Joining Processes
Joining

• An all-inclusive term covering processes such as:
  – Welding
  – Brazing
  – Soldering
  – Adhesive bonding
  – Mechanical fastening
‘Joining’ processes usefulness

- Some (even simple) products are too large to be made by individual processes
  – 3-D Hollow structural member, 5 m

- Easier, more economical to manufacture & join individual components
  – Cooking pot with handle

- Products to be disassembled for maintenance
  – Appliances; engines

- Varying functionality of product
  – Carbide inserts in tool steels; Brake shoes

- Transportation + assembly is less costly
  – Shelving units; Machinery
FIGURE VI.1 Various parts in a typical automobile that are assembled by the processes described in Part VI.
FIGURE VI.2 Examples of parts utilizing joining processes. (a) A tubular part fabricated by joining individual components. This product cannot be manufactured in one piece by any of the methods described in the previous chapters if it consists of thin-walled, large-diameter, tubular-shaped long arms. (b) A drill bit with a carbide cutting insert brazed to a steel shank—an example of a part in which two materials need to be joined for performance reasons. (c) Spot welding of automobile bodies. Source: (c) Courtesy of Ford Motor Co.
FIGURE VI.3  Outline of topics described in Part VI.

- Joining processes and equipment
  - The weld joint, quality, and testing (Chapter 30)
  - Safety and environmental considerations
- Welding
- Adhesive bonding (Chapter 32)
- Mechanical fastening
  - Fastening
  - Seaming
  - Crimping
  - Stitching
  (Chapter 32)
- Fusion
- Brazing and soldering (Chapter 32)
- Solid state
- Chemical
  - Oxyfuel gas
  - Thermit
  (Chapter 30)
- Electrical
  - Arc
  - Resistance
  - Electron beam
  - Laser beam
- Electrical
  - Resistance
- Chemical
  - Diffusion
  - Explosion
  (Chapter 31)
- Mechanical
  - Cold
  - Friction
  - Ultrasonic
FIGURE 1.6f  Schematic illustrations of various joining processes.
TABLE VI.1  Comparison of Various Joining Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Strength</th>
<th>Design</th>
<th>Small parts</th>
<th>Large parts</th>
<th>Tolerances</th>
<th>Reliability</th>
<th>Ease of manufacture</th>
<th>Ease of inspection</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc welding</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Resistance welding</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Brazing</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Bolts and nuts</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Riveting</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fasteners</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Seaming and crimping</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Adhesive bonding</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: 1 = very good; 2 = good; 3 = poor. For cost, 1 is the lowest.
FIGURE VI.4  Examples of joints that can be made through the various joining processes described in Chapters 30 through 32.

(a) Butt joint  (b) Corner joint  (c) T joint  (d) Lap joint  (e) Edge joint
Fusion-Welding Processes

Text Reference: “Manufacturing Engineering and Technology”, Kalpakjian & Schmid, 6/e, 2010
Chapter 30
Fusion Welding

The *melting together and coalescing* of materials by means of heat

The heat is usually supplied by chemical or electrical means

Filler metals may or may not be used
Oxyfuel-gas Welding (OFW)

- OFW describes any welding process that uses a fuel gas combined with oxygen to produce a flame.

- The most common gas-welding process is oxyacetylene-gas welding (OAW)
  - OAW is typically used for structural metal fabrication and repair
FIGURE 30.1 Three basic types of oxyacetylene flames used in oxyfuel–gas welding and cutting operations: (a) neutral flame; (b) oxidizing flame; (c) carburizing, or reducing, flame. The gas mixture in (a) is basically equal volumes of oxygen and acetylene. (d) The principle of the oxyfuel–gas welding process.
FIGURE 30.2  (a) General view of, and (b) cross section of, a torch used in oxyacetylene welding. The acetylene valve is opened first. The gas is lit with a spark lighter or a pilot light. Then the oxygen valve is opened and the flame adjusted. (c) Basic equipment used in oxyfuel–gas welding. To ensure correct connections, all threads on acetylene fittings are left handed, whereas those for oxygen are right handed. Oxygen regulators usually are painted green and acetylene regulators red.
FIGURE 30.3  Schematic illustration of the pressure-gas welding process: (a) before and (b) after. Note the formation of a flash at the joint; later the flash can be trimmed off.
Arc-Welding Processes

• The required heat is obtained from electrical energy
• Process involves a consumable or a non-consumable electrode
• An AC or DC power supply produces an arc between the tip of the electrode and the workpiece to be welded
• The arc generates temperatures of 30,000°C (50,000°F); much hotter than OFW
FIGURE 30.5  The effect of polarity and current type on weld beads: (a) DC current with straight polarity; (b) DC current with reverse polarity; (c) AC current.
FIGURE 30.4  (a) The gas tungsten-arc welding process, formerly known as TIG (for tungsten–inert-gas) welding. (b) Equipment for gas tungsten-arc welding operations.
**TABLE 30.2** Approximate Specific Energies Required to Melt a Unit Volume of Commonly Welded Metals

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific energy, ( u )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>J/mm(^3)</td>
</tr>
<tr>
<td>Aluminum and its alloys</td>
<td>2.9</td>
</tr>
<tr>
<td>Cast irons</td>
<td>7.8</td>
</tr>
<tr>
<td>Copper</td>
<td>6.1</td>
</tr>
<tr>
<td>Bronze (90Cu–10Sn)</td>
<td>4.2</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2.9</td>
</tr>
<tr>
<td>Nickel</td>
<td>9.8</td>
</tr>
<tr>
<td>Steels</td>
<td>9.1–10.3</td>
</tr>
<tr>
<td>Stainless steels</td>
<td>9.3–9.6</td>
</tr>
<tr>
<td>Titanium</td>
<td>14.3</td>
</tr>
</tbody>
</table>

*Note: 1 BTU = 1055 J = 778 ft-lb.*
FIGURE 30.6 Two types of plasma-arc welding processes: (a) transferred and (b) nontransferred. Deep and narrow welds can be made by these processes at high welding speeds.
FIGURE 30.7 Schematic illustration of the shielded metal-arc welding process. About 50% of all large-scale industrial-welding operations use this process.
FIGURE 30.8  A deep weld showing the buildup sequence of eight individual weld beads.
FIGURE 30.9  Schematic illustration of the submerged-arc welding process and equipment. The unfused flux is recovered and reused.
FIGURE 30.10  (a) Schematic illustration of the gas metal-arc welding process, formerly known as MIG (for metal inert-gas) welding. (b) Basic equipment used in gas metal-arc welding operations.
FIGURE 30.11  Schematic illustration of the flux-cored arc-welding process. This operation is similar to gas metal-arc welding, shown in Fig. 30.10.
FIGURE 30.12 Schematic illustration of the electrogas-welding process.
FIGURE 30.13  Equipment used for electroslag-welding operations.
TABLE 30.3  Designations for Mild-steel Coated Electrodes

<table>
<thead>
<tr>
<th>Designations for Mild-steel Coated Electrodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>The prefix “E” designates arc welding electrode.</td>
</tr>
<tr>
<td>The first two digits of four-digit numbers and the first three digits of five-digit numbers indicate minimum tensile strength:</td>
</tr>
<tr>
<td>E60XX</td>
</tr>
<tr>
<td>E70XX</td>
</tr>
<tr>
<td>E110XX</td>
</tr>
<tr>
<td>The next-to-last digit indicates position:</td>
</tr>
<tr>
<td>EXX1X</td>
</tr>
<tr>
<td>EXX2X</td>
</tr>
<tr>
<td>The last two digits together indicate the type of covering and the current to be used.</td>
</tr>
<tr>
<td>The suffix (Example: EXXXX-A1) indicates the approximate alloy in the weld deposit:</td>
</tr>
<tr>
<td>—A1</td>
</tr>
<tr>
<td>—B1</td>
</tr>
<tr>
<td>—B2</td>
</tr>
<tr>
<td>—B3</td>
</tr>
<tr>
<td>—B4</td>
</tr>
<tr>
<td>—B5</td>
</tr>
<tr>
<td>—C1</td>
</tr>
<tr>
<td>—C2</td>
</tr>
<tr>
<td>—C3</td>
</tr>
<tr>
<td>—D1 and D2</td>
</tr>
<tr>
<td>—G</td>
</tr>
</tbody>
</table>
FIGURE 30.14 Comparison of the sizes of weld beads: (a) laser-beam or electron-beam welding and (b) tungsten arc welding. Source: Courtesy of American Welding Society.
FIGURE 30.15  Detail of Gillette Sensor™ razor cartridge, showing laser spot welds.
## TABLE 30.1 General Characteristics of Fusion-welding Processes

<table>
<thead>
<tr>
<th>Joining process</th>
<th>Operation</th>
<th>Advantage</th>
<th>Skill level required</th>
<th>Welding position</th>
<th>Current type</th>
<th>Distortion $^*$</th>
<th>Typical cost of equipment ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shielded metal arc</td>
<td>Manual</td>
<td>Portable and flexible</td>
<td>High</td>
<td>All</td>
<td>AC, DC</td>
<td>1 to 2</td>
<td>Low (1500+)</td>
</tr>
<tr>
<td>Submerged arc</td>
<td>Automatic</td>
<td>High deposition</td>
<td>Low to medium</td>
<td>Flat and horizontal</td>
<td>AC, DC</td>
<td>1 to 2</td>
<td>Medium (5000+)</td>
</tr>
<tr>
<td>Gas metal arc</td>
<td>Semiautomatic or automatic</td>
<td>Most metals</td>
<td>Low to high</td>
<td>All</td>
<td>DC</td>
<td>2 to 3</td>
<td>Medium (3000+)</td>
</tr>
<tr>
<td>Gas tungsten arc</td>
<td>Manual or automatic</td>
<td>Most metals</td>
<td>Low to high</td>
<td>All</td>
<td>AC, DC</td>
<td>2 to 3</td>
<td>Medium (5000+)</td>
</tr>
<tr>
<td>Flux-cored arc</td>
<td>Semiautomatic or automatic</td>
<td>High deposition</td>
<td>Low to high</td>
<td>All</td>
<td>DC</td>
<td>1 to 3</td>
<td>Medium (2000+)</td>
</tr>
<tr>
<td>Oxyfuel</td>
<td>Manual</td>
<td>Portable and flexible</td>
<td>High</td>
<td>All</td>
<td>—</td>
<td>2 to 4</td>
<td>Low (500+)</td>
</tr>
<tr>
<td>Electron beam, laser beam</td>
<td>Semiautomatic or automatic</td>
<td>Most metals</td>
<td>Medium to high</td>
<td>All</td>
<td>—</td>
<td>3 to 5</td>
<td>High (100,000–1 million)</td>
</tr>
</tbody>
</table>

$^*$ 1 = highest; 5 = lowest.
Cutting

Material can be cut with the use of a heat source that melts and removes a narrow zone in the workpiece

• Can cut contours
• Heat source may be:
  – Torch
  – Electric arc
  – Laser
Oxyfuel-gas Cutting (OFC)

- Similar to Oxyfuel-gas Welding
- Process is particularly suited for steels
- A two-stage chemical process
- Iron combines with oxygen exothermically to oxidize the metal
- Need additional preheat, provided by the fuel gas, to reach melting point
FIGURE 30.16  (a) Flame cutting of a steel plate with an oxyacetylene torch, and a cross section of the torch nozzle. (b) Cross section of a flame-cut plate, showing drag lines.
Arc Cutting

- Based on same principles as arc-welding processes
- Can cut a variety of materials at high speeds
- Creates heat affected zone
Arc Cutting

Air carbon-arc Cutting (CAC-A)
• Use carbon electrode
• Air jet blows away molten metal (no oxidation necessary)
  – Need to contain blown molten metal
• Good for gouging & scarfing
• Noisy
Arc Cutting

Plasma-arc Cutting (PAC)
- Produces highest temperatures
- For rapid cutting of non-ferrous & SS plates
- Higher productivity than OFC methods
- Produces good surface finish & narrow kerfs
- Most common manufacturing process utilizing programmable controllers
Arc Cutting

Electron Beams and Lasers

• Can accurately cut many metals
• Narrow kerf
• Better surface finish than other thermal cutting processes