acrylics
- Anaerobic systems
- Cyanoacrylate
- Urethanes
- Silicones

Adhesives

- Many adhesives may be combined to optimize properties
- Epoxies & phenolics are least expensive
- High temperature (up to 260°C (500°F)) applications are most expensive
- Most adhesives have an optimum temperature (between 20°C and 200°C) for maximum shear strength
- Adhesive bonding can be combined with mechanical joining methods to improve strength
TABLE 32.4 General Characteristics of Adhesives

<table>
<thead>
<tr>
<th>Type</th>
<th>Contents</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>Thermoset plastic, quick setting, tough bonds at room temperat</td>
<td>Strengths and steel sandwich bonds, continuous quarts, metal parts, and pla</td>
</tr>
<tr>
<td>Acrylate</td>
<td>Thermoset, fast setting, tough bonds at room temperatur</td>
<td>Shelves, flooring, sandwich bonds, metal parts, and bolts, and buildings and</td>
</tr>
<tr>
<td>Epoxide</td>
<td>Thermoset, one or two components, tough bonds, strength and engineering</td>
<td>Metal, ceramic, and rigid plastic parts</td>
</tr>
<tr>
<td>Cynoacrylate</td>
<td>Thermoset, quick setting, tough bonds at room temperatur</td>
<td>&quot;Crazy glue&quot;</td>
</tr>
<tr>
<td>Hot melt</td>
<td>Thermoset, quick setting, tough bonds at room temperatur</td>
<td>Bond, most metals, packaging, food binding, and metal art joints</td>
</tr>
</tbody>
</table>

FIGURE 32.9 Characteristic behavior of (a) brittle and (b) tough adhesives in a peeling test. This test is similar to the peeling of adhesive tape from a solid surface.

Adhesive Bonding

Advantages
- Nonstructural: sealing, insulation, vibration & noise damping
- Load distribution at bond surface
- Unaffected external appearance
- Bond thin & fragile components; little weight gain
- Can join porous materials & materials with very different properties & sizes
- Minimal distortion; because relatively low temperatures

Limitations
- Limited range of service temperatures
- Bonding time can be long
- Need for care in surface preparation
- Difficult to test nondestructively
- Limited long term reliability

Design for Adhesive Bonding
- Ensure that joints are subjected only to compressive, tensile & shear forces
- Ensure joints are NOT subject to peeling or cleavage
- Consider loading and environmental conditions
- Butt joints require large bonding surfaces
- Simple lap joints tend to distort under tension; (cause force couple at the joint)
- Join components with similar coefficients of thermal expansion;
- Avoid thermal cycling; (causes differential movement across joint)

FIGURE 32.10 Various joint designs in adhesive bonding. Note that good designs require large contact areas between the members to be joined.
FIGURE 32.11 Desirable configurations for adhesively bonded joints: (a) single lap, (b) double lap, (c) scarf, and (d) strap.

FIGURE 32.12 Two examples of combination joints, for purposes of improved strength, air tightness, and resistance to crevice corrosion.

FIGURE 32.13 The Cobe Laboratories blood reservoir. The lid is bonded to the bowl with an airtight adhesive joint and tongue-in-groove joint. Source: Courtesy of Cobe Laboratories.

Mechanical Fastening
- Often use bolts, nuts, screws, pins, rivets
- Usually require a hole
  - Must be designed with care
- Design the joints to resist shear & tensile stresses
- Holes often formed, machined (many processes; many characteristics)
- A hole in a solid body tends to cause stress concentrations, reducing fatigue life
- Can improve fatigue life by inducing compressive residual forces on cylindrical surface of the hole
  - Use drift pin

FIGURE 32.14 Examples of rivets: (a) solid, (b) tubular, (c) split or bifurcated, and (d) compression.

FIGURE 32.15 Design guidelines for riveting.
(a) Exposed shank is too long; the result is buckling instead of upsetting.
(b) Rivets should be placed sufficiently far from edges to avoid stress concentrations.
(c) Joined sections should allow ample clearance for the riveting tools.
(d) Section curvature should not interfere with the riveting process.

Source: After J.G. Bralla.

(a) (b) (c) (d)
Mechanical Fasteners

- Threaded Fasteners
- Rivets & pins
- Metal Stitching & Stapling
- Seaming
- Crimping
- Spring & Snap-in Fasteners
- Shrink & Press Fit
- Shape-Memory Alloys

Design for Mechanical Fastening

- Consider type of loading
- Consider size & spacing of holes
- Compatibility of fastener and component materials
- Avoid galvanic corrosion
- “Fewer, larger” cheaper than “More, smaller”
- Assemble parts with minimum number of fasteners
- Use loose fit, when feasible
  - facilitate assembly; reduce costs
- Use standard size fasteners
- Careful placement and location of holes
## Summary

- **Brazing and soldering:**
  - Are non-fusion joining processes
  - Utilize a filler material, requiring some temperature rise at joint
  - Can be used to join dissimilar materials, sizes, shapes
- **Use adhesive bonds for strength, to seal, to insulate, prevent corrosion, reduce vibration & noise**
- **Surface preparation for adhesive bonds is important**
- **Use bolts, nuts, screws for maintenance, reassembly**
- **Use rivets and other mechanical fastening techniques for many permanent & semi-permanent applications**
- **Thermoplastics can be joined by fusion-welding, adhesive bonding, mechanical fasteners**
- **Thermosets can be joined by mechanical fasteners or by solvent bonding**
- **Ceramics can be joined by adhesive bonding**
- **Glasses can be joined by heating interface & using adhesives**