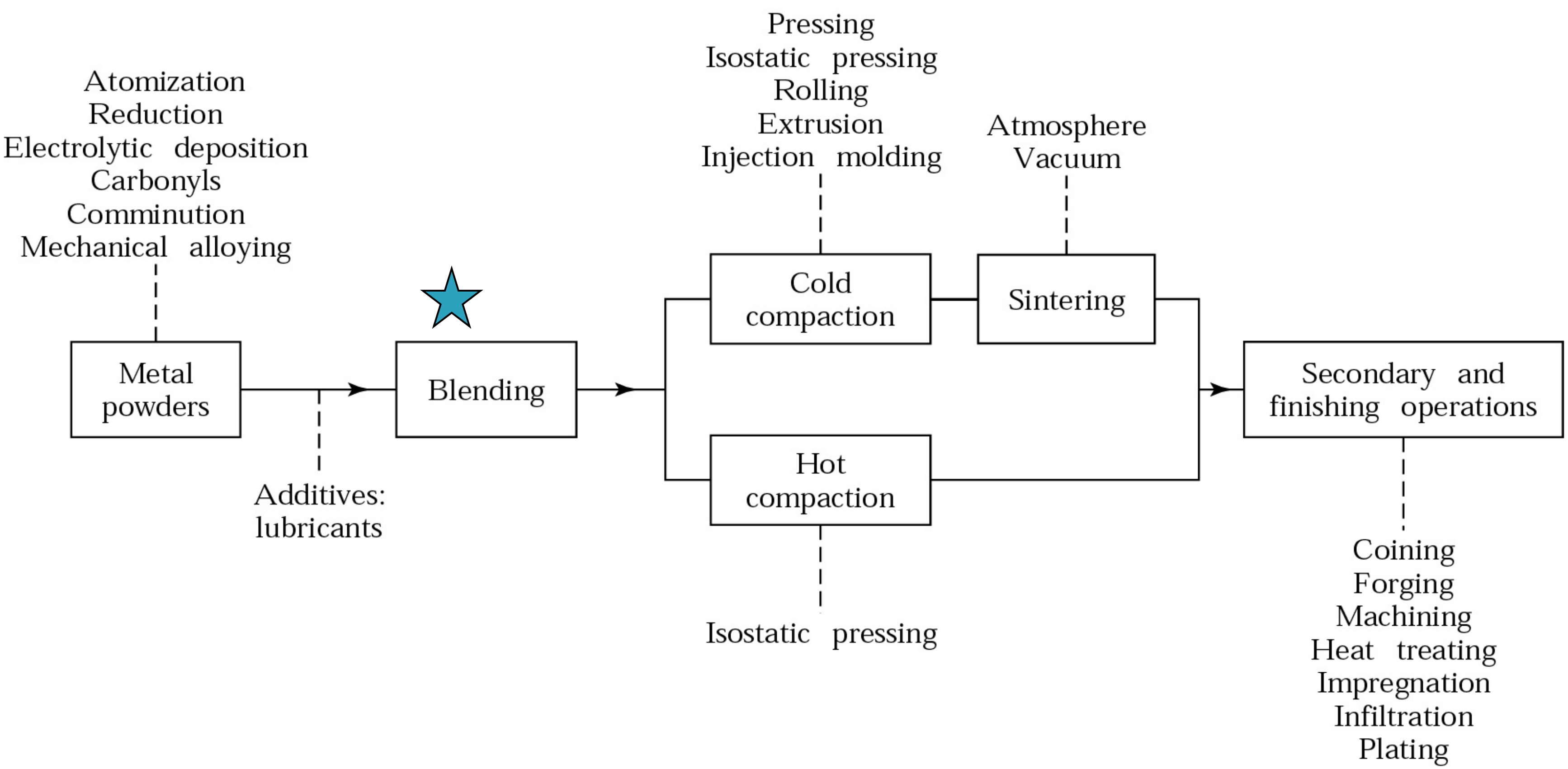
# Powder Metallurgy

by
Haipan Salam

# Powder Metallurgy Process



# Powder Mixing and Blending

- The majority of powders are mixed with other powders, binders, and lubricants to achieve the desired characteristics in the finished product
- The ideal mix is one in which all the particles of each material are distributed uniformly
- Sufficient diffusion must occur during sintering to ensure a uniform chemistry and structure
- Unique composites can be produced
- Blending or mixing operations can be done either wet or dry
- Hazards:  Over-mixing may wear particles or work-harden them.  High surface area to volume ratio – susceptible to oxidation; and may explode!

# Blending metal powders

- Mix to obtain uniformity
- Mix to obtain desired physical and mechanical properties
- Mix lubricants to improve flow characteristics
- **Binders such as wax or thermoplastic polymers are added to improve green strength (0,25%-5%.wt binders).**
- Blend in air, inert(to avoid oxidation) or in liquids

# Blending metal powders

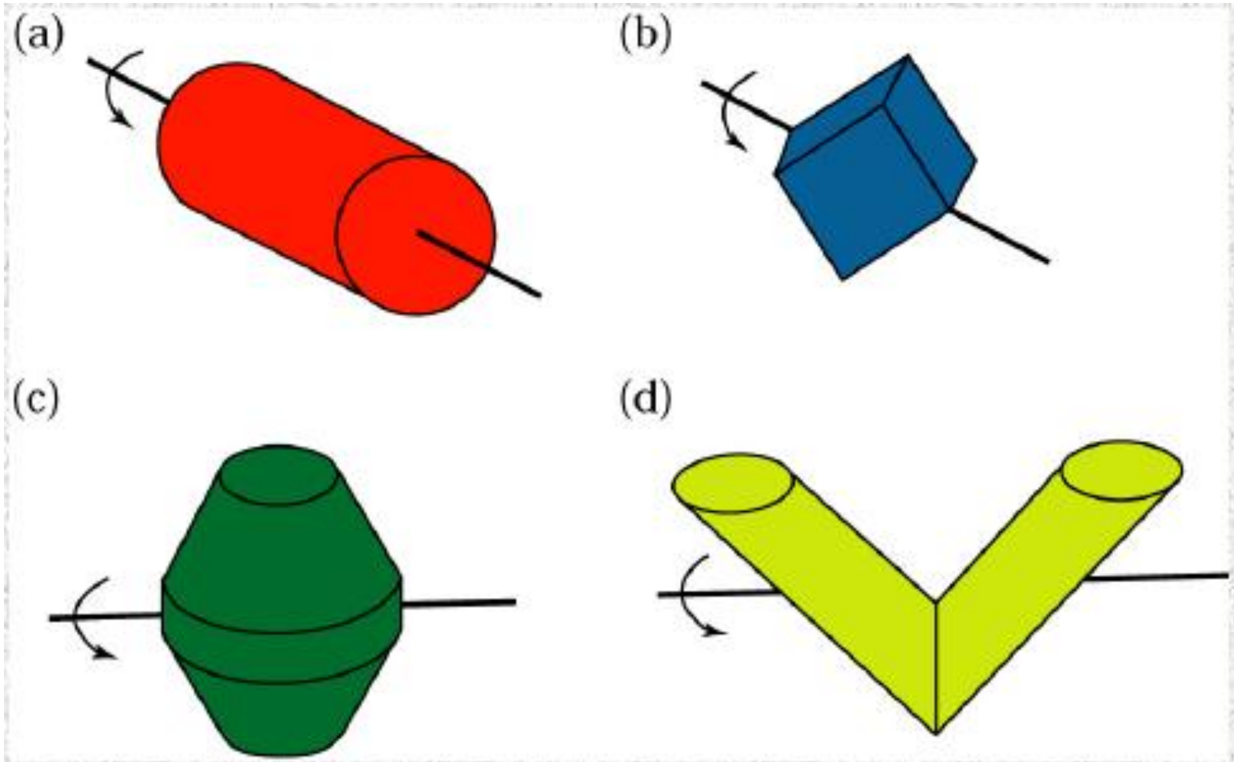
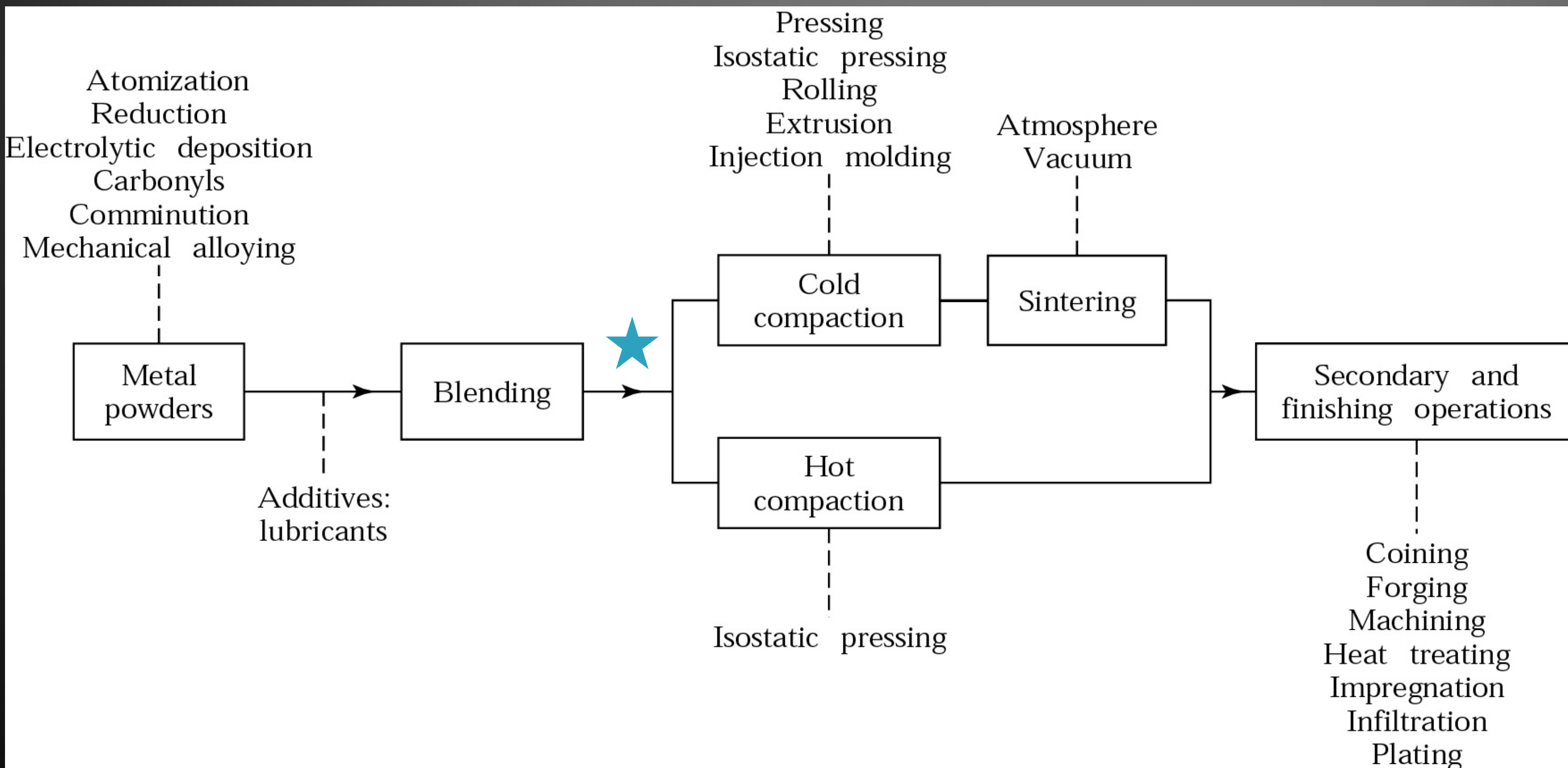



Figure extra Some common equipment geometries for mixing or blending powders: (a) cylindrical, (b) rotating cube, (c) double cone, and (d) twin shell. *Source*: Reprinted with permission from R. M. German, *Powder Metallurgy Science*. Princeton, NJ; Metal Powder Industries Federation, 1984.

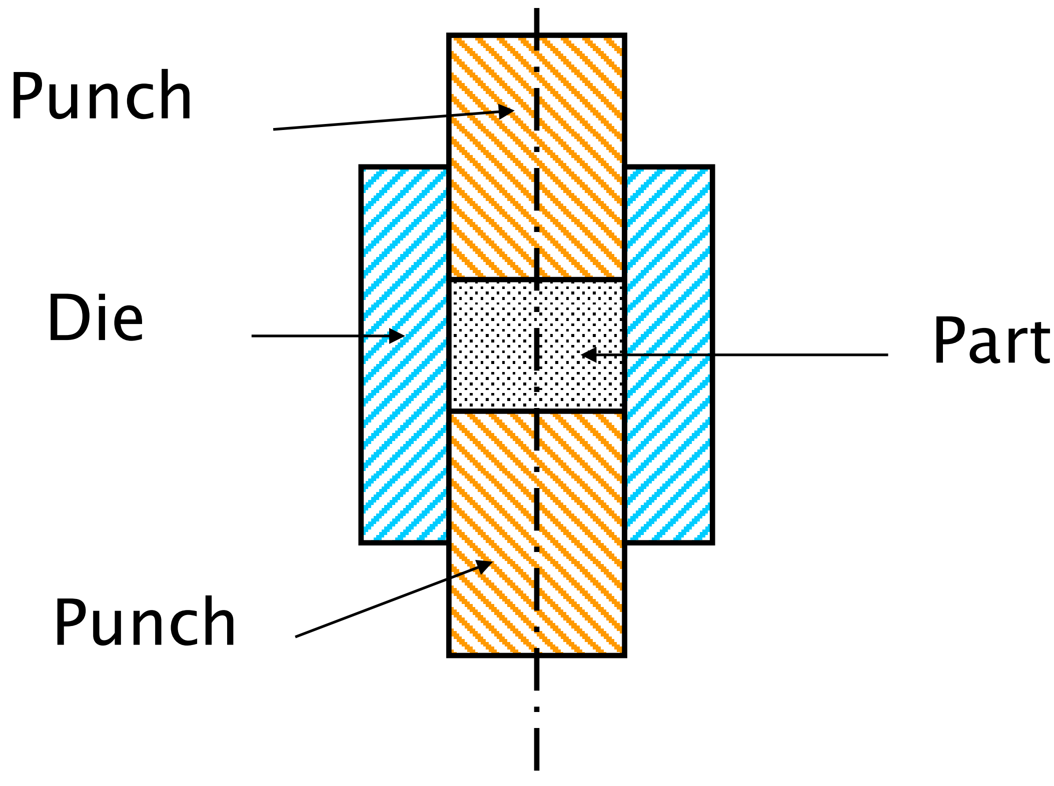
# Making Powder-Metallurgy Parts



# Powder Processing

- Cold compaction and sintering
  - Pressing
  - Rolling
  - Extrusion
  - Injection molding
  - Isostatic pressing
- Hot Isostatic Pressing

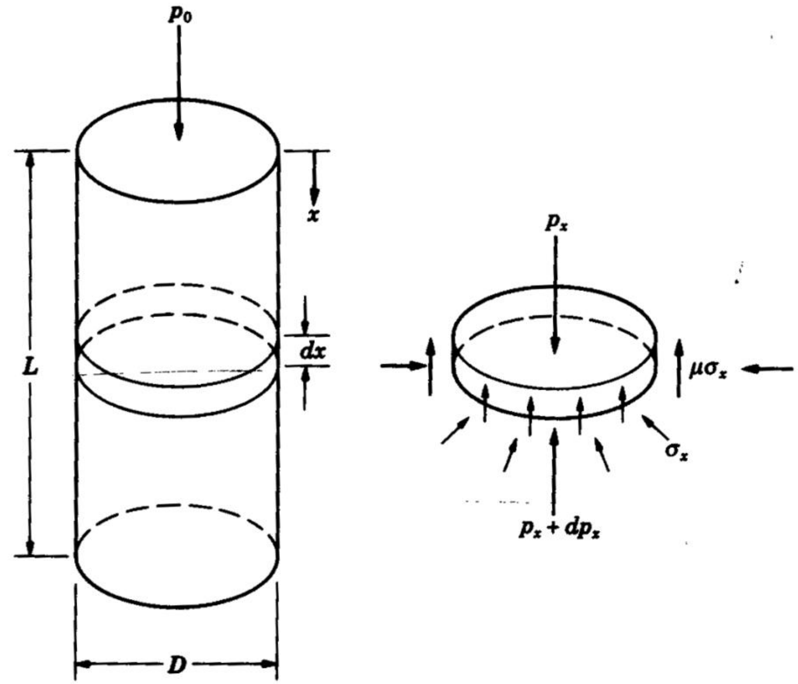
# Powder Pressing




Dual action press

Balancing the vertical forces:

$$\left(\frac{\pi D^2}{4}\right)p_x - \left(\frac{\pi D^2}{4}\right)(p_x + dp_x) - (\pi D)(\mu\sigma_x)dx = 0$$




which simplifies to

$$Ddp_x + 4\mu\sigma_x = 0$$

introduce k (interparticle friction)

$$\sigma_x = kp_x$$

$$dp_x + \frac{4\mu k p_x dx}{D} = 0 \quad \text{or} \quad \frac{dp_x}{p_x} = \frac{-4\mu k dx}{D}$$

Integrating and using boundary conditions:

$$p_x = p_0 e^{-4\mu kx/D}$$

**Example 11.3:** Pressure decay in compaction

Assume that a powder mix has $k = 0.5$ and $\mu = 0.3$. At what depth will the pressure in a straight cylindrical compact 10 mm in diameter become (a) zero and (b) one-half the pressure at the punch?

SOLUTION. For case (1) from Eq. 11.2, $p_x = 0$. Consequently, we have the expression

$$0 = p_o e^{-(4)(0.3)(0.5)x/10}, \text{ or } e^{-0.06x} = 0.$$

The value of $x$ must approach $\infty$ for the pressure to decay to 0.

For case (2), we have $p_x/p_o = 0.5$. Therefore

$$e^{-0.06x} = 0.5, \text{ or } x = 11.55 \text{ mm}.$$

In a practical case, a pressure drop of 50 percent is quite severe, as the compact density will then be unacceptably low. This example shows that, under the conditions assumed, uniaxial compaction of even a cylinder of length/diameter ratio of about 1.2 will be unsatisfactory.

# Compacting

- Loose powder is compacted and densified into a shape, known as green compact
- Most compacting is done with mechanical presses and rigid tools
  - Hydraulic and pneumatic presses are also used

**TABLE 18-1** Typical Compacting Pressures for Various Applications

| Application | Compaction Pressures tons/in.$^2$ | Mpa |
|---|---|---|
| Porous metals and filters | 3–5 | 40–70 |
| Refractory metals and carbides | 5–15 | 70–200 |
| Porous bearings | 10–25 | 146–350 |
| Machine parts (medium-density iron & steel) | 20–50 | 275–690 |
| High-density copper and aluminum parts | 18–20 | 250–275 |
| High-density iron and steel parts | 50–120 | 690–1650 |

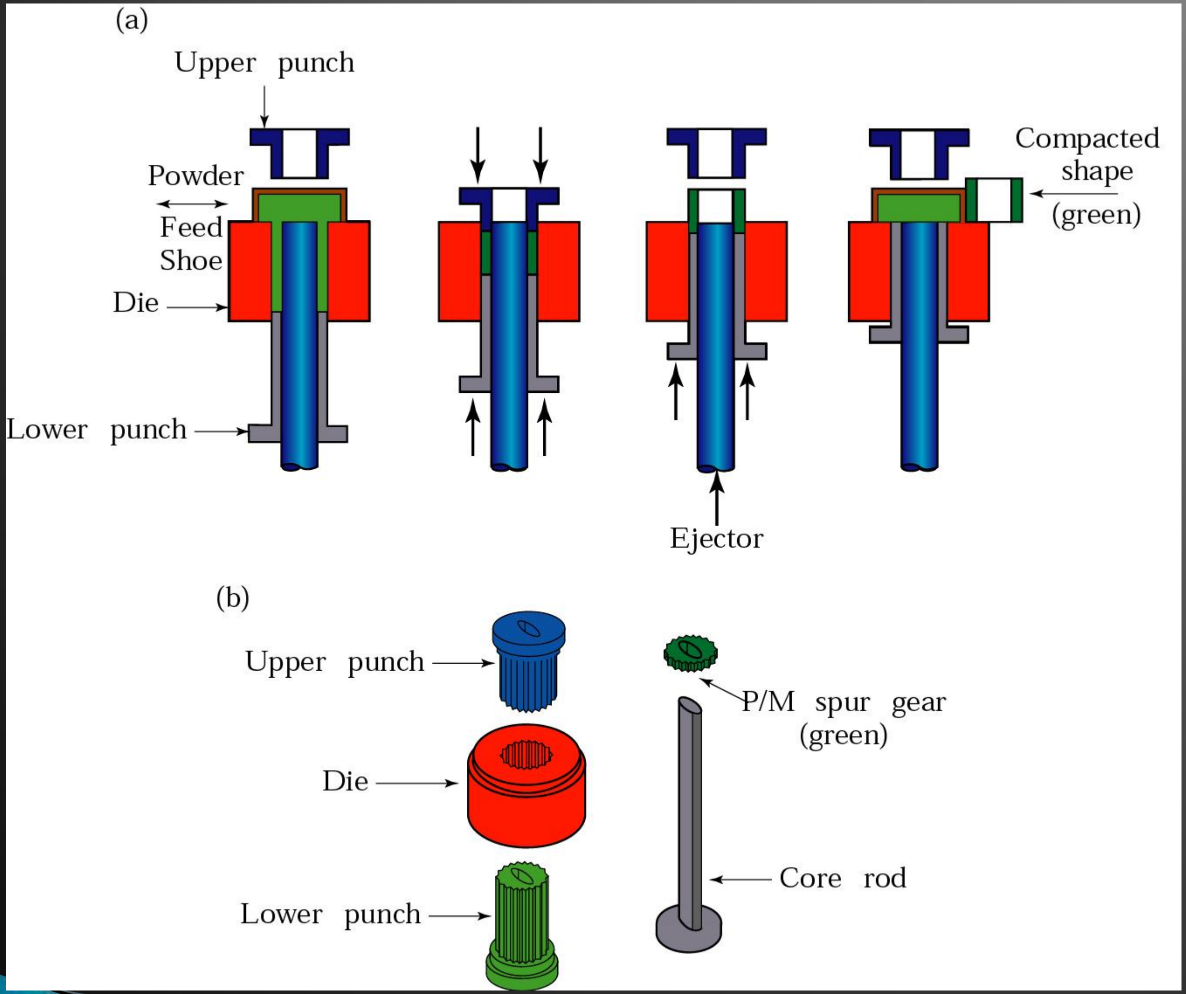
# Compacting Pressure for Various Metals Powders

TABLE 11.3

| Metal | Pressure (MPa) |
|---|---|
| Aluminum | 70–275 |
| Brass | 400–700 |
| Bronze | 200–275 |
| Iron | 350–800 |
| Tantalum | 70–140 |
| Tungsten | 70–140 |
| **Other materials** | |
| Aluminum oxide | 110–140 |
| Carbon | 140–165 |
| Cemented carbides | 140–400 |
| Ferrites | 110–165 |

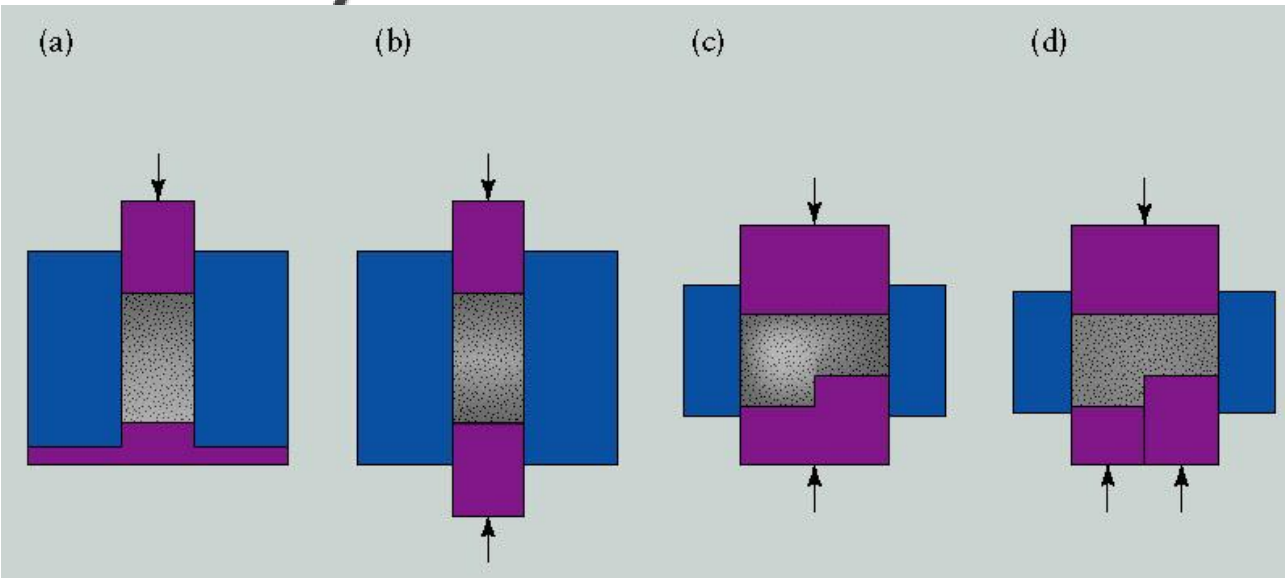

**Figure 18-3** (Left) Typical press for the compacting of metal powders. A removable die set (right) allows the machine to be producing parts with one die set while another is being fitted to produce a second product. (*Courtesy of Alfa Laval, Inc., Warminster, PA.*)

# Compaction




(a) Compaction of metal powder to form a bushing. The pressed powder part is called green compact.
(b) Typical tool and die set for compacting a spur gear.

# Density Variation




Density variation in compacting metal powders in different dies:
(a) and (c) single-action press
(b) and (d) double-action press.
Note in (d) the greater uniformity of density in pressing with two punches with separate movements as compared with (c).
Generally, uniformity of density is preferred, although there are situations in which density variation, and hence variation of properties, within a apart may be desirable.

# Additional Considerations During Compacting

- When the pressure is applied by only one punch, the maximum density occurs right below the punch surface and decreases away from the punch
- For complex shapes, multiple punches should be used

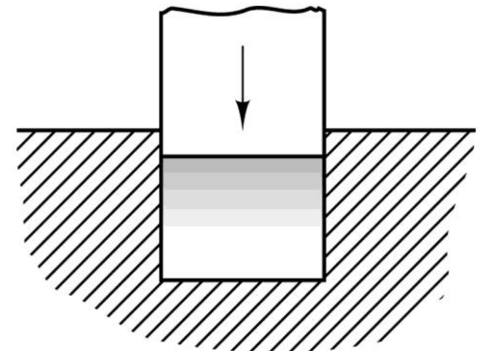


**Figure 18-5** Compaction with a single moving punch, showing the resultant nonuniform density (shaded), highest where particle movement is the greatest.

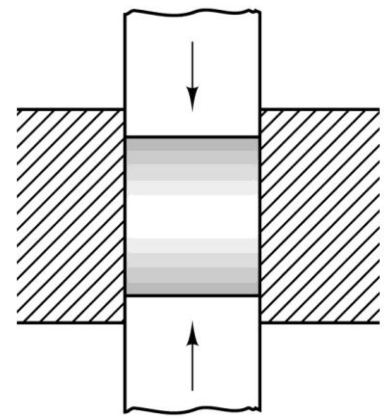
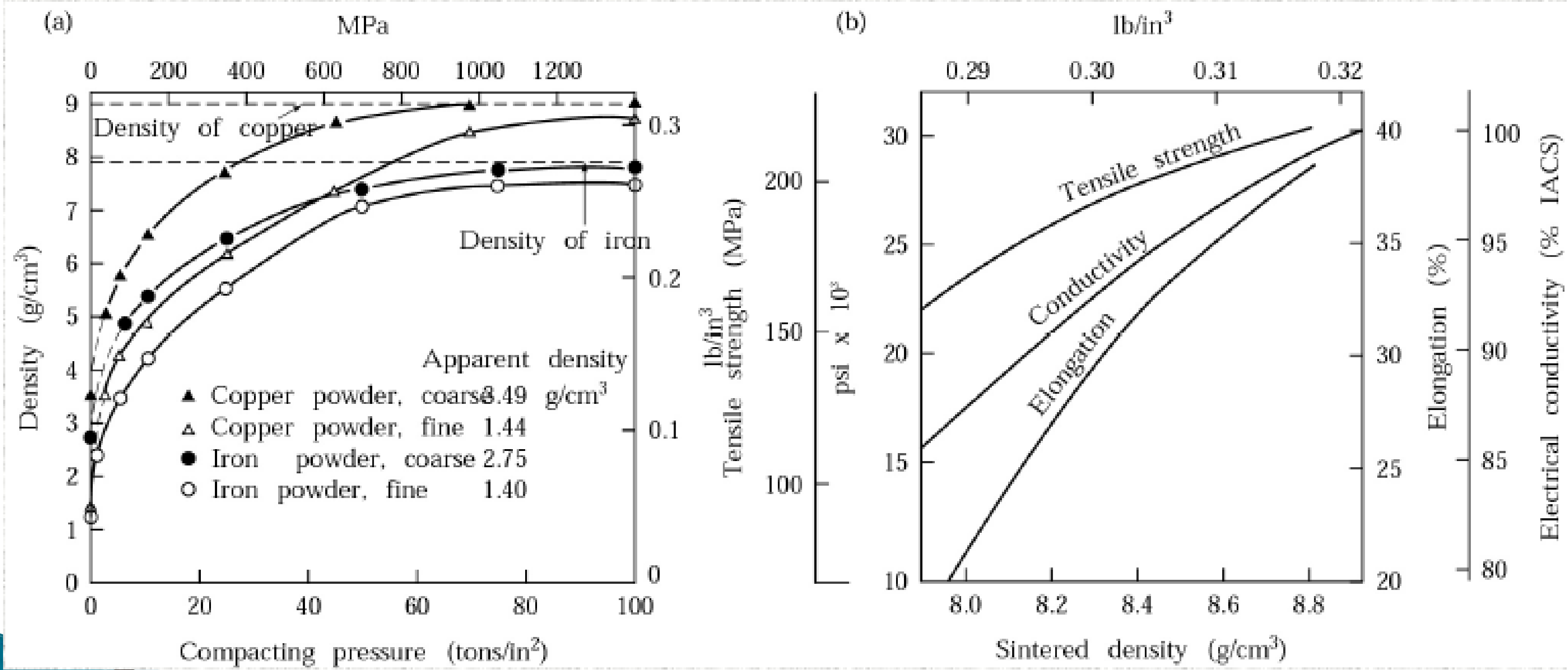


**Figure 18-6** Density distribution obtained with a double-acting press and two moving punches. Note the increased uniformity compared to Figure 18-5. Thicker parts can be effectively compacted.

# Density Effect

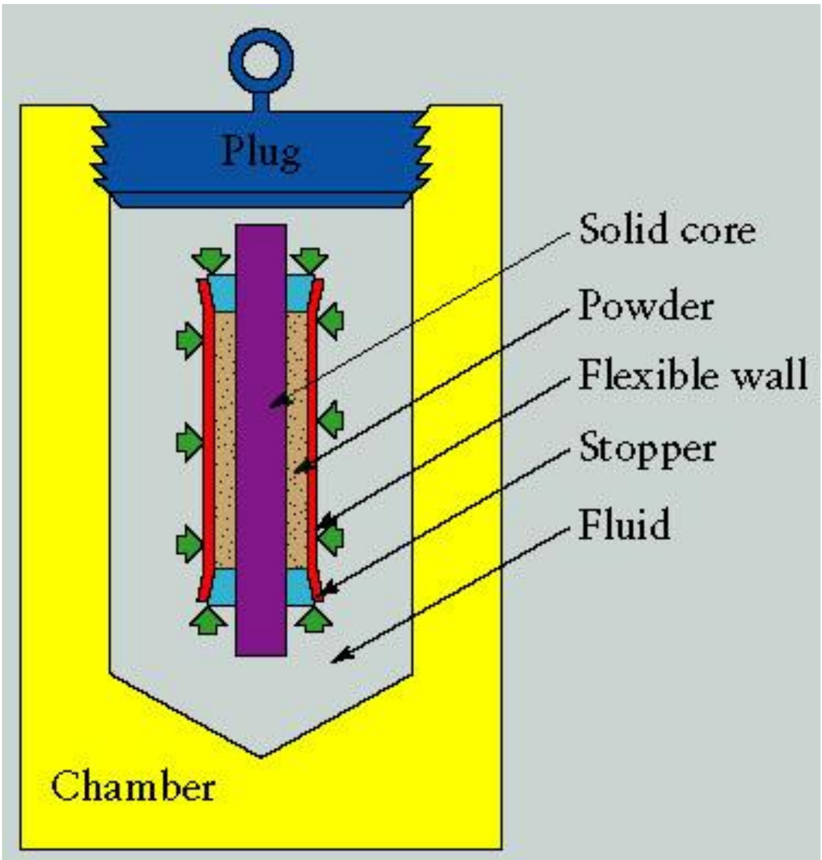
Figure 11.7 (a) Density of copper- and iron-powder compacts as a function of compacting pressure. Density greatly influences the mechanical and physical properties of P/M parts. *Source*: F. V. Lenel, *Powder Metallurgy: Principles and Applications*. Princeton, NJ; Metal Powder Industries Federation, 1980. (b) Effects of density on tensile strength, elongation, and electrical conductivity of copper powder. IACS means International Annealed Copper Standard for electrical conductivity.



# Complex Compacting

- If an extremely complex shape is desired, the powder may be encapsulated in a flexible mold, which is then immersed in a pressurized gas or liquid
  - Process is known as isostatic compaction
- In warm compaction, the powder is heated prior to pressing
- The amount of lubricant can be increased in the powder to reduce friction
- Because particles tend to be abrasive, tool wear is a concern in powder forming

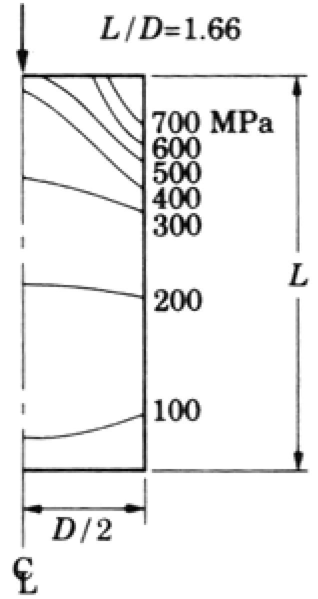
# Cold Isostatic Pressing(CIP)

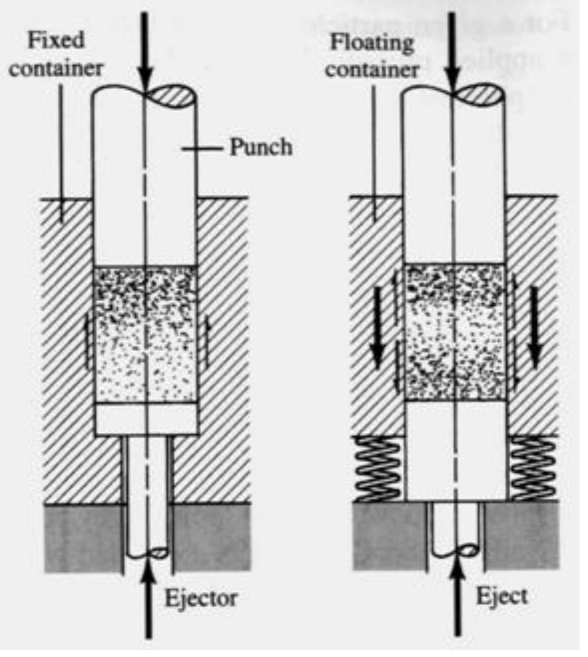



- Schematic illustration of cold isostatic pressing as applied to formation of a tube. The powder is enclosed in a flexible container around a solid core rod. Pressure is applied isostatically to the assembly inside a high-pressure chamber.

# Friction problem in cold compaction

- **The effectiveness of pressing with a single-acting punch is limited. Wall friction opposes compaction.**
- **The pressure tapers off rapidly and density diminishes away from the punch.**
- **Floating container and two counteracting punches help alleviate the problem.**

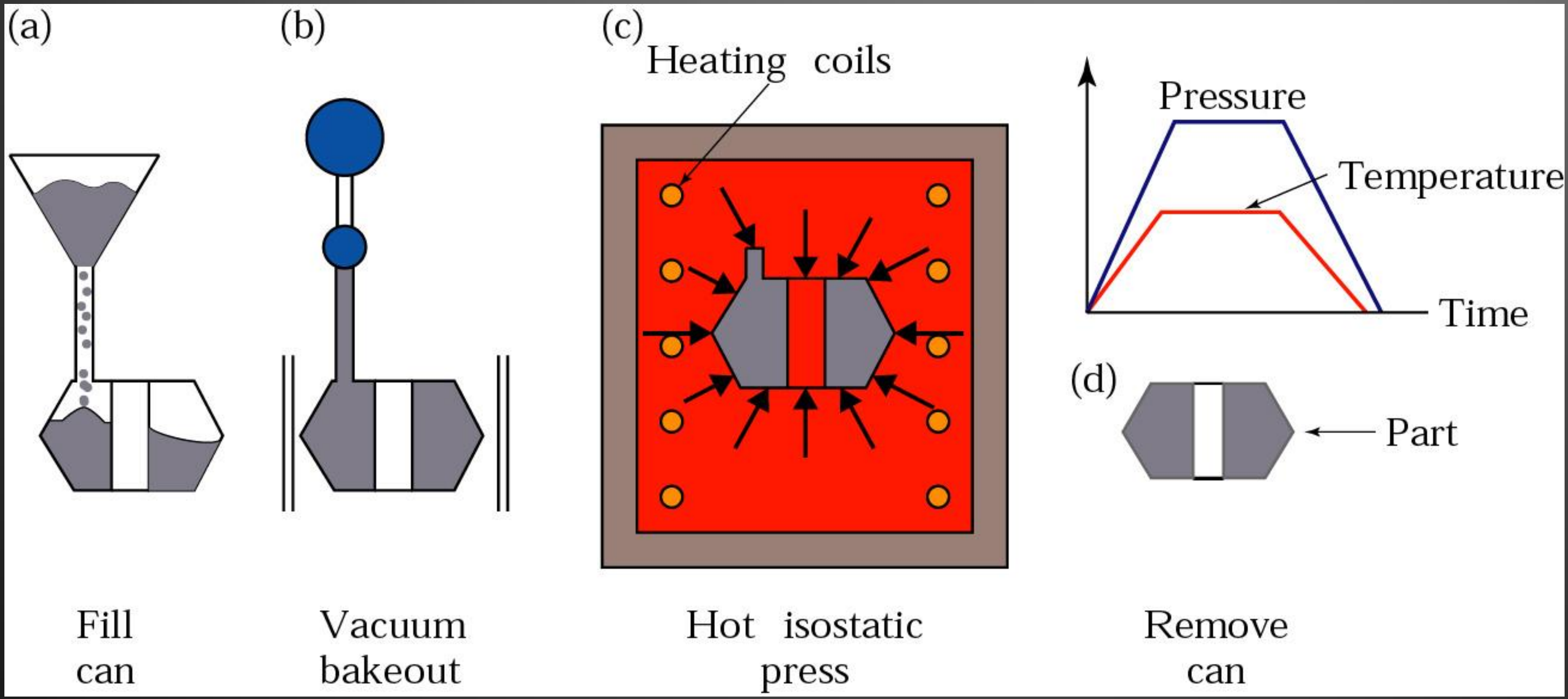


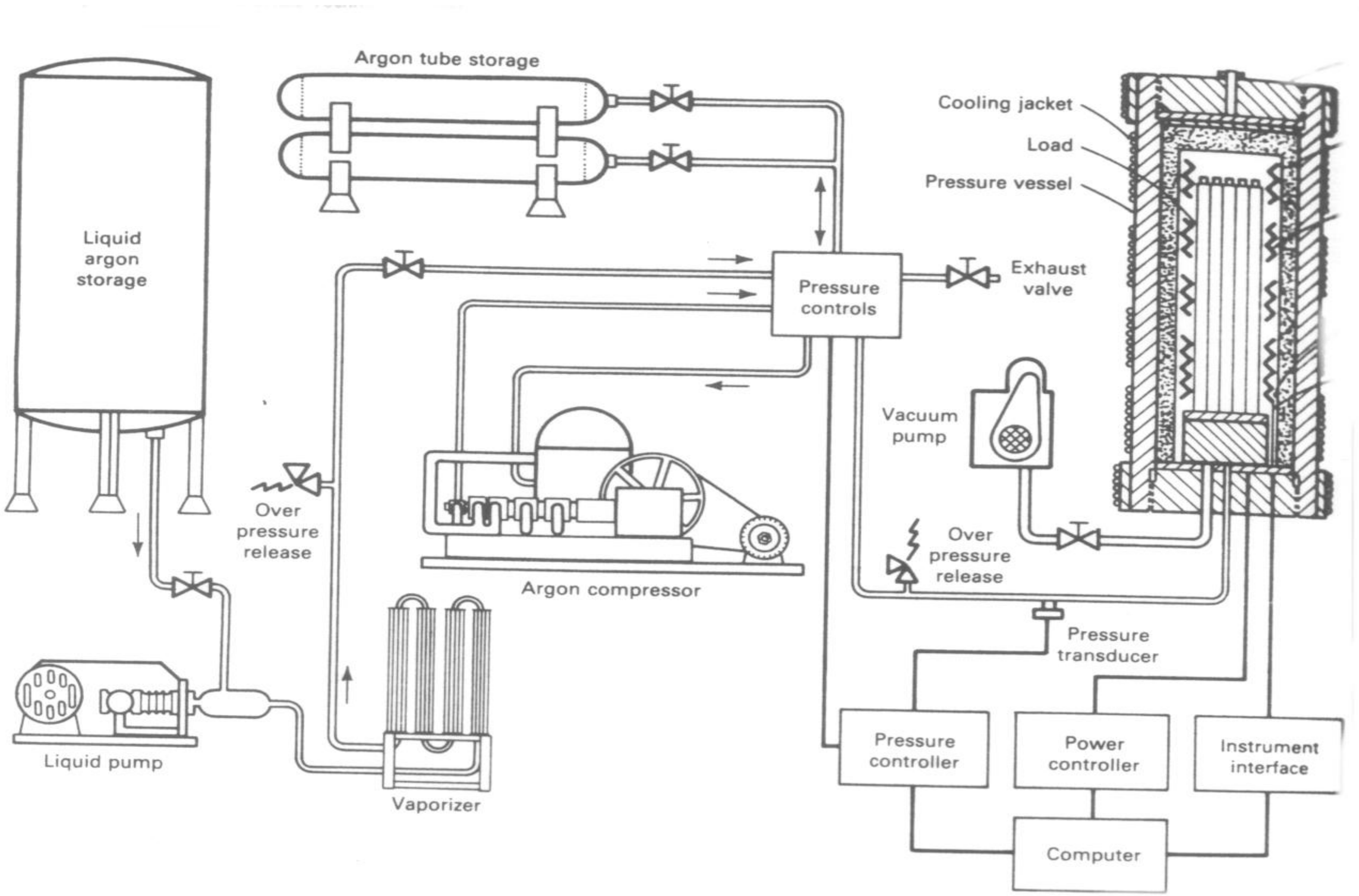
# Hot-Isostatic Pressing

- Hot-isostatic pressing (HIP) combines powder compaction and sintering into a single operation
  - Gas-pressure squeezing at high temperatures
  - Common condition for HIP are 100 Mpa at 1100°C
- Heated powders may need to be protected from harmful environments
- Products emerge at full density with unifrom, isotropic properties
- Near-net shapes are possible

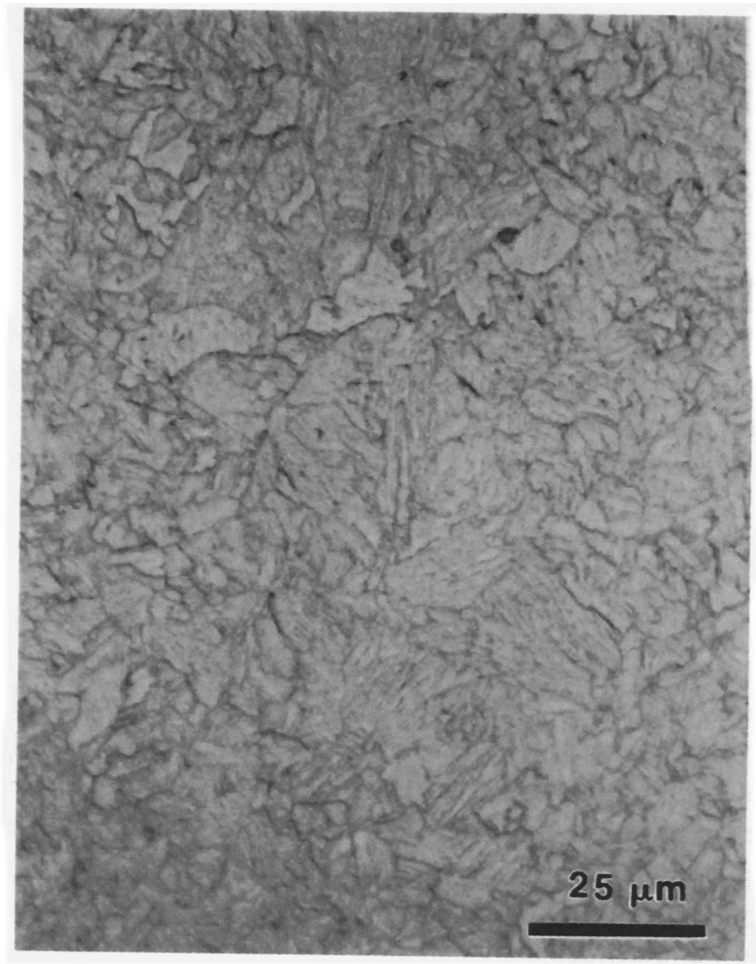
# Hot Isostatic Pressing(HIP)



# Hot Isostatic Pressure System

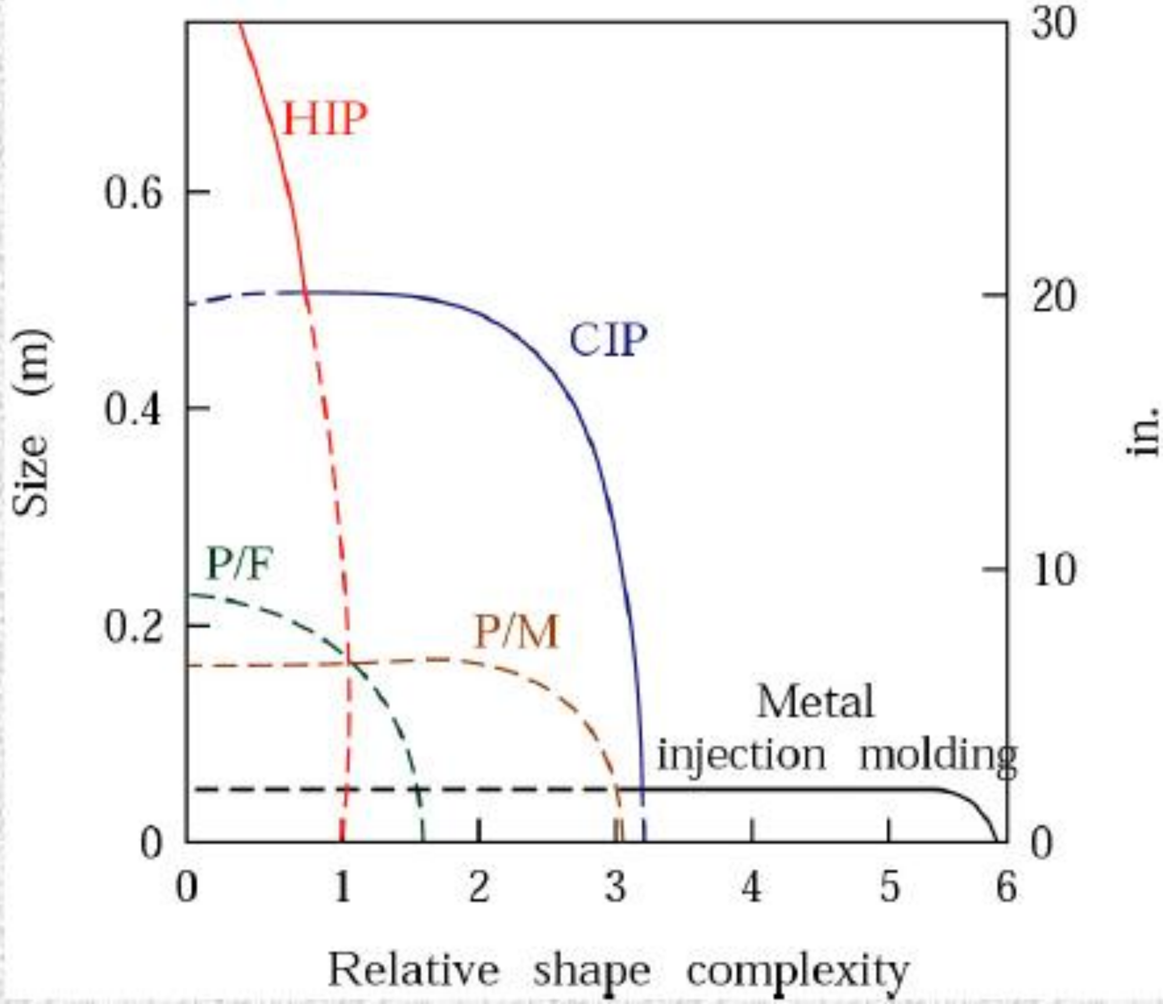


# Steel formed from HIP



# Capabilities Available from P/M Operation

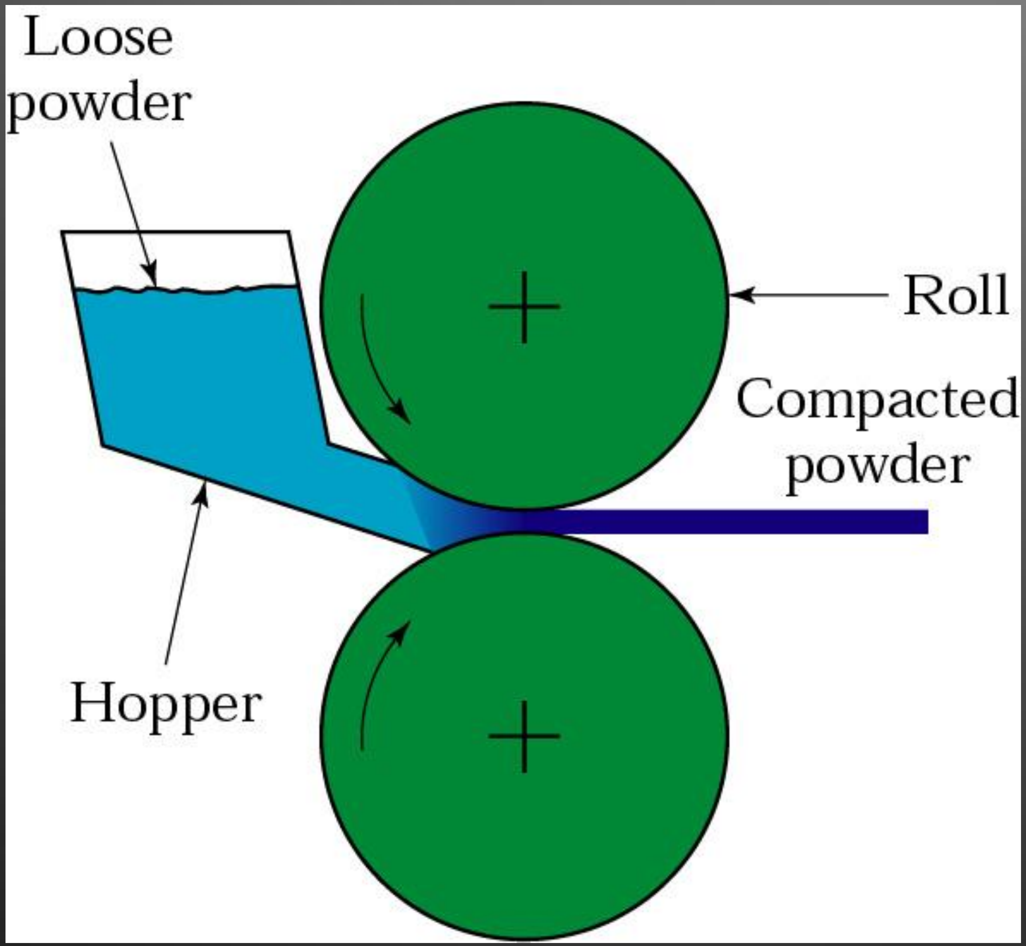
Figure 11.11 Capabilities, with respect to part size and shape complexity, available from various P/M operations. P/F means powder forging. *Source:* Metal Powder Industries Federation.



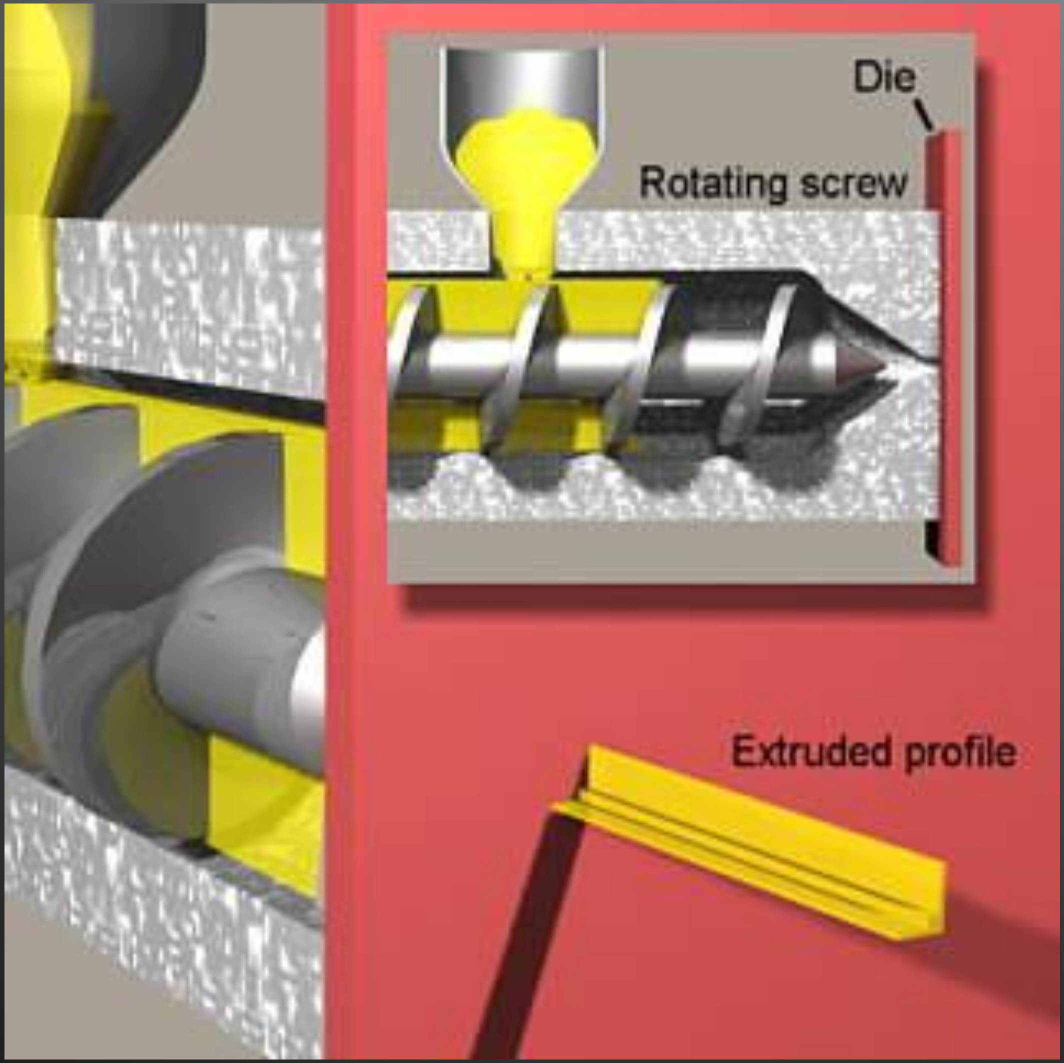
# Other compacting and shaping operations

Metal Injection Molding (MIM)
Rolling
Pressureless Compacting
Ceramic mold
Extrusion
Spray Deposition

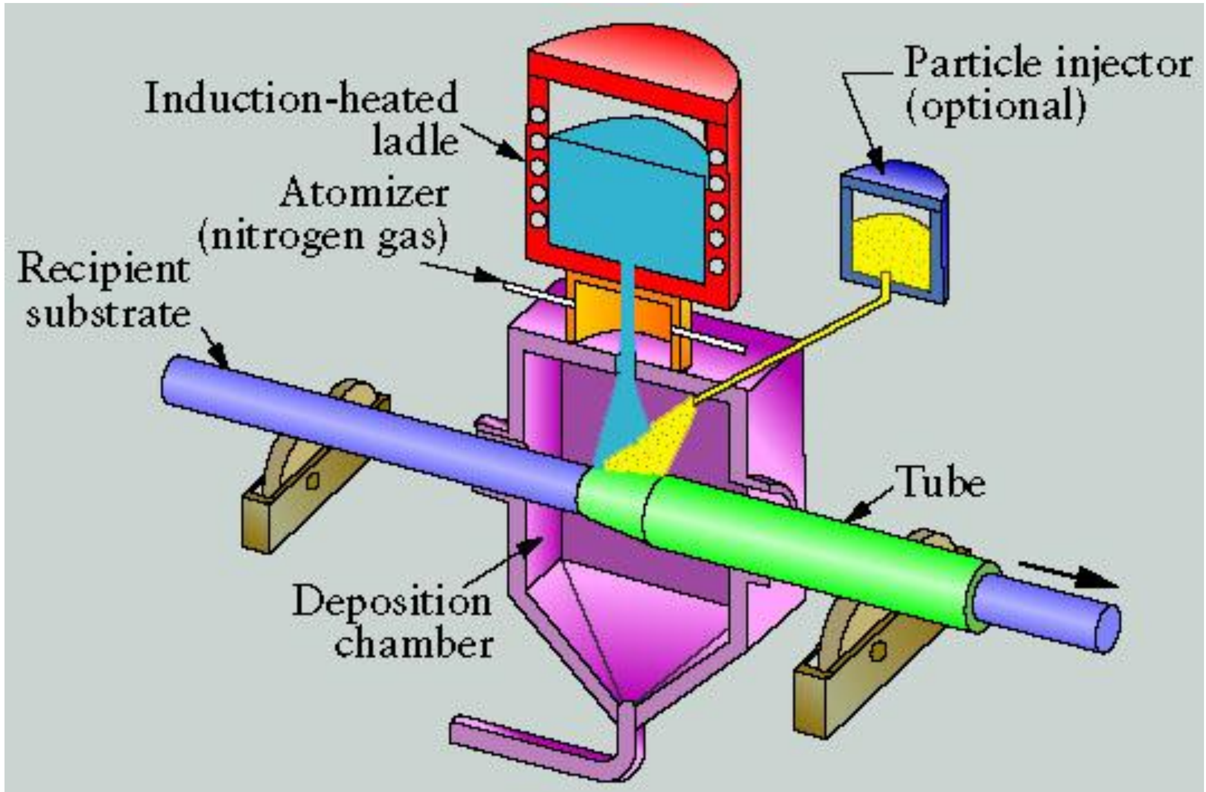
# Powder Rolling



# Powder Extrusion



# Spray Casting




Spray casting (Osprey process) in which molten metal is sprayed over a rotating mandrel to produce seamless tubing and pipe..

# References


- M. P. Groover, “Fundamentals of Modern Manufacturing 2/e”, 2002 John Wiley & Sons, Inc.
- Kalpakjian & Schmid, “Manufacturing Processes for Engineering Materials, 1997, Addison Wesley