BMM3643 Manufacturing Processes
Powder Metallurgy Process

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Chapter Synopsis

This chapter will expose students to the sequence steps in making powder metal such as methods to produce the metal powders, blending, compaction, sintering and finishing operations.

Chapter Information

Lesson Objectives:

Powder Metallurgy Process

Lesson Objective:

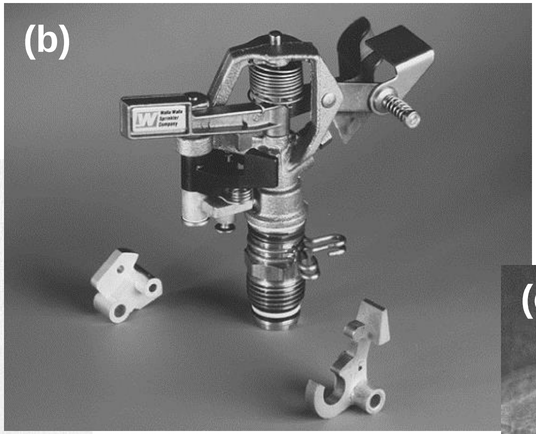
At the end of this lecture, students should be able to understand and explain the following:

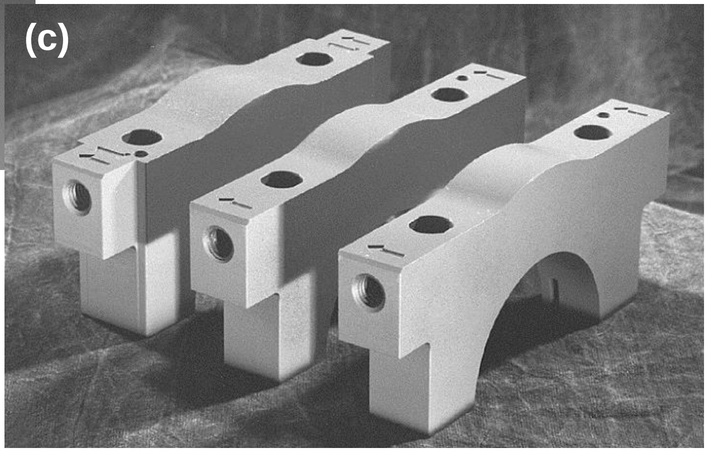
- Differentiate the various operations needed in powder-metallurgy process
- Analyze the characteristics of production, blending and compaction of metal powders operations

Introduction

- In powder metallurgy process (P/M), metal powders are compacted into desired shapes and sintered to form a solid metal.
- Commonly used metals in P/M are:
  - Iron, Tin, Copper, Aluminum, and Nickel
- It is a completive process with forging and machining
- Parts can weight from 2.5Kg up to 50Kg

PRODUCTS MADE BY POWDER-METALLURGY

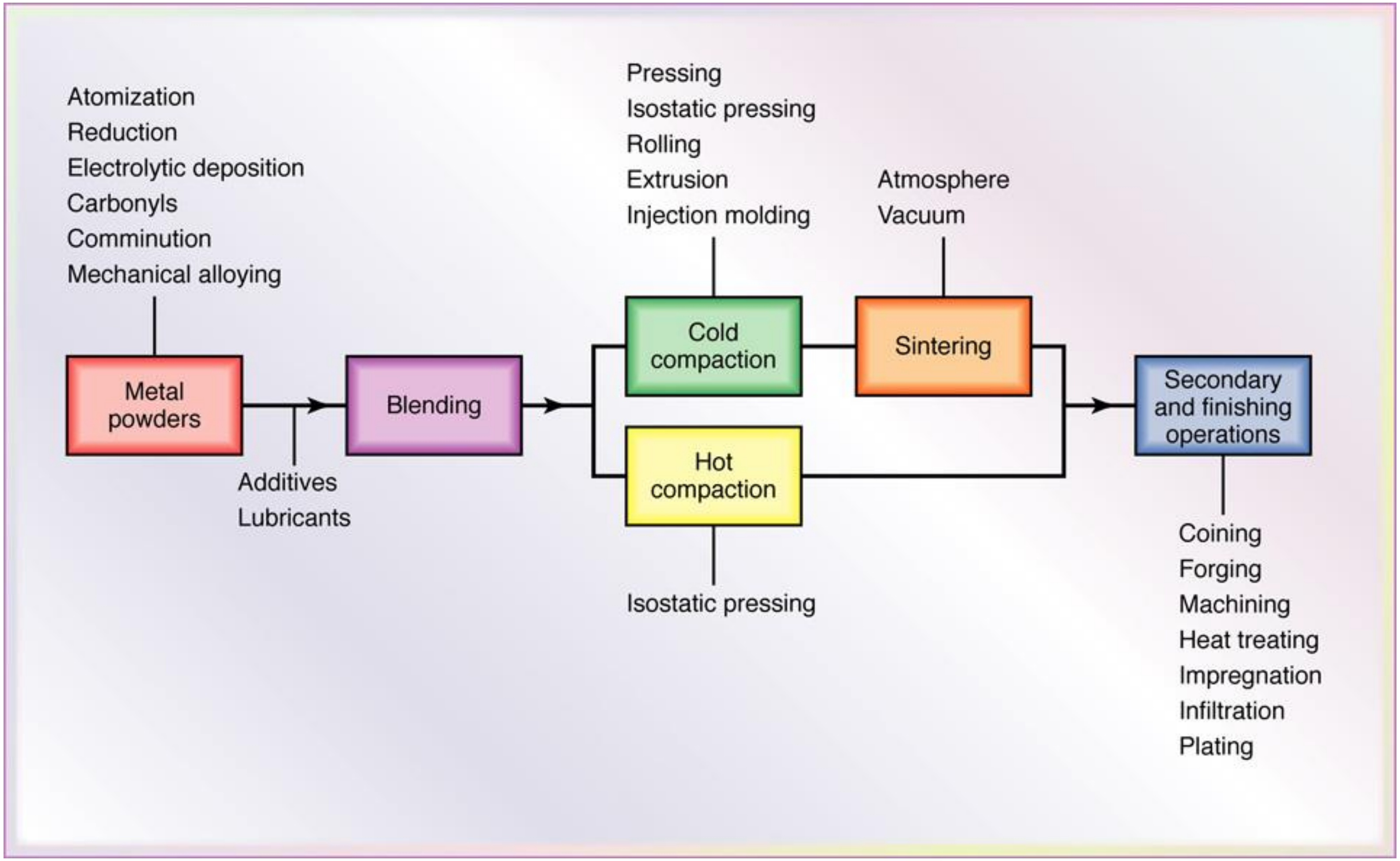




(a) Examples of typical parts made by powder-metallurgy processes. (b) Upper trip lever for a commercial sprinkler made by P/M. This part is made of an unleaded brass alloy; it replaces a die-cast part with a 60% savings. (c) Main-bearing metal-powder caps for 3.8 and 3.1 liter General Motors automotive engines.

Source: (a) and (b) Reproduced with permission from Success Stories on P/M Parts, 1998. Metal Powder Industries Federation, Princeton, New Jersey, 1998. (c) Courtesy of Zenith Sintered Products, Inc., Milwaukee, Wisconsin.

Sequence in Producing Powder-Metallurgy Parts

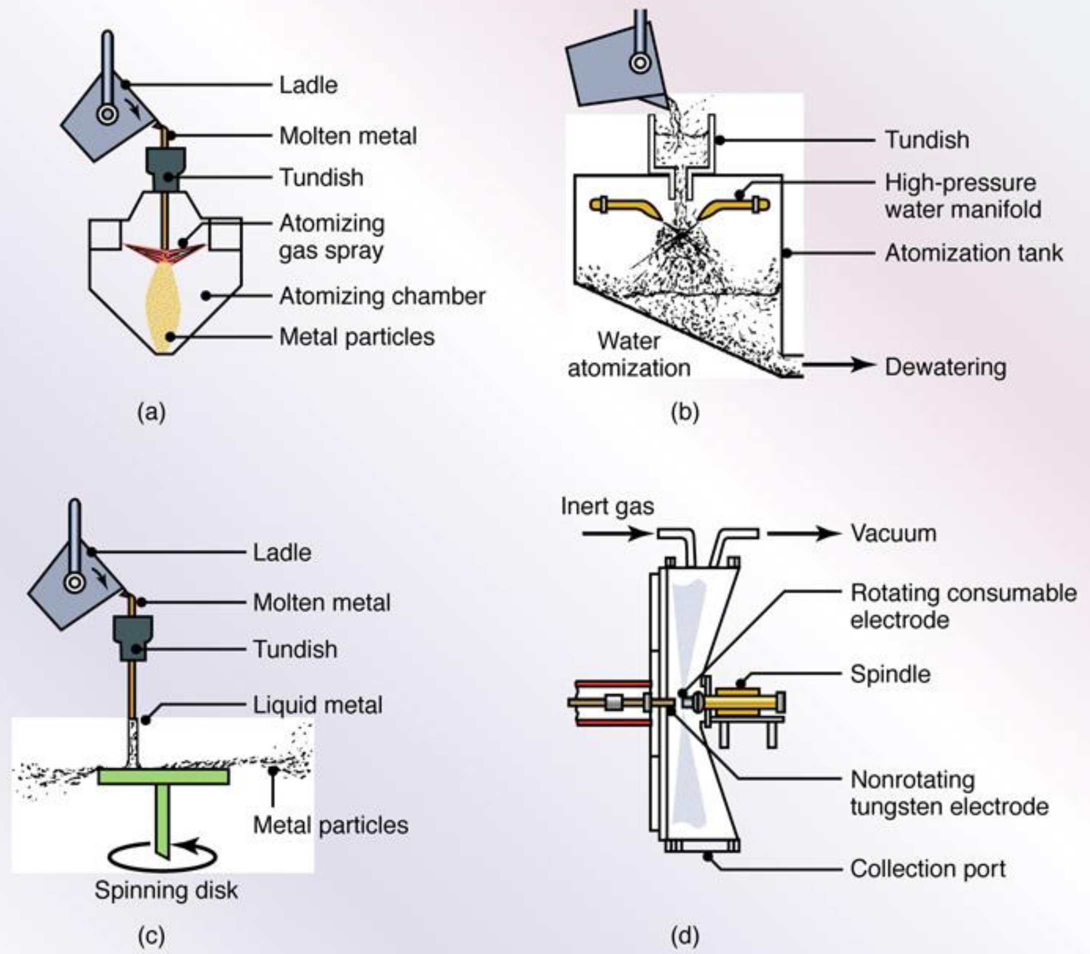


Source by Kalpakjian Book, 2014

1. Production of Metal Powders

1. **Atomization**
   – Injecting molten metal through a small orifice
2. Reduction
   – Using gases (H & CO) to produce fine metallic oxides
3. Electrolytic deposition
   – Either aqueous solutions or fused salts
4. Carbonyls
   – Iron & nickels react with CO creating metal carbonyls such as $Fe(CO)_5$ & $Ni(CO)_4$
5. **Comminution**
   – Crushing, milling, grinding metals into small particles
6. **Mechanical alloying**
   – Impacts of hard balls, the powders fracture & join together by diffusion, forming alloy powders.

PRODUCTION OF METAL POWDERS: ATOMIZATION



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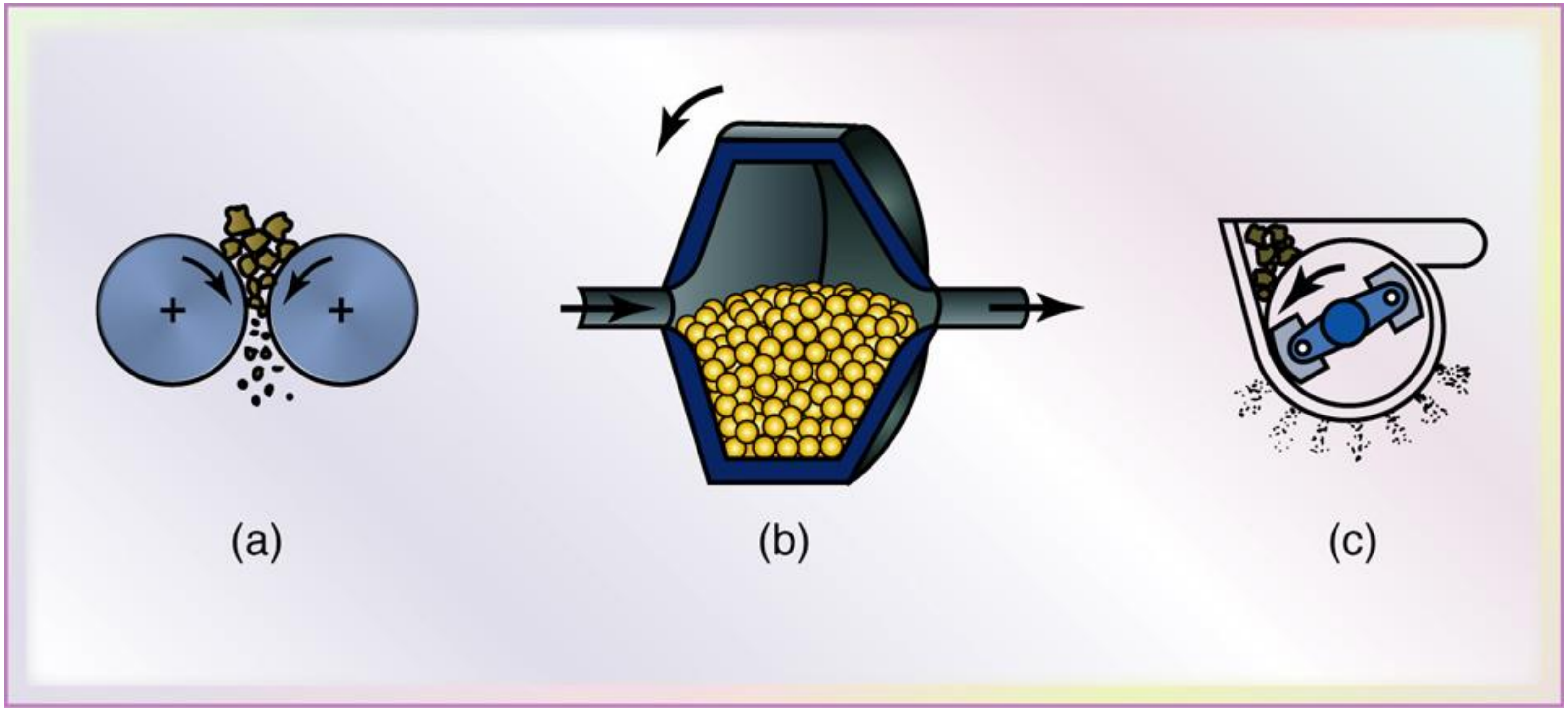
Methods of metal-powder production **by atomization**:

(a) gas atomization; (b) water atomization; (c) atomization with a rotating consumable electrode; and (d) centrifugal atomization with a spinning disk or cup.

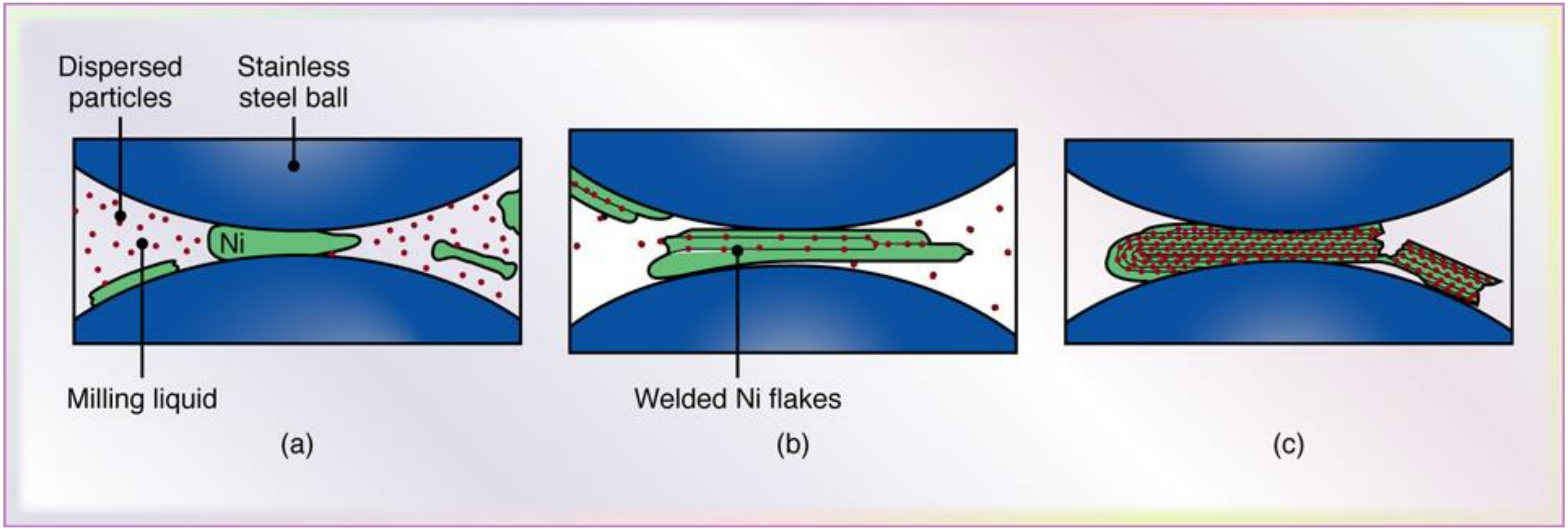
PRODUCTION OF METAL POWDERS: MECHANICAL COMMINUTION



Methods of mechanical comminution to obtain fine particles: (a) roll crushing, (b) ball mill, and (c) hammer milling.

Source by Kalpakjian Book, 2014

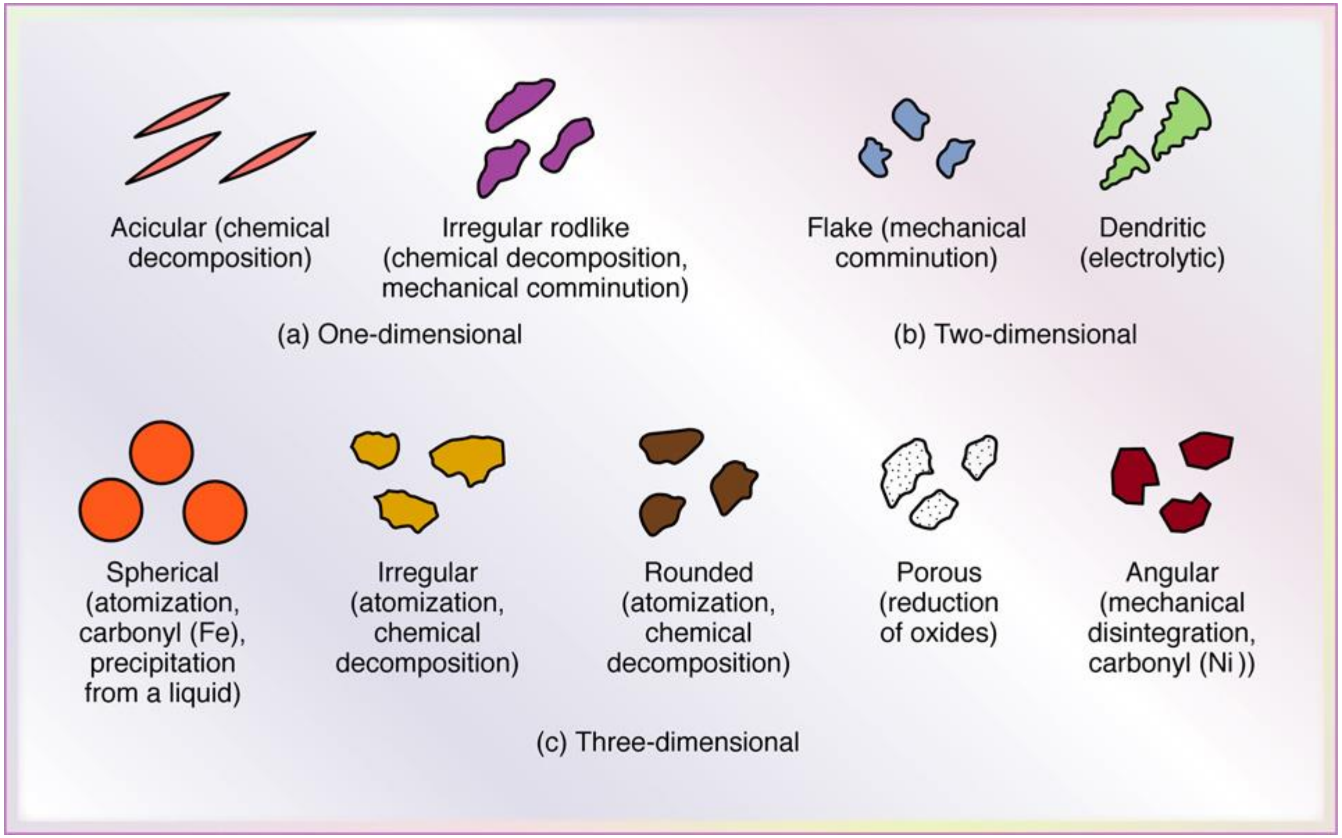
PRODUCTION OF METAL POWDERS: MECHANICAL ALLOYING



Mechanical alloying of nickel particles with dispersed smaller particles. As nickel particles are flattened between the two balls, the second smaller phase is impresses into the nickel surface and eventually is dispersed throughout the particle due to successive flattening, fracture, and welding events.

Source by Kalpakjian Book, 2014

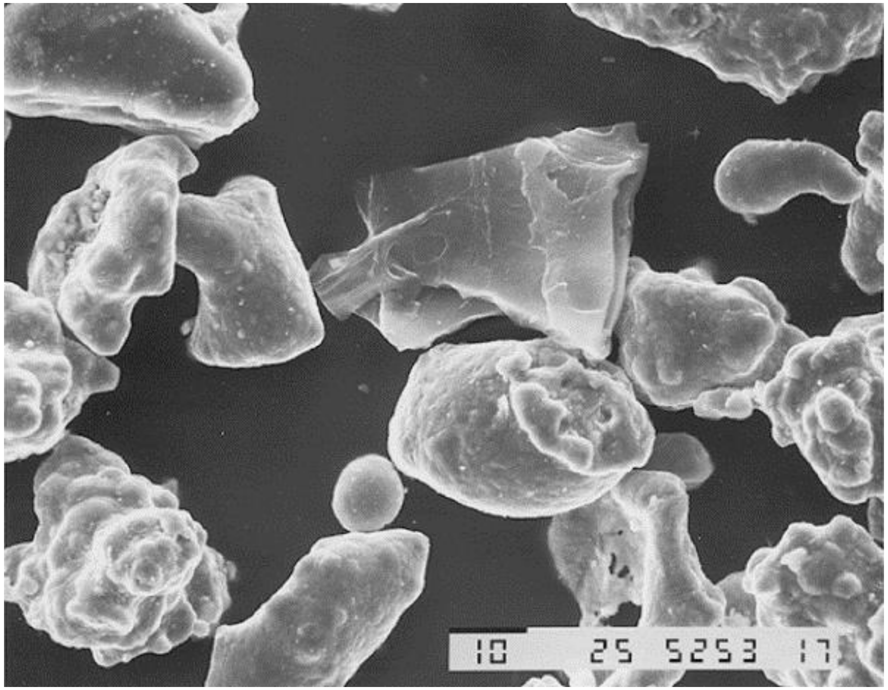
Particle Shapes in Metal Powders



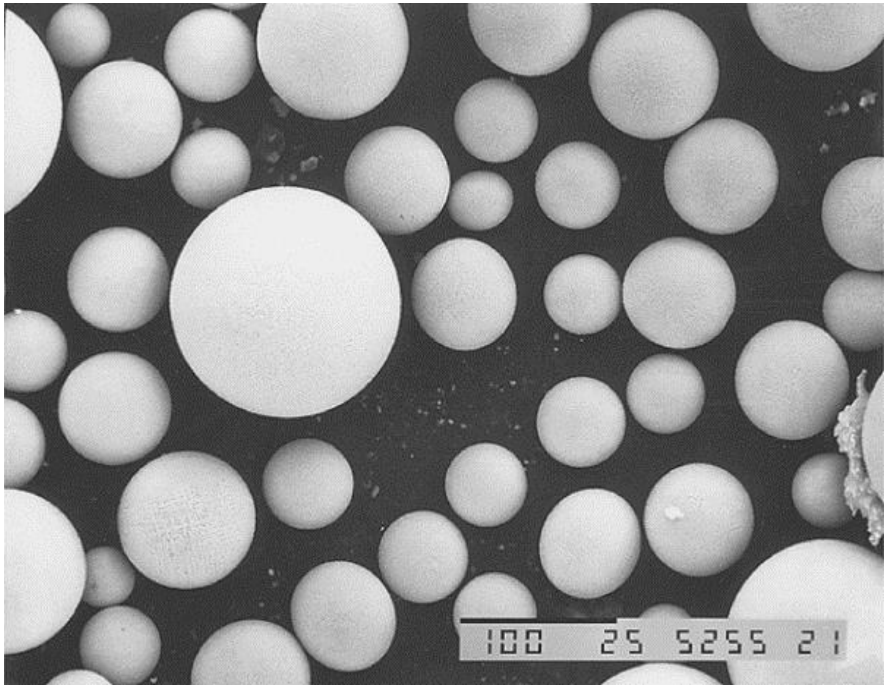
Particle shapes in metal powders, and the processes by which they are produced. Iron powders are produced by many of these processes.

Source by Kalpakjian Book, 2014

SEM images: Metal Powder Particles



(a)



(b)

(a) Scanning-electron-microscopy photograph of iron-powder particles made by atomization. (b) Nickel-based superalloy (Udimet 700) powder particles made by the rotating electrode process.

Source: Courtesy of P.G. Nash, Illinois Institute of Technology, Chicago.

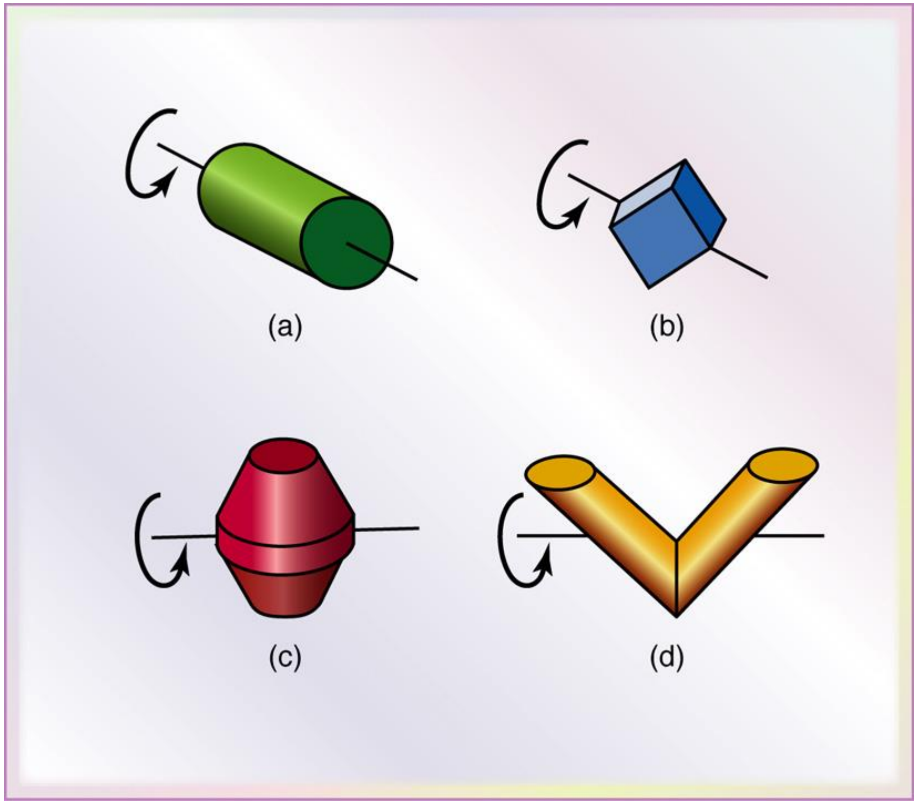
Screening Metal Particle Size and Shapes

- In addition to screen analysis one can use:
  1. Sedimentation - measuring the rate that particles settle in a fluid
  2. Microscopic analysis - using a scanning electron microscope (SEM) and FESEM
  3. Light scattering - Using laser to illuminates particles
  4. Optical - particles blocking a beam of light that is sensed by a photocell
  5. Suspending particles in a liquid & detecting particle size & distribution

2. Blending Metal Powders

- Powders made by different processes will have different sizes and shapes and must be well mixed-impart special physical & mechanical properties & characteristic.
- Blending can obtain uniformity from part to part.
- Lubricants can be mixed with the powders to improve their flow characteristics (reduce friction, improve flow & die life).

Bowl Geometries in Blending Metal Powders



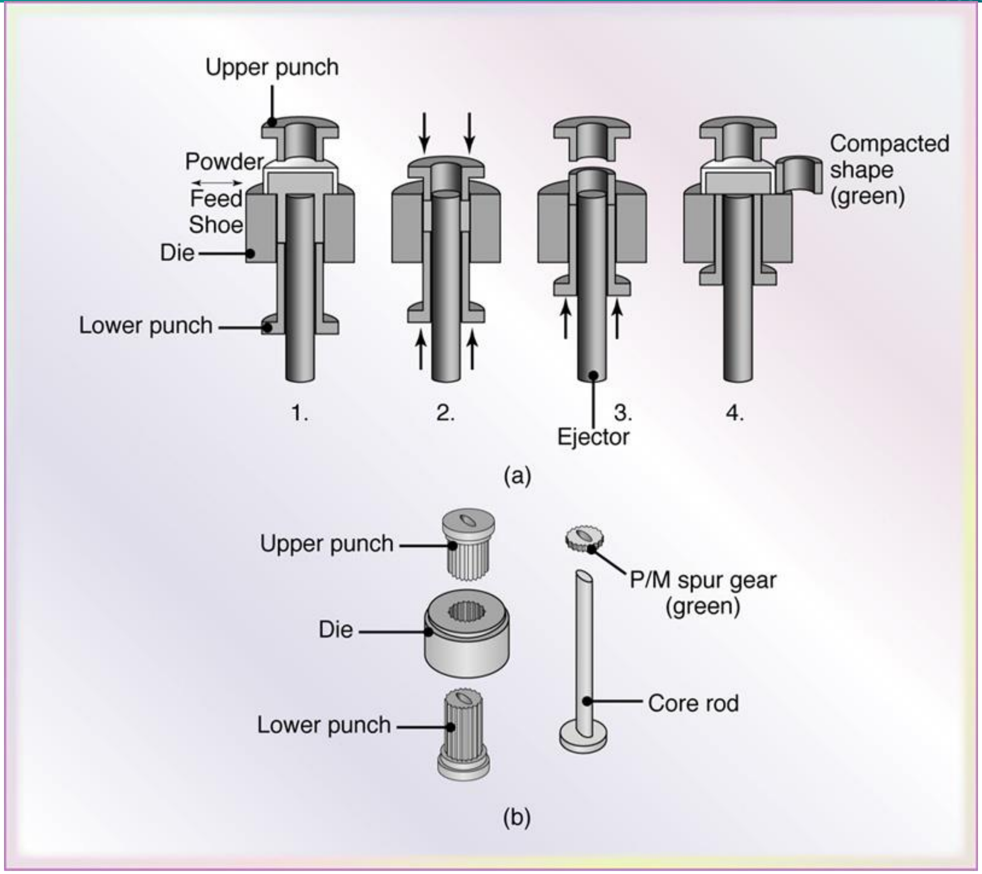
(a) to (d) Some common bowl geometries for mixing or blending powders. (e) A mixer suitable for blending metal powders. Since metal powders are abrasive, mixers rely on the rotation or tumbling of enclosed geometries as opposed to using aggressive agitators.

Source: Courtesy of Gardner Mixers, Inc.

3. Compaction of Metal Powders

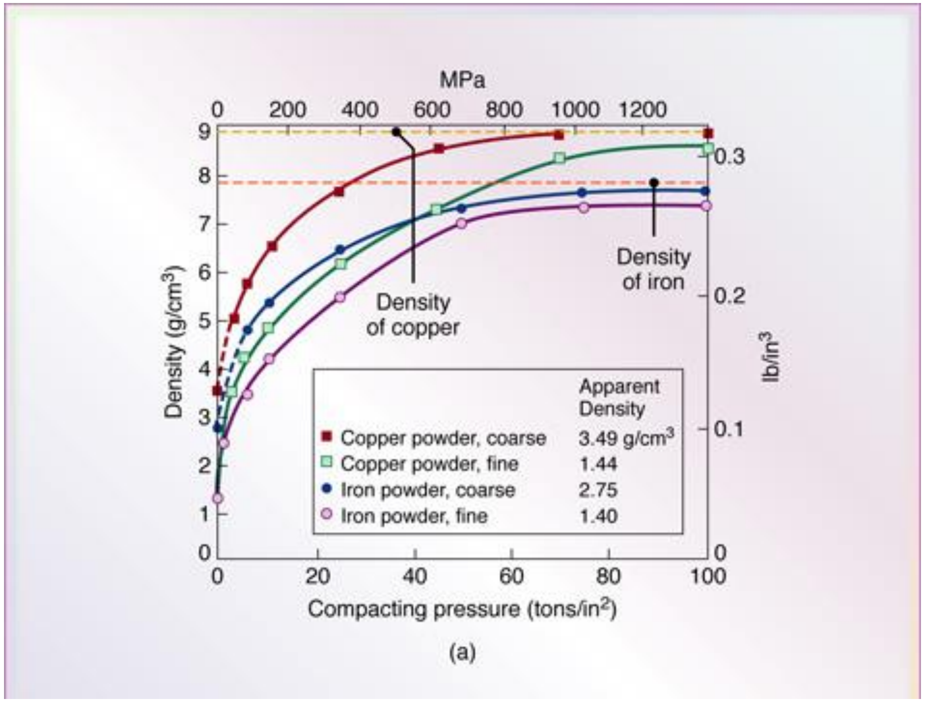
- Blended metal powders are pressed together into various shape of die.
- The powder must flow easily into the die.
- In compaction, size distribution is important that:
    i. They should not be all the same size
    ii. Should be a mixture of large and small particle
- The higher the density; the higher the strength
- The density of the metal powders depends on the pressure applied.

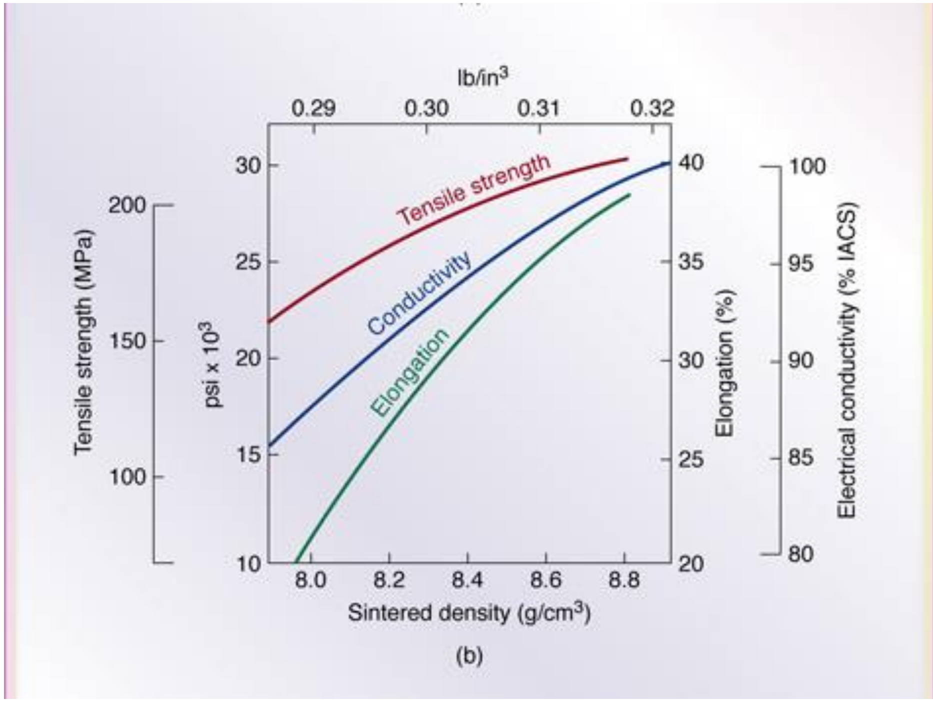
Sequence in Compaction Metal Powders



(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. *Source:* Courtesy of Metal Powder Industries Federation.

THE EFFECTS OF DENSITY IN P/M PARTS





(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.

(b) Effect of density on tensile strength, elongation, and electrical conductivity of copper powder.

Source: (a) After F. V. Lenel, (b) IACS: International Annealed Copper Standard (for electrical conductivity).

Compacting Pressures for Various Powders

TABLE 17.1

Compacting Pressures for Various Powders

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

Compaction of Metal Powders (continue)

Compaction Equipment

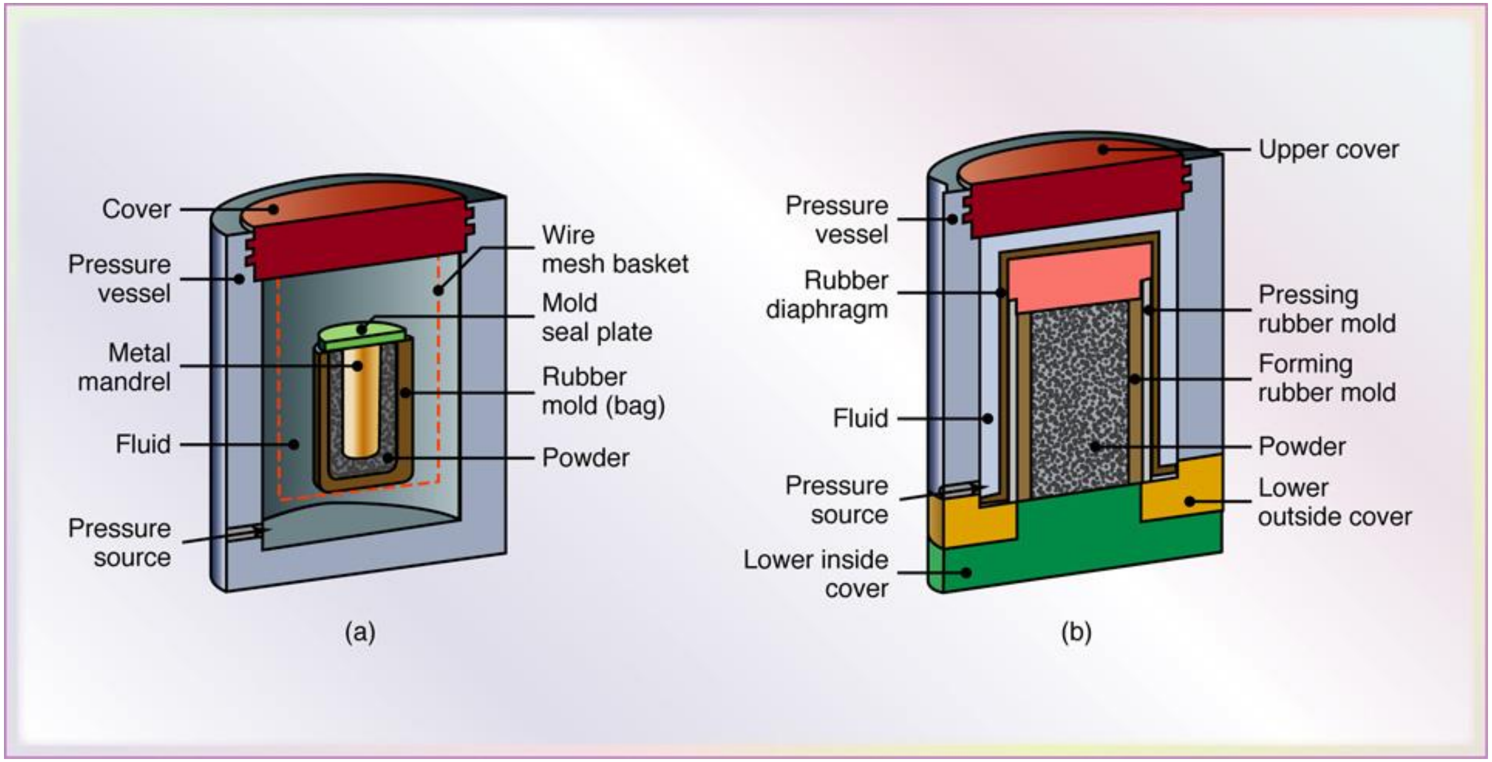
- Different metal powders need to be compacted using different pressure.
- Compaction equipment are divided into 2 categories:
  1. Cold compaction
  2. Hot compaction

i. Cold Compaction

Cold isostatic Pressing (CIP)

- Metal powder is placed in a flexible rubber mold
- Pressurized hydrostatically
- Uses pressures up to 400 MPa
- Typical application is automotive cylinder liners

Cold Isostatic Pressing



Schematic illustration of cold isostatic pressing, as applied to forming 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.

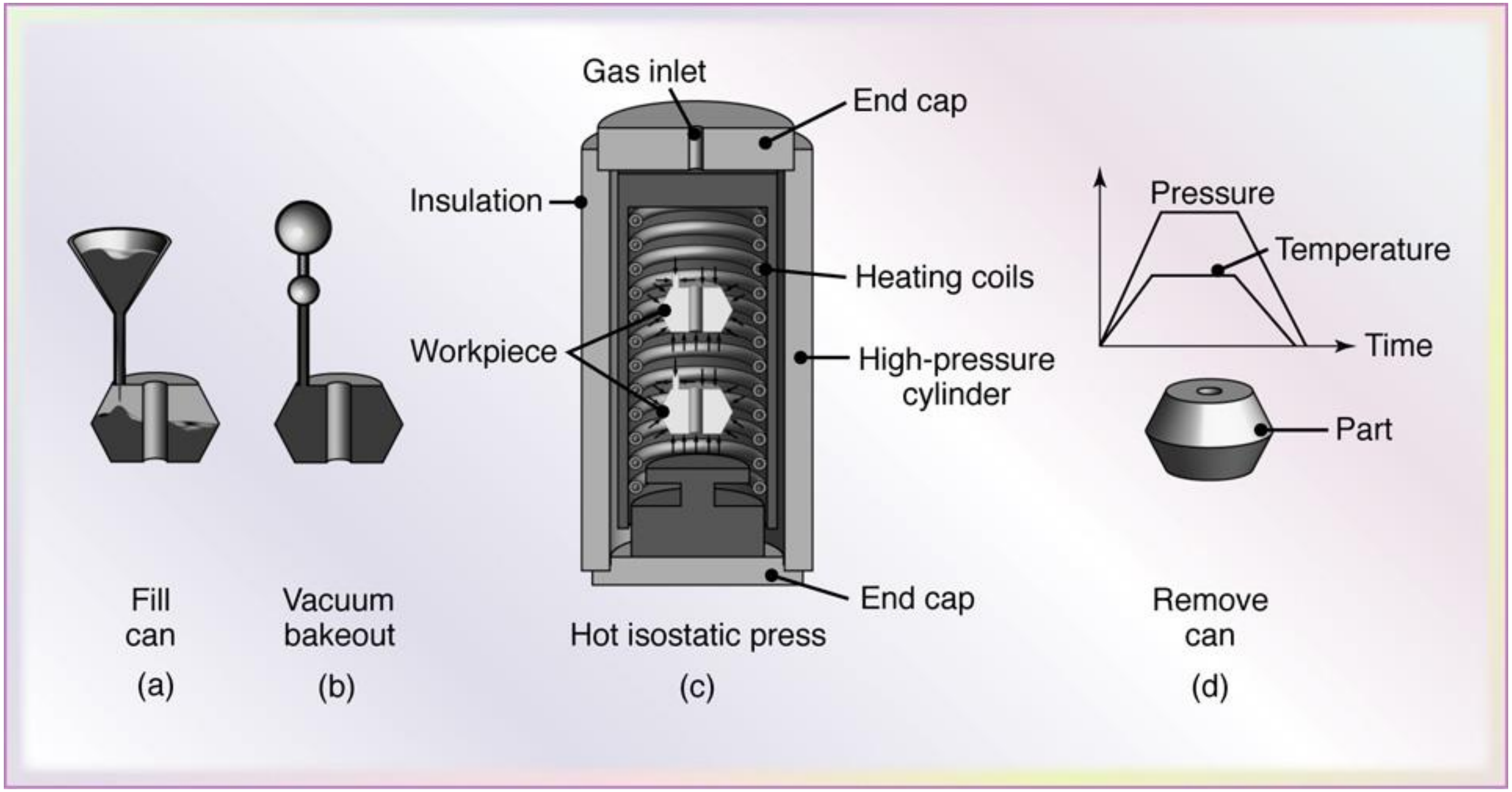
Source: Reprinted with permission from R. M. German, *Powder Metallurgy Science*, Metal Powder Industries Federation, Princeton, NJ; 1984.

ii. Hot Compaction

<u>Hot Isostatic pressing (HIP)</u>

- Container is made of high-melting-point sheet metal
- Uses a inert gas as the pressurizing medium
- Common conditions for HIP are 100 MPa & 1200^{o}C
- Mainly used for super alloy casting, aircraft, military & medical

Hot Isostatic Pressing



Schematic diagram of hot isostatic pressing. The pressure and temperature variation versus time are shown in the diagram.

Source by Kalpakjian Book, 2014

4. Sintering

- Green compacts are heated in a furnace to a temp. below melting point
- Improves the strength of the material
- Proper furnace control is important for optimum properties
- Particles start forming a bond by diffusion
- Vapor phase transport – heated very close to melting temperature allows metal atoms to release to the vapor phase

Mechanisms for Sintering Metal Powders

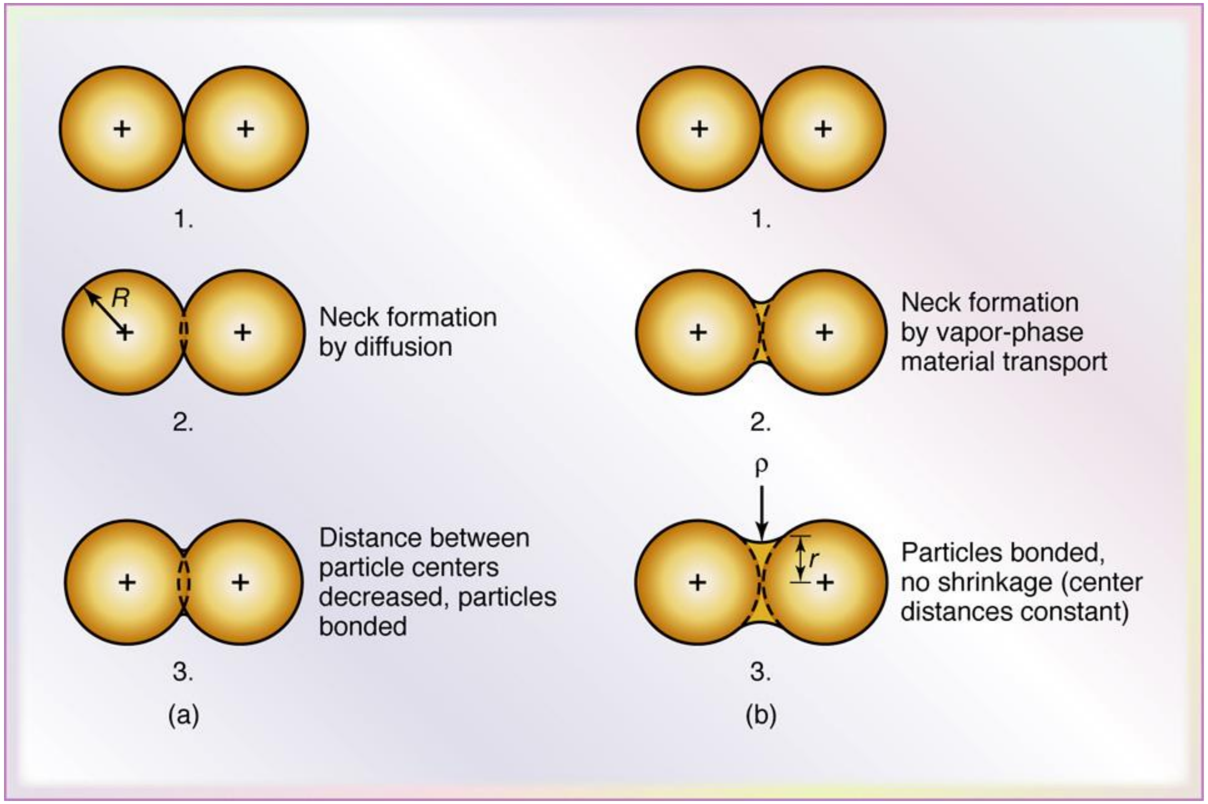


Illustration of two mechanisms for sintering metal powders:
(a) solid-state material transport; and (b) vapor-phase material transport.
R = particle radius, *r* = neck radius, and *p* = neck-profile radius.

Source by Kalpakjian Book, 2014

Sintering Temperature and Time for Various Metals

TABLE 17.2

Sintering Temperature and Time for Various Metals

Material	Temperature (°C)	Time (min)
Copper, brass, and bronze	760-900	10-45
Iron and iron-graphite	1000-1150	8-45
Nickel	1000-1150	30-45
Stainless steels	1100-1290	30-60
Alnico alloys (for permanent magnets)	1200-1300	120-150
Ferrites	1200-1500	10-600
Tungsten carbide	1430-1500	20-30
Molybdenum	2050	120
Tungsten	2350	480
Tantalum	2400	480

Source by Kalpakjian Book, 2014

WROUGHT VERSUS P/M METALS

TABLE 17.4

Comparison of Mechanical Properties of Some Wrought and Equivalent P/M Metals (as Sintered)

	Metal Condition	Density (%)	UTS (MPa)	Elongation in 50 mm (%)
Aluminum				
2014-T6	Wrought (W)	-	480	20
	P/M	94	330	2
6061-T6	W	-	310	15
	P/M	94	250	2
Copper, OFHC	W, annealed	-	235	50
	P/M	89	160	8
Brass, 260	W, annealed	-	300	65
	P/M	89	255	26
Steel, 1025	W, hot rolled	-	590	25
	P/M	84	235	2
Stainless steel, 303	W, annealed	-	620	50
	P/M	82	360	2

Note : The density and strength of P/M materials greatly increase with further processing, such as forging, isostatic pressing, and heat treatments.

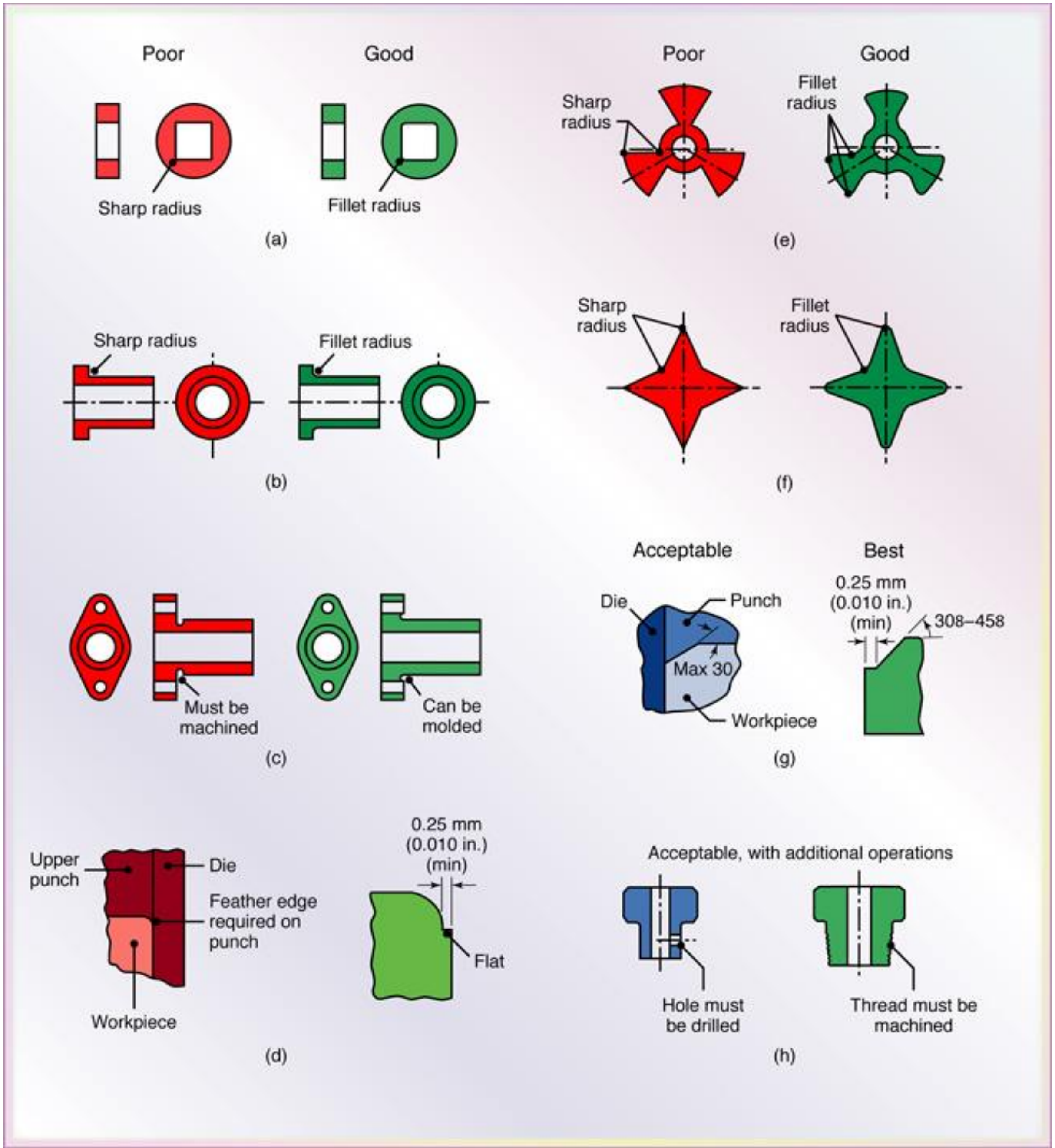
5. Secondary & Finishing Operations

To improve the properties of sintered P/M products several additional operations may be used:

- Coining and sizing – compaction operations
- Impact forging – cold or hot forging may be used
- Parts may be impregnated with a fluid to reduce the porosity
- Infiltration – metal infiltrates the pores of a sintered part to produce a stronger part and produces a pore free part
- Other finishing operations:
  i. Heat treating
  ii. Machining
  iii. Grinding
  iv. Plating

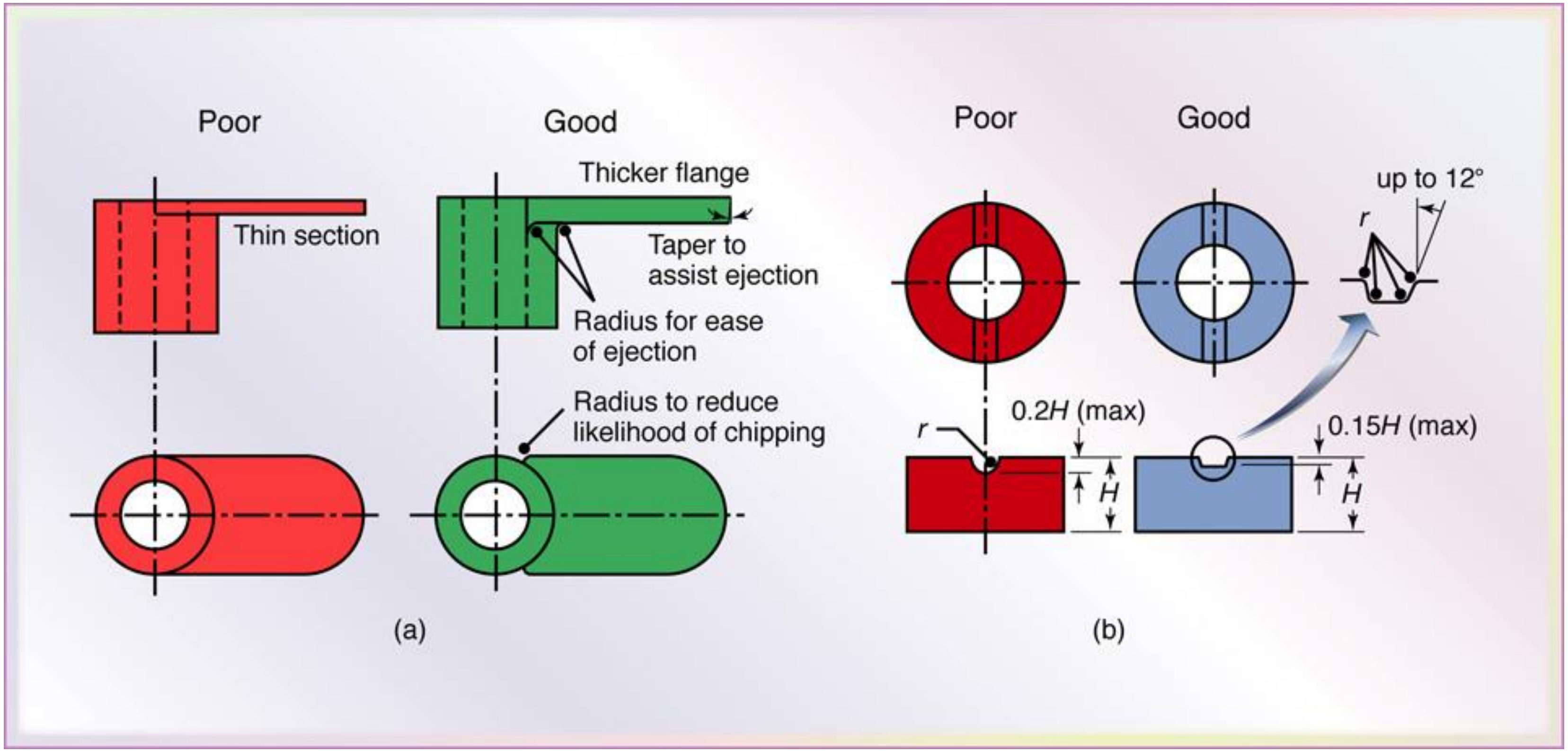
Design Considerations for P/M Parts

- Simple and uniform shape as possible.
- Provision for ejection without damaging the green compact.
- Made with the widest acceptable tolerances to maximize tool life.
- Walls should not be less than 1.5 mm thick; walls with length-to-thickness ratios above 8:1 are difficult to press.
- A true radius cannot be pressed; instead use a chamfer.



Examples of P/M parts showing **poor and good** designs. Note that sharp radii and reentry corners should be avoided and that threads and transverse holes have to be produced separately by additional machining operations. *Source*: Courtesy of Metal Powder Industries Federation.

DESIGN FEATURES FOR USE WITH UNSUPPORTED FLANGES OR GROOVES



Design features for use with unsupported flanges. (b) Design features for use with grooves. *Source*: Courtesy of Metal Powder Industries Federation.

P/M Process Capabilities

- **Capabilities;**
  - Suitable for parts from high melting refractory metals
  - High production rates
  - Good dimensional control
  - Wide range of compositions in obtaining the properties
- **Limitations;**
  - High tooling cost for short production runs
  - Limitations on part size and shape complexity
  - Mechanical properties of the part strength & ductility

End of chapter
Powder Metallurgy Process