Types of Welding

- Fusion Welding (Chap. 27)
  - Oxyfuel Gas Welding
  - Arc-Welding Processes
    - Consumable-Electrode
    - Nonconsumable-Electrode
  - Others
    - Electron-Beam Welding
    - Laser-Beam Welding

- Solid State Welding (Chap. 28)
  - Cold Welding
  - Ultrasonic Welding
  - Friction Welding
  - Resistance Welding
    - Spot Welding
    - Seam Welding
    - High Frequency Welding
    - Projection Welding
  - Explosion Welding
  - Diffusion Bonding

Oxyfuel Gas Welding (OFW)

- Uses acetylene fuel (C_2H_2), known as oxyacetylene welding

(a) Neutral flame
   2100 °C (3800 °F)
   1290 °C (2300 °F)
   Inner cone 3040-3300 °C (5500-6000 °F) envelope
   Outer envelope

(b) Oxidizing flame
   Inner cone (pointed)
   Outer envelope (small and narrow)

(c) Carburizing (reducing) flame
   Acetylene feather
   Bright luminous inner cone
   Blue envelope
Torch Used in OFW

Arc-Welding Processes

- **Consumable-Electrode**
  - Shielded Metal-Arc Welding
  - Submerged Arc Welding
  - Gas Metal-Arc Welding
  - Flux-Cored Arc Welding
  - Electrolysis Welding

- **Nonconsumable-Electrode**
  - Gas Tungsten Arc-Welding
  - Plasma-Arc Welding
Shielded Metal-Arc Welding

Figure 27.4 Schematic illustration of the shielded metal-arc welding process. About 50% of all large-scale industrial welding operations use this process.

Figure 27.5 Schematic illustration of the shielded metal-arc welding operations (also known as stick welding, because the electrode is in the shape of a stick).

Submerged Arc Welding

Figure 27.7 Schematic illustration of the submerged-arc welding process and equipment. The unfused flux is recovered and reused.
Gas Metal-Arc Welding

Current conductor

Solid wire electrode

Shielding gas: Ar, He, CO₂

Wire guide and contact tube

Nozzle

Shielding gas

Arc

Base metal

Molten weld metal

Figure 27.8 Schematic illustration of the gas metal-arc welding process, formerly known as MIG (for metal inert gas) welding.

Flux-Cored Arc Welding

Arc shield composed of vaporized and slag-forming compounds protects metal transfer through arc

Current-carrying guide tube

Insulated extension tip

Powdered metal, vapor or gas forming materials, deoxidizers and scavengers

Solidified slag

Molten slag

Solidified weld metal

Molten weld metal

Metal droplets covered with thin slag coating forming molten puddle

Figure 27.10 Schematic illustration of the flux-cored arc-welding process. This operation is similar to gas metal-arc welding, showing in Fig. 27.8.
Electrogas Welding

- For welding the edges of sections vertically in one pass, with the pieces placed edge to edge

Electrogas welding using flux cored electrode wire:
(a) front view with molding shoe removed for clarity, and (b) side view showing molding shoes on both sides

Gas Tungsten-Arc Welding

Figure 27.13 The gas tungsten-arc welding process, formerly known as TIG (for tungsten inert gas) welding.

Figure 27.14 Equipment for gas tungsten-arc welding operations.
Plasma-Arc Welding

Figure 27.15 Two types of plasma-arc welding processes: (a) transferred, (b) nontransferred. Deep and narrow welds can be made by this process at high welding speeds.

Other Fusion Welding Processes

- Electron-Beam Welding
  - Heat is generated by high-velocity narrow-beam electrons.

- Laser-Beam Welding
  - Utilizes a high-power laser beam as the source of heat
Summary: Fusion Welding

<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>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</td>
</tr>
<tr>
<td>Submerged arc</td>
<td>Automatic</td>
<td>High</td>
<td>Low to medium</td>
<td>Flat and horizontal</td>
<td>ac, dc</td>
<td>1 to 2</td>
<td>Medium</td>
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<tr>
<td>Gas metal-arc</td>
<td>Semiautomatic or automatic</td>
<td>Flat and horizontal</td>
<td>Low to high</td>
<td>All</td>
<td>dc</td>
<td>2 to 3</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Gas tungsten-arc</td>
<td>Manual or automatic</td>
<td>Flat and horizontal</td>
<td>Low to high</td>
<td>All</td>
<td>ac, dc</td>
<td>2 to 3</td>
<td>Medium</td>
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<tr>
<td>Flux-cored arc</td>
<td>Semiautomatic or automatic</td>
<td>Flat and horizontal</td>
<td>Low to high</td>
<td>All</td>
<td>dc</td>
<td>1 to 3</td>
<td>Medium</td>
</tr>
<tr>
<td>Oxyfuel</td>
<td>Manual or automatic</td>
<td>Flat and flexible</td>
<td>High</td>
<td>All</td>
<td>—</td>
<td>2 to 4</td>
<td>Low</td>
</tr>
<tr>
<td>Electron-beam, Laser-beam</td>
<td>Semiautomatic or automatic</td>
<td>Flat and flexible</td>
<td>Medium to high</td>
<td>All</td>
<td>—</td>
<td>3 to 5</td>
<td>High</td>
</tr>
</tbody>
</table>

* 1, highest; 5, lowest.
Ultrasonic Welding

Ultrasonic welding (USW):
(a) general setup for a lap joint; and (b) close up of weld area

Friction Welding

Figure 28.3  (a) Sequence of operations in the friction welding process: (1) Left-hand component is rotated at high speed. (2) Right-hand component is brought into contact under an axial force. (3) Axial force is increased; flash begins to form. (4) Left-hand component stops rotating; weld is completed. The flash can subsequently be removed by machining or grinding. (b) Shape of fusion zone in friction welding, as a function of the force applied and the rotational speed.
Resistance Spot Welding

Figure 28.5  (a) Sequence in resistance spot welding. (b) Cross-section of a spot weld, showing the weld nugget and the indentation of the electrode on the sheet surfaces. This is one of the most commonly used process in sheet-metal fabrication and in automotive-body assembly.

Resistance Seam Welding

Figure 28.9  (a) Seam-welding process in which rotating rolls act as electrodes. (b) Overlapping spots in a seam weld. (c) Roll spot welds. (d) Resistance-welded gasoline tank.
High-Frequency Resistance Welding

(a)

Resistance Projection Welding

Figure 28.11 (a) Schematic illustration of resistance projection welding. (b) A welded bracket. (c) and (d) Projection welding of nuts or threaded bosses and studs. (e) Resistance-projection-welded grills.
Flash Welding

Figure 28.12  (a) Flash-welding process for end-to-end welding of solid rods or tubular parts.  (b) and (c) Typical parts made by flash welding.  (d) Design Guidelines for flash welding.

Stud Welding

Figure 28.13  The sequence of operations in stud welding, which is used for welding bars, threaded rods, and various fasteners onto metal plates.
Explosion Welding

Figure 28.15 Schematic illustration of the explosion welding process: (a) constant interface clearance gap and (b) angular interface clearance gap. (c) and (d) Cross-sections of explosion-welded joints. (c) titanium (top piece) on low-carbon steel (bottom). (d) Incoloy 800 (an iron-nickel-based alloy) on low-carbon steel.

Diffusion Bonding/Superplastic Forming

Figure 28.17 The sequence of operations in the fabrication of various structures by diffusion bonding and then superplastic forming of (originally) flat sheets.