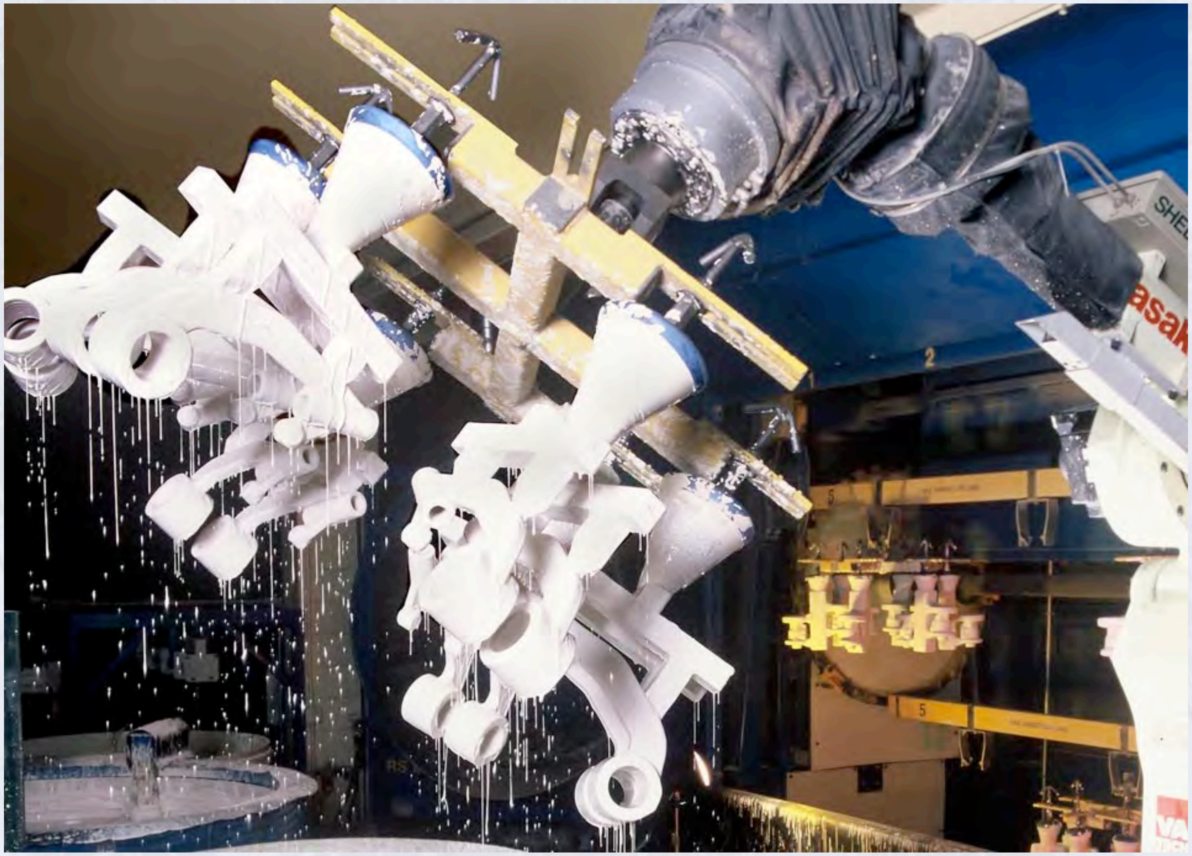
# Chapter 12

## Metal Casting: Design, Materials, and Economics



Manufacturing, Engineering & Technology, Fifth Edition, by Serope Kalpakjian and Steven R. Schmid.
ISBN 0-13-148965-8. 

# General Design Rules for Casting

- Design the part so that the shape is cast easily.
- Select a casting process and material suitable for the part, size, mechanical properties, etc.
- Locate the parting line of the mold in the part.
- Locate and design the gates to allow uniform feeding of the mold cavity with molten metal.
- Select an appropriate runner geometry for the system.
- Locate mold features such as sprue, screens and risers, as appropriate.
- Make sure proper controls and good practices are in place.

# Locating and Designing Gates

- Multiple gates often are preferable and are necessary for large parts.
- Gates should feed into thick sections of castings.
- A fillet should be used where a gate meets a casting; this feature produces less turbulence than abrupt junctions.
- The gate closest to the sprue should be placed sufficiently far away so that the gate can be easily removed.
- The minimum gate length should be three to five times the gate diameter, depending on the metal being cast.
- Curved gates should be avoided, but when necessary, a straight section in the gate should be located immediately adjacent to the casting.

# Riser Design

- The riser must not solidify before the casting.
- The riser volume must be large enough to provide a sufficient amount of liquid metal to compensate for shrinkage in the cavity.
- Junctions between casting and feeder should not develop a hot spot where shrinkage porosity can occur.
- Risers must be placed so that the liquid metal can be delivered to locations where it is most needed.
- There must be sufficient pressure to drive the liquid metal into locations in the mold where it is most needed.
- The pressure head from the riser should suppress cavity formation and encourage complete cavity filling.

# Design Rules for Casting

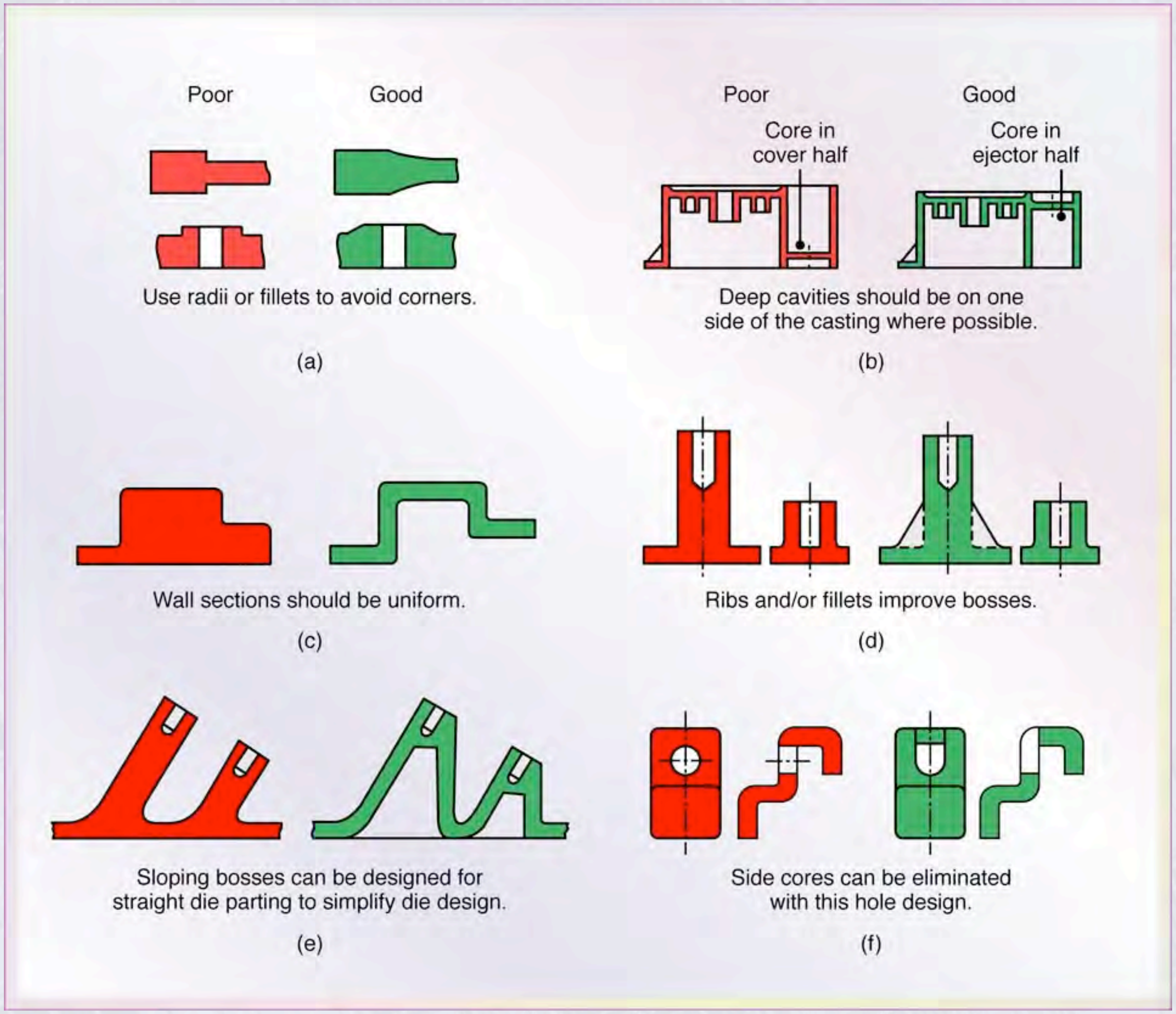



Figure 12.1 Suggested design modifications to avoid defects in castings

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# Elimination of Hot Spots

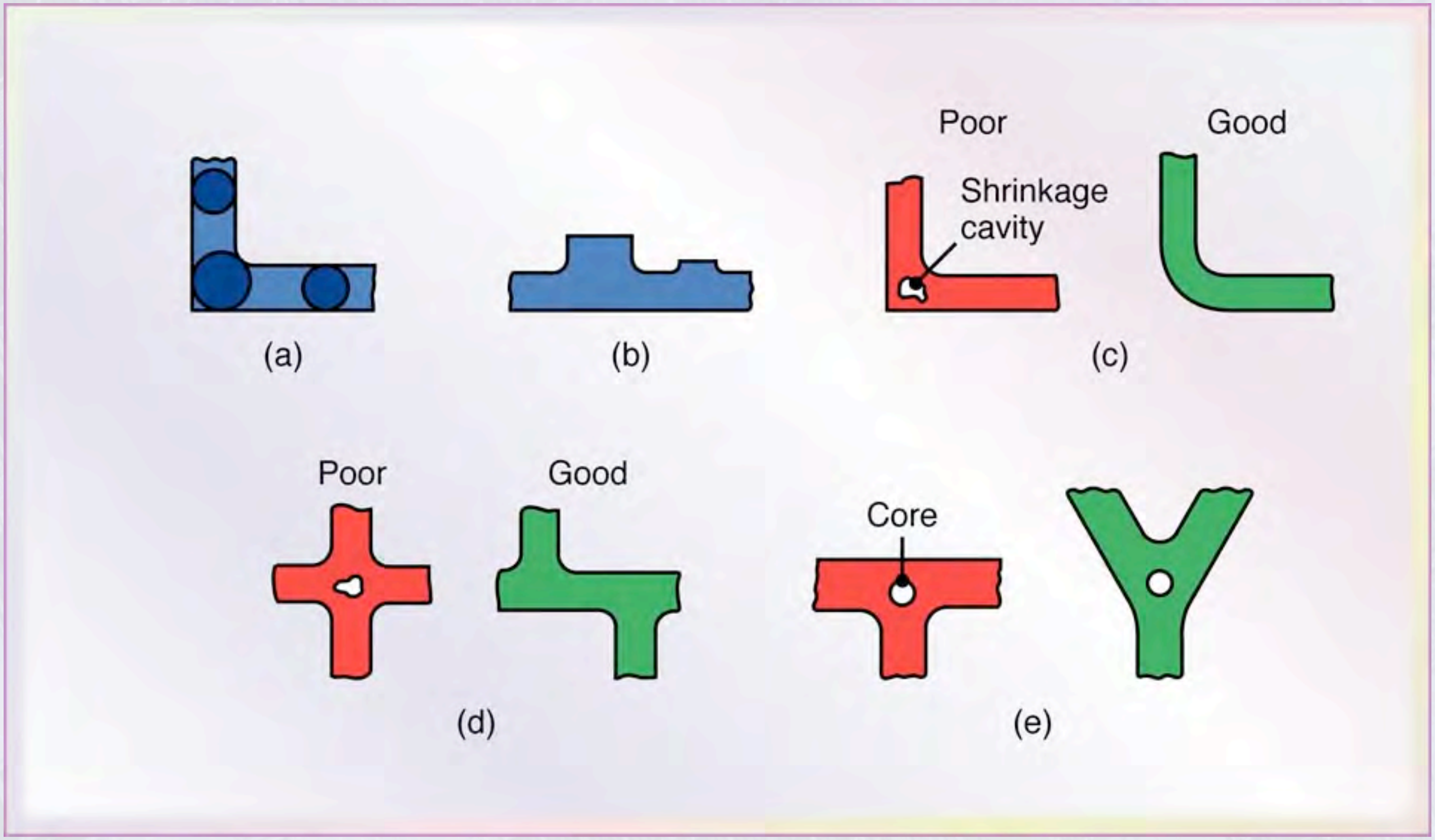


Figure 12.2 Examples of designs showing the importance of maintaining uniform cross-sections in castings to avoid hot spots and shrinkage cavities.

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# Shrinkage Allowance for Casting in Sand Molds

**TABLE 12.1**

**Normal Shrinkage Allowance for Some Metals Cast in Sand Molds**

| Metal | % |
|---|---|
| Gray cast iron | 0.83–1.3 |
| White cast iron | 2.1 |
| Malleable cast iron | 0.78–1.0 |
| Aluminum alloys | 1.3 |
| Magnesium alloys | 1.3 |
| Yellow brass | 1.3–1.6 |
| Phosphor bronze | 1.0–1.6 |
| Aluminum bronze | 2.1 |
| High-manganese steel | 2.6 |

# Examples of Good and Poor Designs

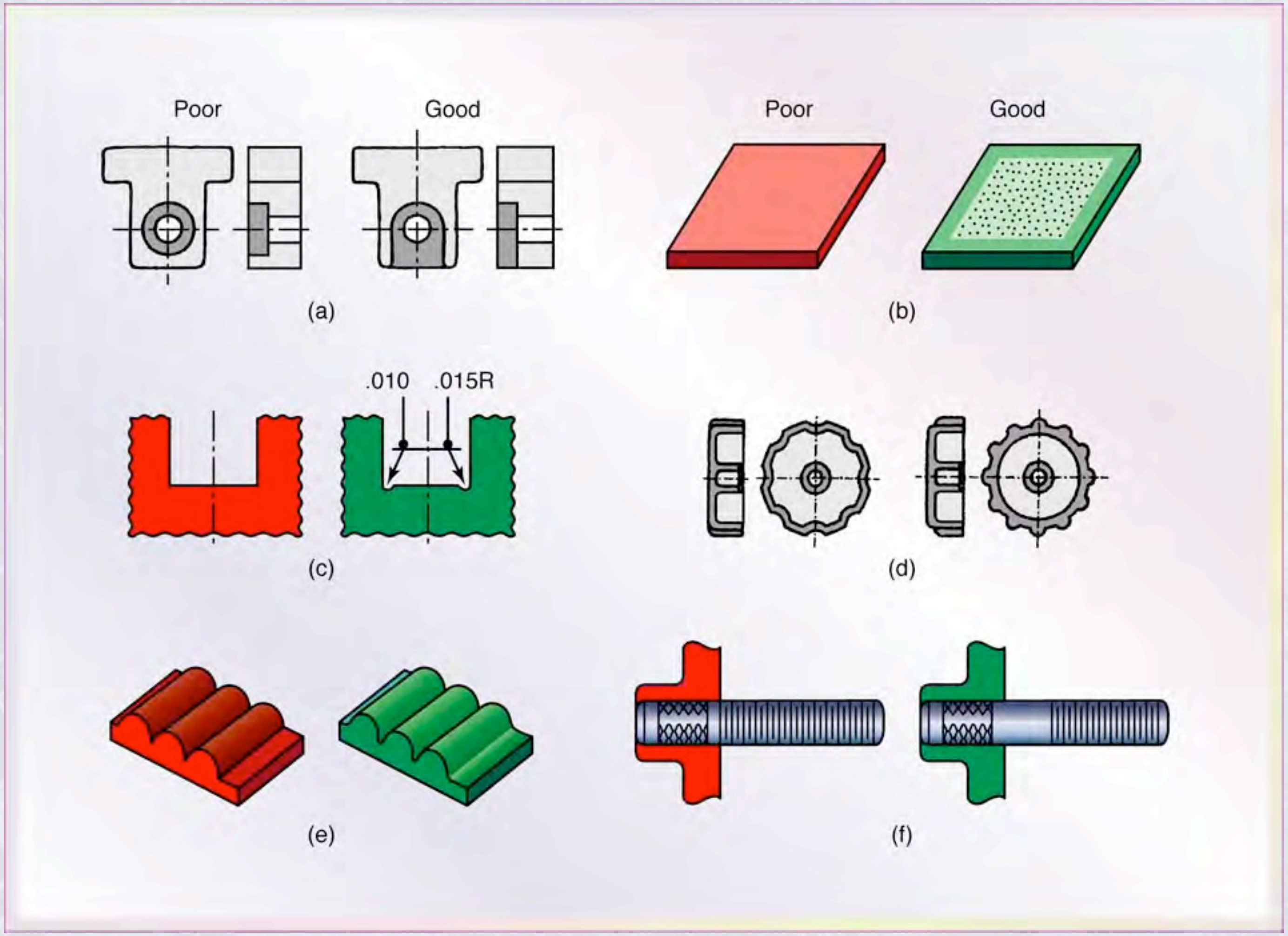


Figure 12.3 Examples of undesirable (poor) and desirable (good) casting designs. *Source:* Courtesy of American Die Casting Institute.

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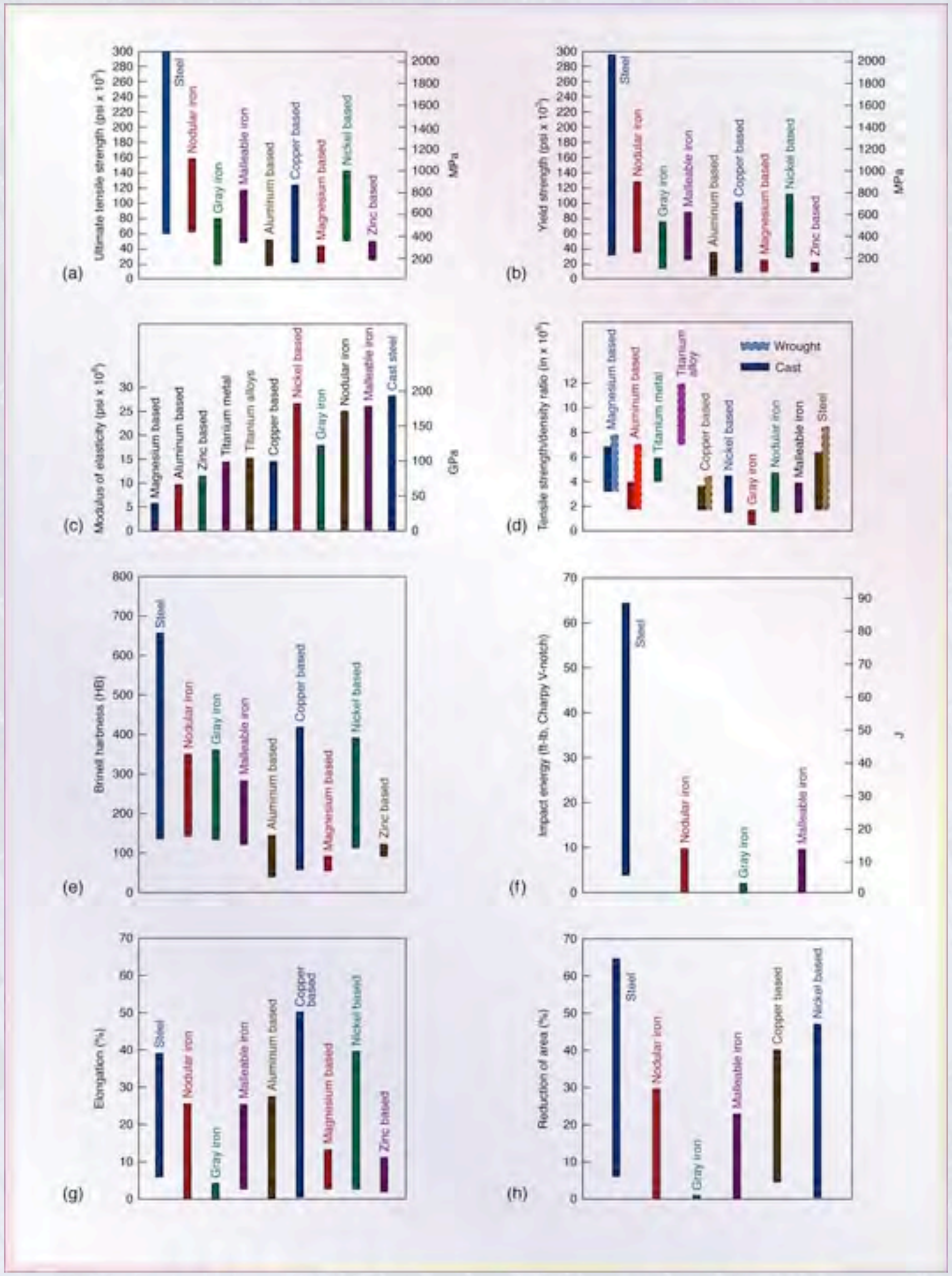


# Mechanical Properties for Cast Alloys

Figure 12.4 Mechanical properties for various groups of cast alloys. Note that even within the same group, the properties vary over a wide range, particularly for cast steels. *Source*: Courtesy of Steel Founders' Society of America.

# Casting Applications and Characteristics

**TABLE 12.2**

**Typical Applications for Castings and Casting Characteristics**

| Type of alloy | Typical applications | Castability* | Weldability* | Machinability* |
|---|---|---|---|---|
| Aluminum | Pistons, clutch housings, intake manifolds | E | F | G-E |
| Copper | Pumps, valves, gear blanks, marine propellers | F-G | F | F-G |
| Ductile iron | Crankshafts, heavy-duty gears | G | D | G |
| Gray iron | Engine blocks, gears, brake disks and drums, machine bases | E | D | G |
| Magnesium | Crankcase, transmision housings | G-E | G | E |
| Malleable iron | Farm and construction machinery, heavy-duty bearings, railroad rolling stock | G | D | G |
| Nickel | Gas turbine blades, pump and valve components for chemical plants | F | F | F |
| Steel (carbon) and low-alloy) | Die blocks, heavy-duty gear blanks, aircraft undercarriage members, railroad wheels | F | E | F |
| Steel (high-alloy) | Gas-turbine housings, pump and valve components, rock-crusher jaws | F | E | F |
| White iron | Mill liners, shot-blasing nozzles, railroad brake shoes, crushers, and pulverizers | G | VP | VP |
| Zinc | Door handles, radiator grills | E | D | E |

*E = excellent; G = good; F = fair; VP = very poor; D = difficult.

# Properties and Applications of Cast Irons

**TABLE 12.3**

**Properties and Typical Applications of Cast Irons**

| Cast iron | Type | Ultimate tensile strength (MPa) | Yield strength (MPa) | Elongation in 50 mm (%) | Typical applications |
|---|---|---|---|---|---|
| Gray | Ferritic | 170 | 140 | 0.4 | Pipe, sanitary ware |
| | Pearilitic | 275 | 240 | 0.4 | Engine blocks, machine tools |
| | Martensitic | 550 | 550 | 0 | Wear surfaces |
| Ductile | Ferritic | 415 | 275 | 18 | Pipe, general service |
| (Nodular) | Pearlitic | 550 | 380 | 6 | Crankshafts, highly stressed parts |
| | Tempered martensite | 825 | 620 | 2 | High-strength machine parts, wear-resistant parts |
| Malleable | Ferritic | 365 | 240 | 18 | Hardware, pipe fittings, general engineering service |
| | Pearlitic | 450 | 310 | 10 | Railroad equipment, couplings |
| | Tempered martensite | 700 | 550 | 2 | Railroad equipment, gears, connecting rods |
| White | Pearlitic | 275 | 275 | 0 | Wear-resistant parts, mill rolls |

# Mechanical Properties of Gray Cast Irons

**TABLE 12.4**

**Mechanical Properties of Gray Cast Irons**

| ASTM class | Ultimate tensile strength (MPa) | Compressive strength (MPa) | Elastic modulus (GPa) | Hardness (HB) |
|---|---|---|---|---|
| 20 | 152 | 572 | 66–97 | 156 |
| 25 | 179 | 669 | 79–102 | 174 |
| 30 | 214 | 752 | 90–113 | 210 |
| 35 | 252 | 855 | 100–119 | 212 |
| 40 | 293 | 965 | 110–138 | 235 |
| 50 | 362 | 1130 | 130–157 | 262 |
| 60 | 431 | 1293 | 141–162 | 302 |

# Properties and Applications of Nonferrous Cast Alloys

**TABLE 12.5**

**Properties and Typical Applications of Nonferrous Cast Alloys**

| Alloys (UNS) | Condition | Ultimate tensile strength (MPa) | Yield strength (MPa) | Elongation in 50 mm (%) | Typical applications |
|---|---|---|---|---|---|
| **Aluminum alloys** | | | | | |
| 195 (AO1950) | Heat treated | 220-280 | 110-220 | 8.5-2 | Sand castings |
| 319 (AO3190) | Heat treated | 185-250 | 125-180 | 2-1.5 | Sand castings |
| 356 (AO3560) | Heat treated | 260 | 185 | 5 | Permanent mold castings |
| **Copper alloys** | | | | | |
| Red brass (C83600) | Annealed | 235 | 115 | 25 | Pipe fittings, gears |
| Yellow brass (C86400) | Annealed | 275 | 95 | 25 | Hardware, ornamental |
| **Manganese bronze** (C86100) | Annealed | 480 | 195 | 30 | Propeller hubs, blades |
| **Leaded tin bronze** (C92500) | Annealed | 260 | 105 | 35 | Gears, bearings, valves |
| **Gun metal** (C90500) | Annealed | 275 | 105 | 30 | Pump parts, fittings |
| **Nickel silver** (C97600) | Annealed | 275 | 175 | 15 | Marine parts, valves |
| **Magnesium alloys** | | | | | |
| AZ91A | F | 230 | 150 | 3 | Die castings |
| AZ63A | T4 | 275 | 95 | 12 | Sand and permanent mold castings |
| AZ91C | T6 | 275 | 130 | 5 | High-strength parts |
| EZ33A | T5 | 160 | 110 | 3 | Elevated-temperature parts |
| HK31A | T6 | 210 | 105 | 8 | Elevated-temperature parts |
| QE22A | T6 | 275 | 205 | 4 | Highest-strength parts |

# Cost Characteristics of Casting

**TABLE 12.6**

**General Cost Characteristics of Casting Processes**

| Casting process | Cost* | | | Production rate (pieces/hr) |
|---|---|---|---|---|
| | Die | Equipment | Labor | |
| Sand | L | L | L-M | <20 |
| Shell mold | L-M | M-H | L-M | <50 |
| Plaster | L-M | M | M-H | <10 |
| Investment | M-H | L-M | H | <1000 |
| Permanent mold | M | M | L-M | <60 |
| Die | H | H | L-M | <200 |
| Centrifugal | M | H | L-M | <50 |

*L = low; M = medium; H = high.

# Automated Shell Production


Figure 12.5 A robot generates a ceramic shell on wax patterns (trees) for investment casting. The robot is programmed to dip the trees and then place them in an automated drying system. With many layers, a thick ceramic shell suitable for investment casting is formed. *Source*: Courtesy of Wisconsin Precision Casting Corporation