POWDER METALLURGY

- The Characterization of Engineering Powders
- Production of Metallic Powders
- Conventional Pressing and Sintering
- Alternative Pressing and Sintering Techniques
- Materials and Products for PM
- Design Considerations in Powder Metallurgy

Powder Metallurgy (PM)

Metal processing technology in which parts are produced from metallic powders

- In the usual PM production sequence, the powders are compressed (*pressed*) into the desired shape and then heated (*sintered*) to bond the particles into a hard, rigid mass
  - *Pressing* is accomplished in a press-type machine using *punch-and-die* tooling designed specifically for the part to be manufactured
  - *Sintering* is performed at a temperature below the melting point of the metal

Why Powder Metallurgy is Important

- PM parts can be mass produced to *net shape* or *near net shape*, eliminating or reducing the need for subsequent machining
- PM process wastes very little material - about 97% of the starting powders are converted to product
- PM parts can be made with a specified level of porosity, to produce porous metal parts
  - Examples: filters, oil-impregnated bearings and gears

More Reasons Why PM is Important

- Certain metals that are difficult to fabricate by other methods can be shaped by powder metallurgy
  - Example: Tungsten filaments for incandescent lamp bulbs are made by PM
- Certain alloy combinations and cermets made by PM cannot be produced in other ways
- PM compares favorably to most casting processes in dimensional control
- PM production methods can be automated for economical production

Limitations and Disadvantages with PM Processing

- High tooling and equipment costs
- Metallic powders are expensive
- Problems in storing and handling metal powders
  - Examples: degradation over time, fire hazards with certain metals
- Limitations on part geometry because metal powders do not readily flow laterally in the die during pressing
- Variations in density throughout part may be a problem, especially for complex geometries

PM Work Materials

- Largest tonnage of metals are alloys of iron, steel, and aluminum
- Other PM metals include copper, nickel, and refractory metals such as molybdenum and tungsten
- Metallic carbides such as tungsten carbide are often included within the scope of powder metallurgy

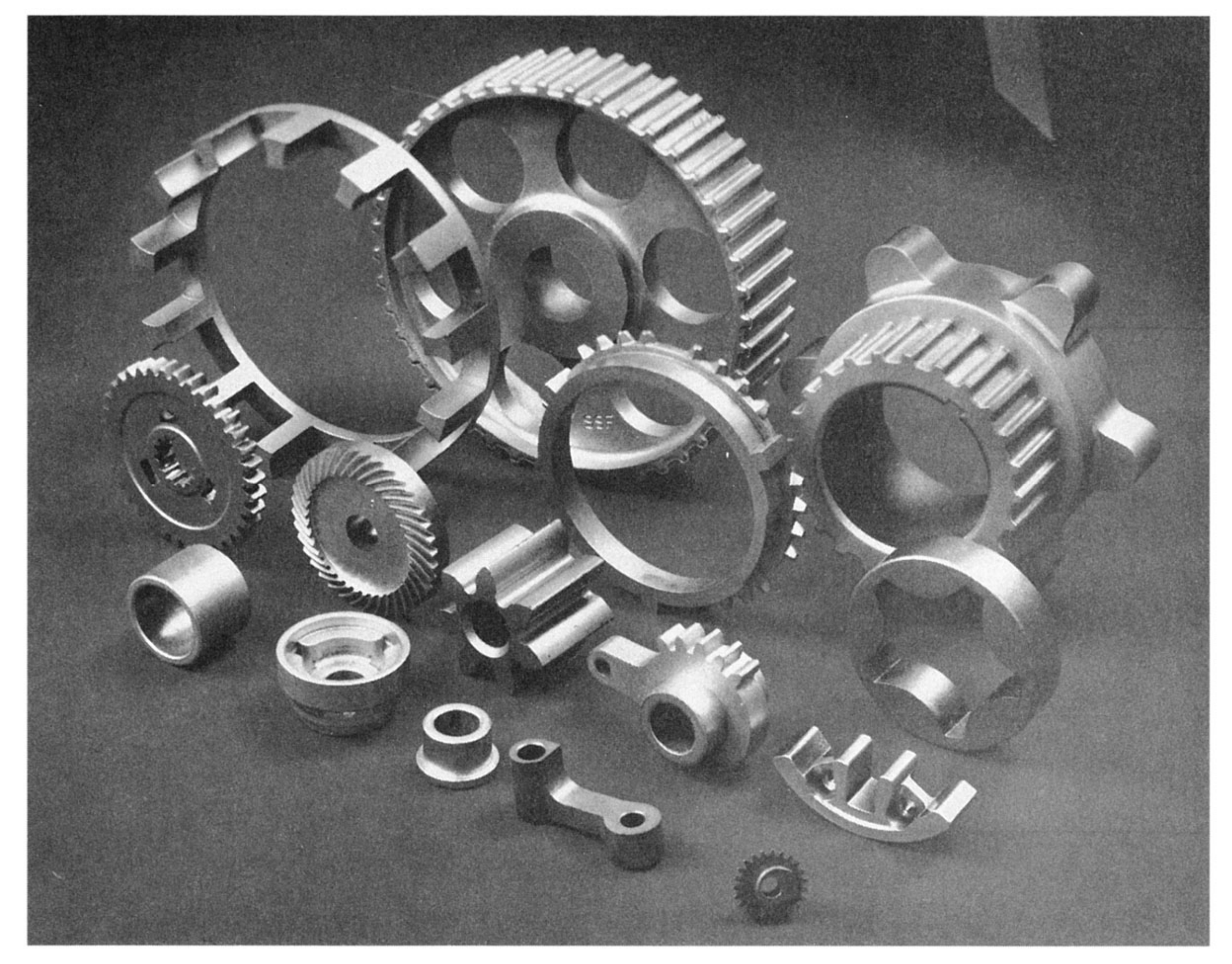

Figure 16.1 - A collection of powder metallurgy parts (courtesy of Dorst America, Inc.)

Engineering Powders

A *powder* can be defined as a finely divided particulate solid

- Engineering powders include metals and ceramics
- Geometric features of engineering powders:
  - Particle size and distribution
  - Particle shape and internal structure
  - Surface area

Measuring Particle Size

- Most common method uses screens of different mesh sizes
- *Mesh count* - refers to the number of openings per linear inch of screen
  - A mesh count of 200 means there are 200 openings per linear inch
  - Since the mesh is square, the count is the same in both directions, and the total number of openings per square inch is $200^2 = 40{,}000$
  - Higher mesh count means smaller particle size

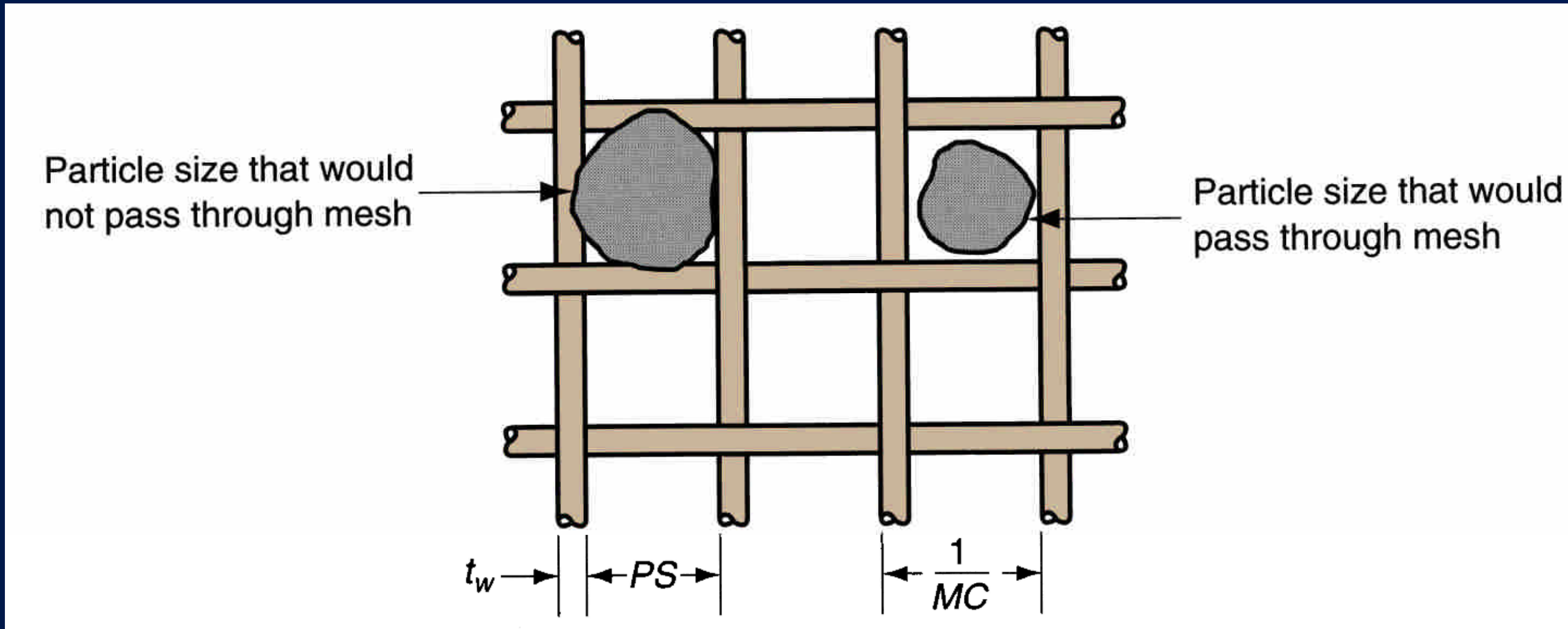

Figure 16.2 - Screen mesh for sorting particle sizes

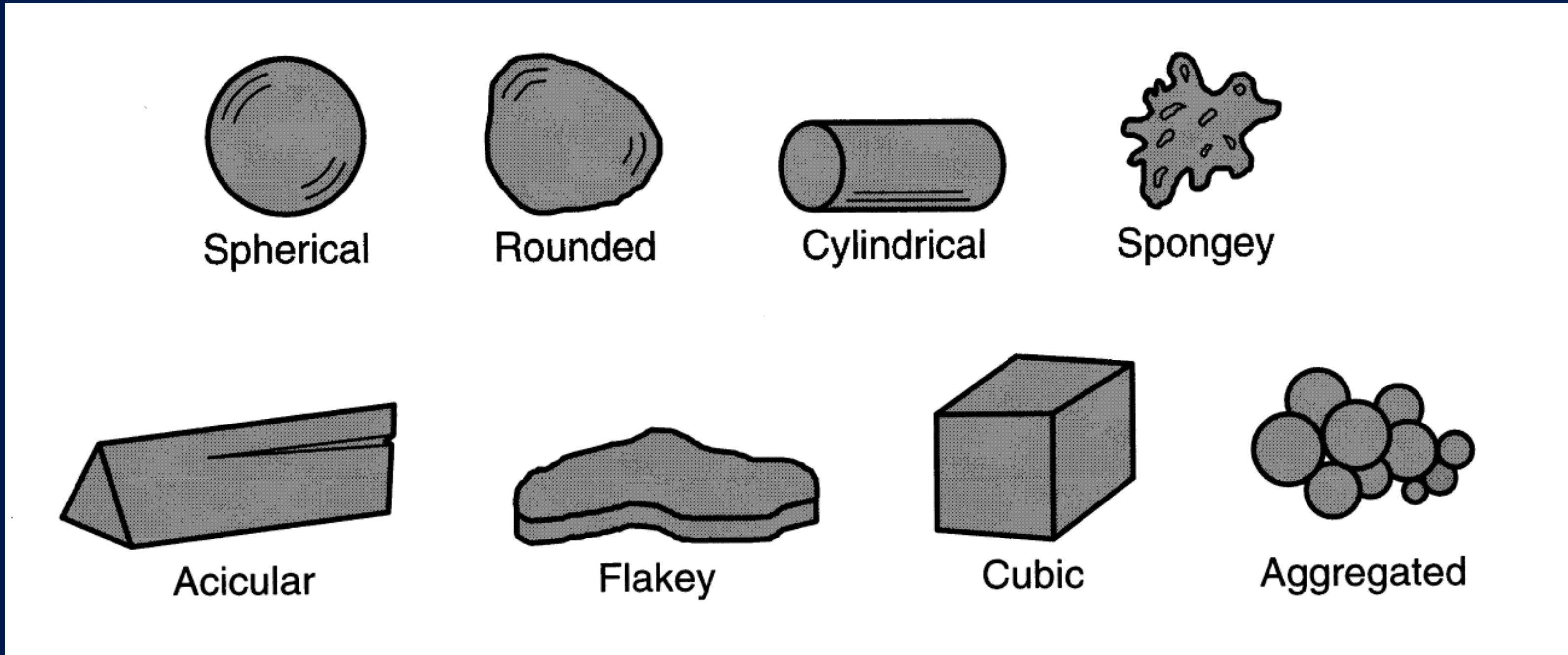

Figure 16.3 - Several of the possible (ideal) particle shapes in powder metallurgy

Interparticle Friction and Flow Characteristics

- Friction between particles affects ability of a powder to flow readily and pack tightly
- A common test of interparticle friction is the *angle of repose*, which is the angle formed by a pile of powders as they are poured from a narrow funnel

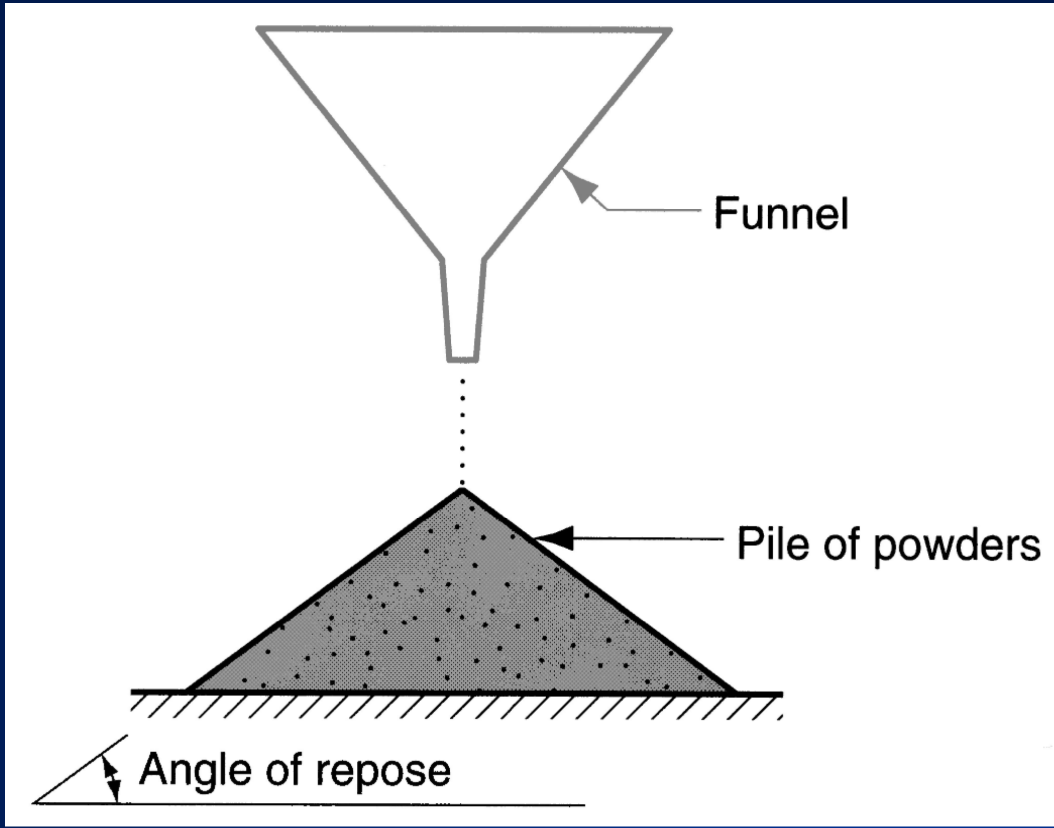

Figure 16.4 - Interparticle friction as indicated by the angle of repose of a pile of powders poured from a narrow funnel. Larger angles indicate greater interparticle friction.

Observations

- Smaller particle sizes generally show greater friction and steeper angles
- Spherical shapes have the lowest interpartical friction
- As shape deviates from spherical, friction between particles tends to increase

Particle Density Measures

- *True density* - density of the true volume of the material
  - The density of the material if the powders were melted into a solid mass
- *Bulk density* - density of the powders in the loose state after pouring
  - Because of pores between particles, bulk density is less than true density

Packing Factor = Bulk Density divided by True Density

- Typical values for loose powders range between 0.5 and 0.7
- If powders of various sizes are present, smaller powders will fit into the interstices of larger ones that would otherwise be taken up by air, thus higher packing factor
- Packing can be increased by vibrating the powders, causing them to settle more tightly
- Pressure applied during compaction greatly increases packing of powders through rearrangement and deformation of particles

Porosity

Ratio of the volume of the pores (empty spaces) in the powder to the bulk volume

- In principle, Porosity + Packing factor = 1.0
- The issue is complicated by the possible existence of closed pores in some of the particles
- If internal pore volumes are included in above porosity, then equation is exact

Chemistry and Surface Films

- Metallic powders are classified as either
  - *Elemental* - consisting of a pure metal
  - *Pre-alloyed* - each particle is an alloy
- Possible surface films include oxides, silica, adsorbed organic materials, and moisture
  - As a general rule, these films must be removed prior to shape processing

Production of Metallic Powders

- In general, producers of metallic powders are not the same companies as those that make PM parts
- Virtually any metal can be made into powder form
- Three principal methods by which metallic powders are commercially produced
  1. Atomization
  2. Chemical
  3. Electrolytic
- In addition, mechanical methods are occasionally used to reduce powder sizes

Gas Atomization Method

High velocity gas stream flows through an expansion nozzle, siphoning molten metal from below and spraying it into a container

- Droplets solidify into powder form

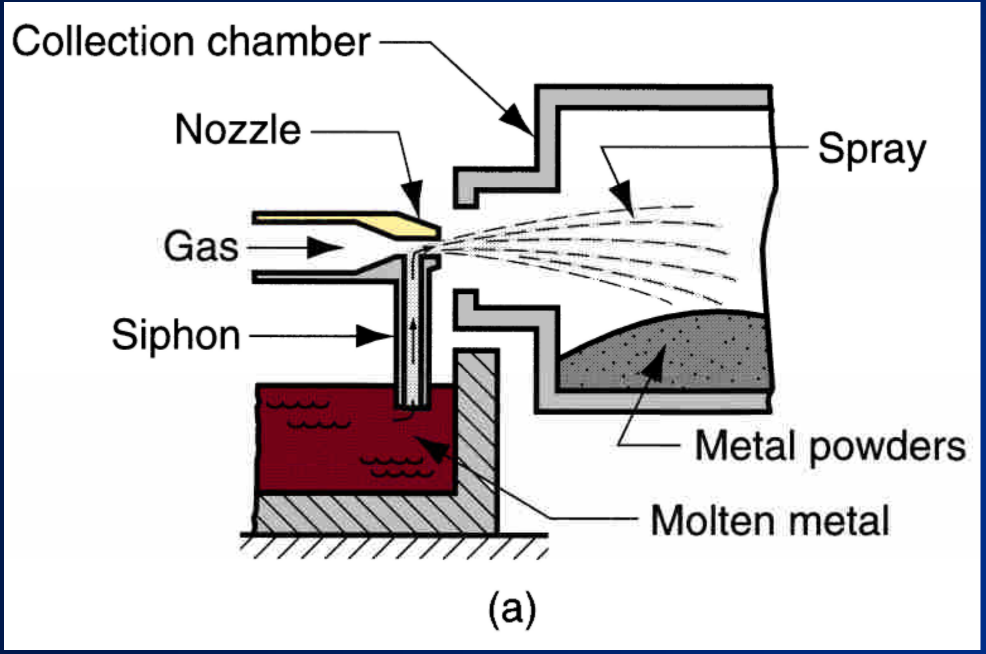

Figure 16.5 (a) gas atomization method

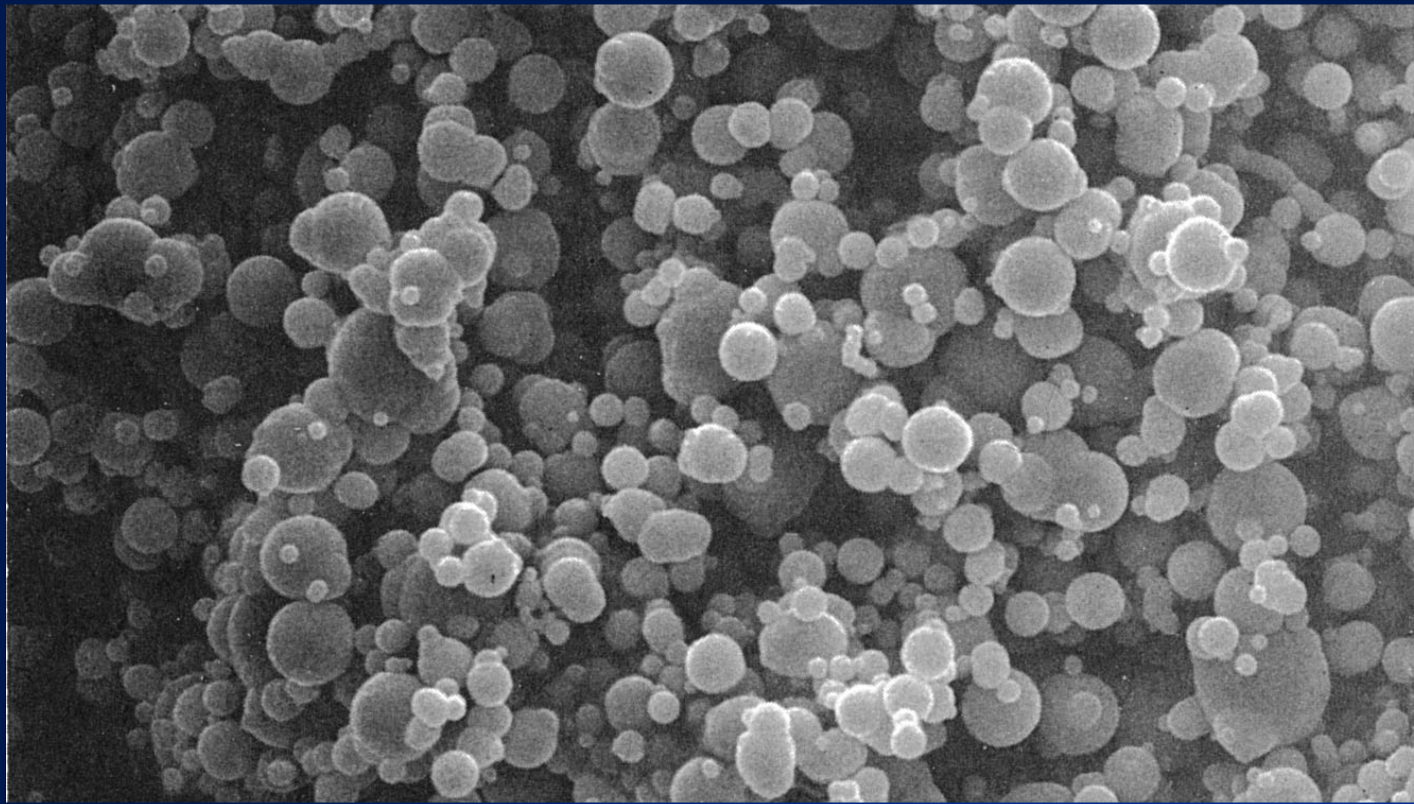

Figure 16.6 - Iron powders produced by decomposition of iron pentacarbonyl; particle sizes range from about 0.25 - 3.0 microns (10 to 125 μ-in) (photo courtesy of GAF Chemicals Corporation, Advanced Materials Division)

Conventional Press and Sinter

- After the metallic powders have been produced, the conventional PM sequence consists of three steps:
  1. *Blending* and *mixing* of the powders
  2. *Compaction* - pressing into desired part shape
  3. *Sintering* - heating to a temperature below the melting point to cause solid-state bonding of particles and strengthening of part
- In addition, secondary operations are sometimes performed to improve dimensional accuracy, increase density, and for other reasons

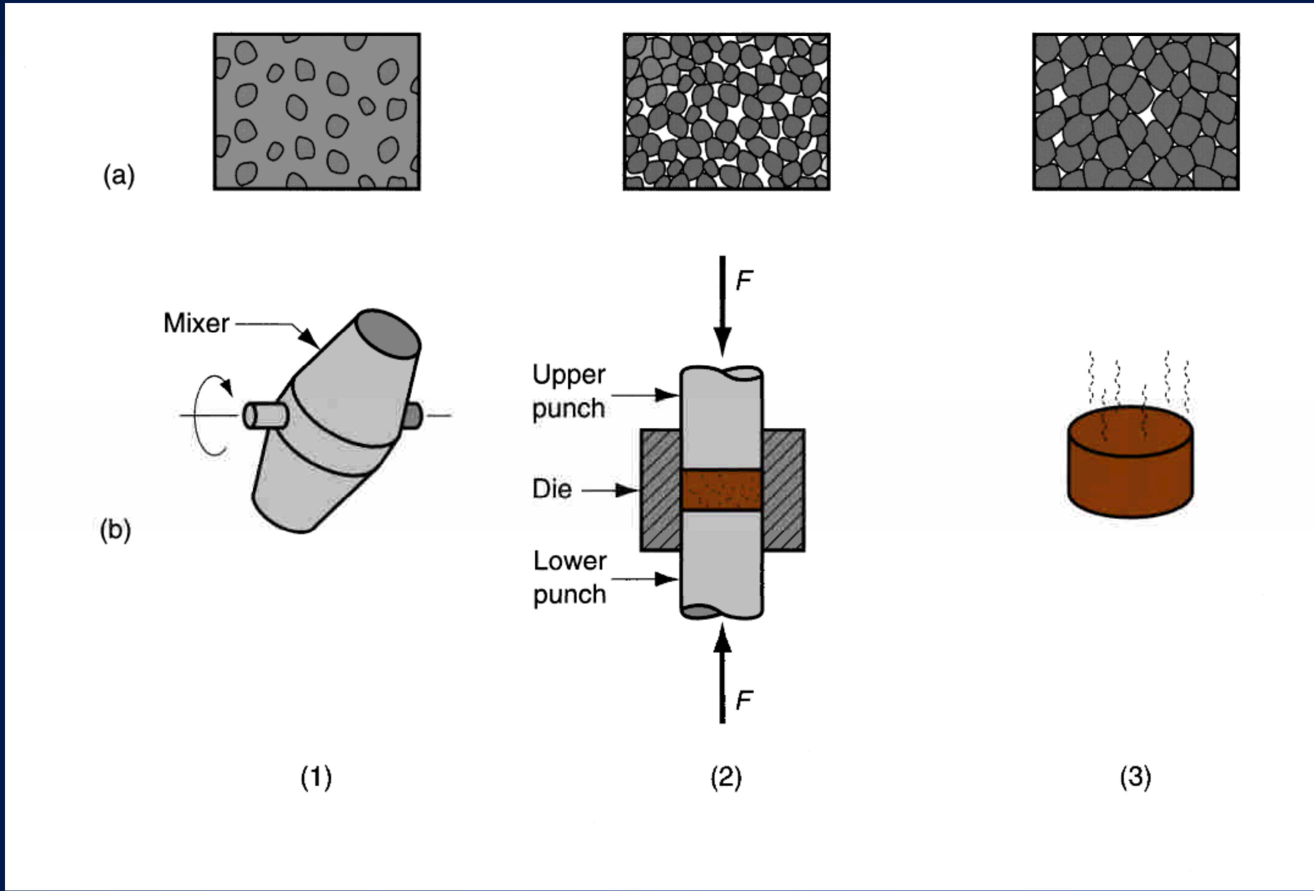

Figure 16.7 ‑ Conventional powder metallurgy production sequence: (1) blending, (2) compacting, and (3) sintering; (a) shows the condition of the particles while (b) shows the operation and/or workpart during the sequence

Blending and Mixing of Powders

- For successful results in compaction and sintering, the starting powders must be homogenized
- *Blending* - powders of the same chemistry but possibly different particle sizes are intermingled
  - Different particle sizes are often blended to reduce porosity
- *Mixing* - powders of different chemistries are combined
  - PM technology allows mixing various metals into alloys that would be difficult or impossible to produce by other means

Compaction

Application of high pressure to the powders to form them into the required shape

- The conventional compaction method is *pressing*, in which opposing punches squeeze the powders contained in a die
- The workpart after pressing is called a *green compact*, the word green meaning not yet fully processed
- The *green strength* of the part when pressed is adequate for handling but far less than after sintering

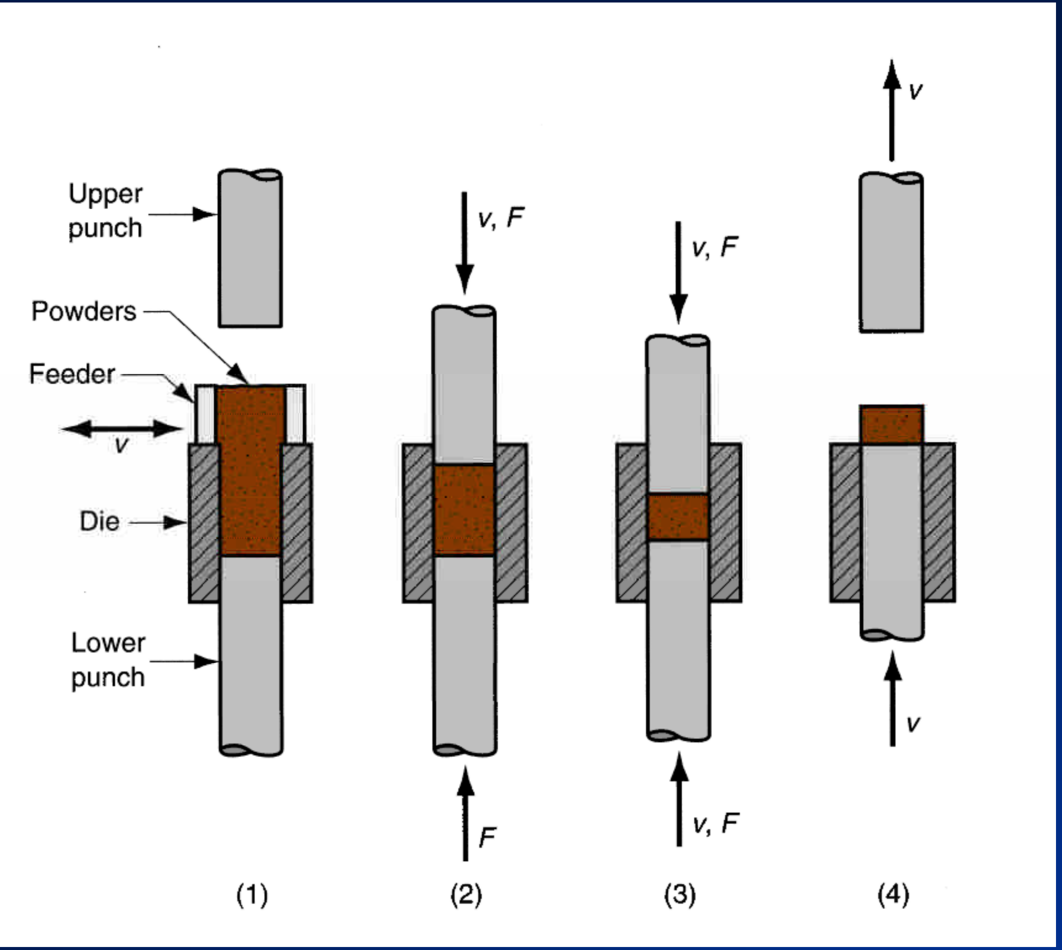

Figure 16.9 - Pressing in PM: (1) filling die cavity with powder by automatic feeder; (2) initial and (3) final positions of upper and lower punches during pressing, and (4) ejection of part

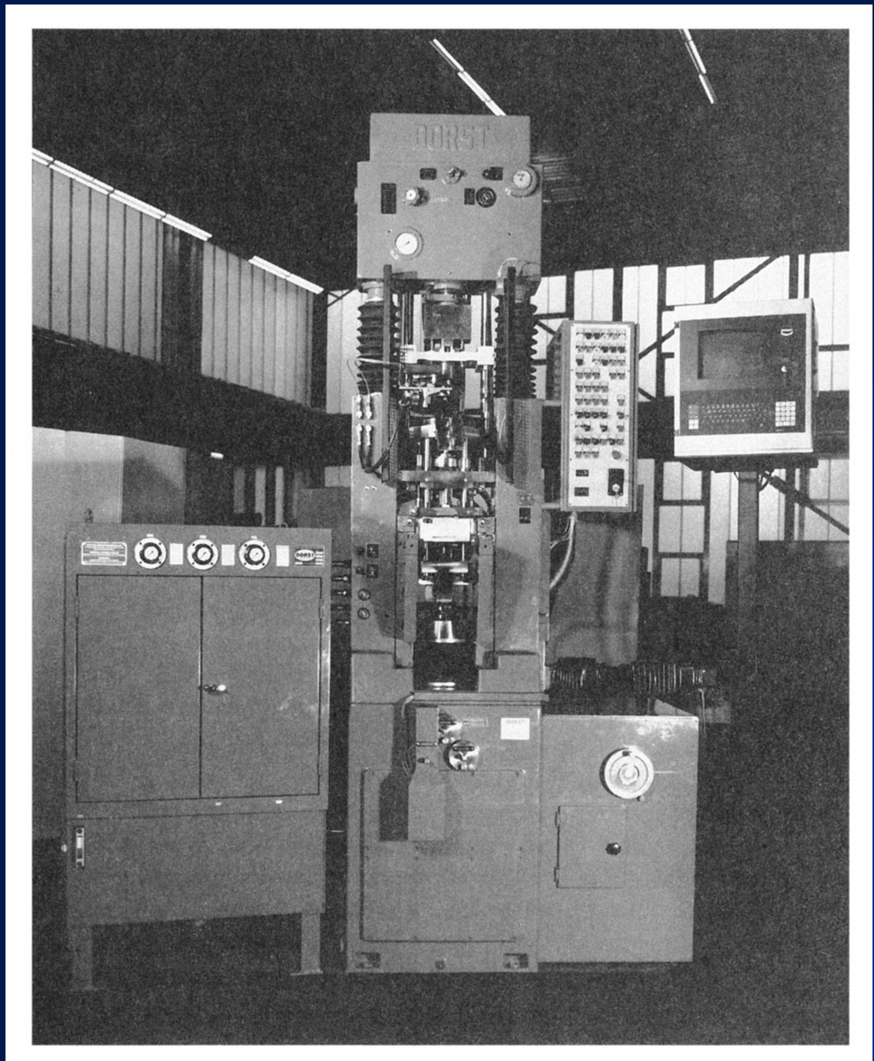

Figure 16.11 - A 450 kN (50-ton) hydraulic press for compaction of powder metallurgy components. This press has the capability to actuate multiple levels to produce complex PM part geometries (photo courtesy Dorst America, Inc.).

Sintering

Heat treatment to bond the metallic particles, thereby increasing strength and hardness

- Usually carried out at between 70% and 90% of the metal's melting point (absolute scale)
- Generally agreed among researchers that the primary driving force for sintering is reduction of surface energy
- Part shrinkage occurs during sintering due to pore size reduction

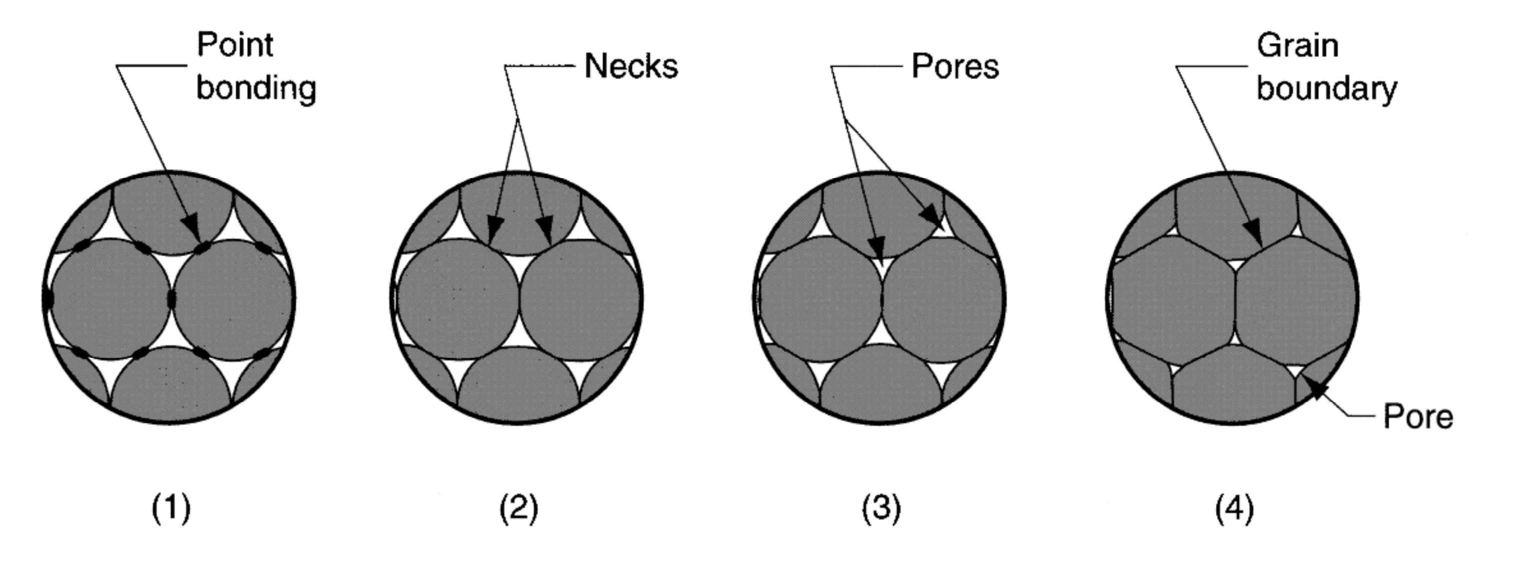

Figure 16.12 ‑ Sintering on a microscopic scale: (1) particle bonding is initiated at contact points; (2) contact points grow into "necks"; (3) the pores between particles are reduced in size; and (4) grain boundaries develop between particles in place of the necked regions

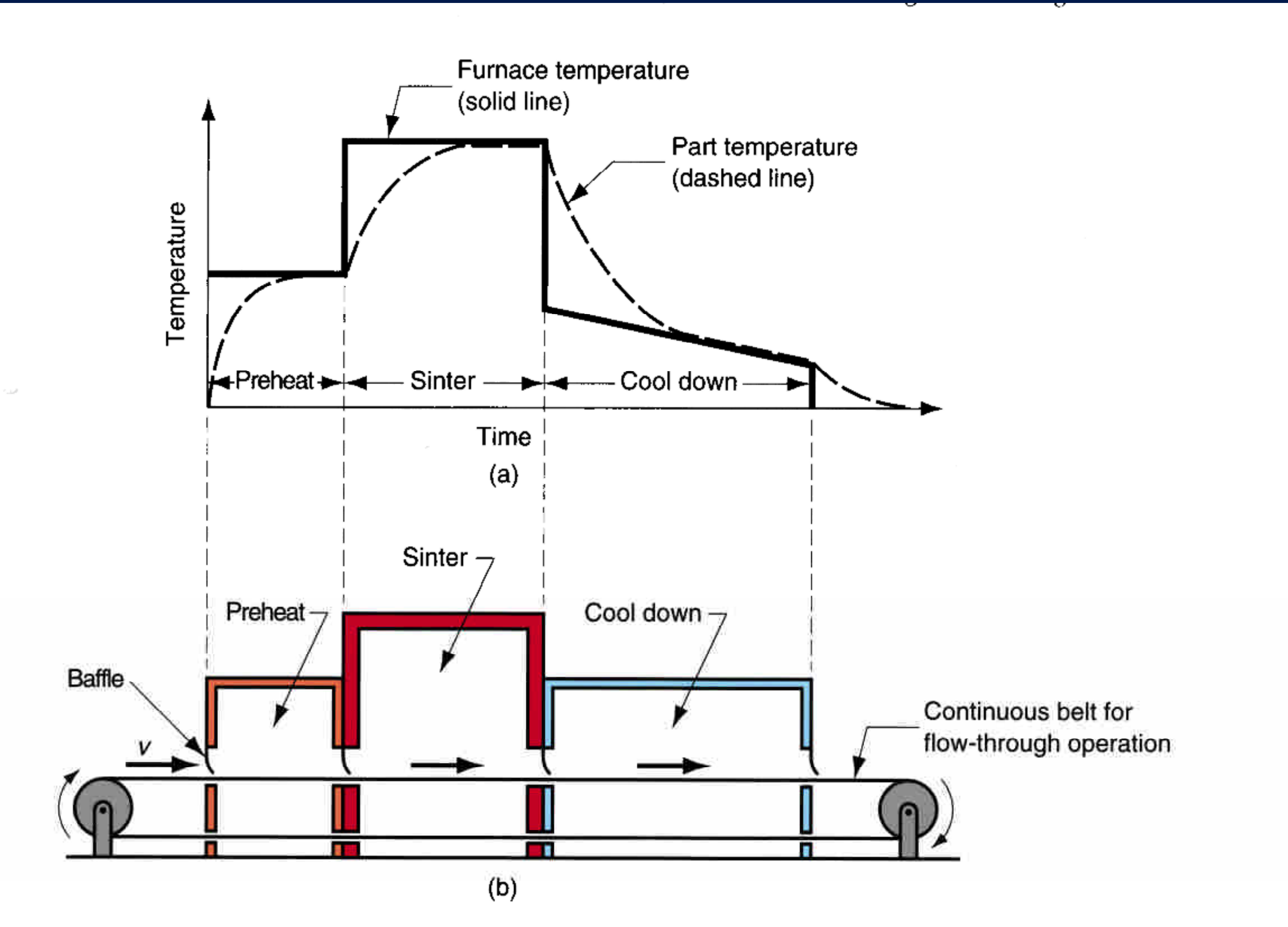

Figure 16.13 - (a) Typical heat treatment cycle in sintering; and (b) schematic cross-section of a continuous sintering furnace

Densification and Sizing

Secondary operations are performed to increase density, improve accuracy, or accomplish additional shaping of the sintered part

- *Repressing* - pressing the sintered part in a closed die to increase density and improve properties
- *Sizing* - pressing a sintered part to improve dimensional accuracy
- *Coining* - pressworking operation on a sintered part to press details into its surface
- *Machining* - creates geometric features that cannot be achieved by pressing, such as threads, side holes, and other details

Impregnation and Infiltration

- Porosity is a unique and inherent characteristic of PM technology
- It can be exploited to create special products by filling the available pore space with oils, polymers, or metals
- Two categories:
  1. Impregnation
  2. Infiltration

Impregnation

The term used when oil or other fluid is permeated into the pores of a sintered PM part

- Common products are oil-impregnated bearings, gears, and similar components
- An alternative application is when parts are impregnated with polymer resins that seep into the pore spaces in liquid form and then solidify to create a pressure tight part

Infiltration

An operation in which the pores of the PM part are filled with a molten metal

- The melting point of the filler metal must be below that of the PM part
- Involves heating the filler metal in contact with the sintered component so capillary action draws the filler into the pores
- The resulting structure is relatively nonporous, and the infiltrated part has a more uniform density, as well as improved toughness and strength

Alternative Pressing and Sintering Techniques

- The conventional press and sinter sequence is the most widely used shaping technology in powder metallurgy
- Additional methods for processing PM parts include:
  - Isostatic pressing
  - Hot pressing - combined pressing and sintering

Materials and Products for PM

- Raw materials for PM are more expensive than for other metalworking because of the additional energy required to reduce the metal to powder form
- Accordingly, PM is competitive only in a certain range of applications
- What are the materials and products that seem most suited to powder metallurgy?

PM Materials – Elemental Powders

A pure metal in particulate form

- Used in applications where high purity is important
- Common elemental powders:
  - Iron
  - Aluminum
  - Copper
- Elemental powders are also mixed with other metal powders to produce special alloys that are difficult to formulate by conventional methods
  - Example: tool steels

PM Materials – Pre-Alloyed Powders

Each particle is an alloy comprised of the desired chemical composition

- Used for alloys that cannot be formulated by mixing elemental powders
- Common pre-alloyed powders:
  - Stainless steels
  - Certain copper alloys
  - High speed steel

PM Products

- Gears, bearings, sprockets, fasteners, electrical contacts, cutting tools, and various machinery parts
- Advantage of PM: parts can be made to near net shape or net shape
  - They require little or no additional shaping after PM processing
- When produced in large quantities, gears and bearings are ideal for PM because:
  - The geometry is defined in two dimensions
  - There is a need for porosity in the part to serve as a reservoir for lubricant

PM Parts Classification System

- The Metal Powder Industries Federation (MPIF) defines four classes of powder metallurgy part designs, by level of difficulty in conventional pressing
- Useful because it indicates some of the limitations on shape that can be achieved with conventional PM processing

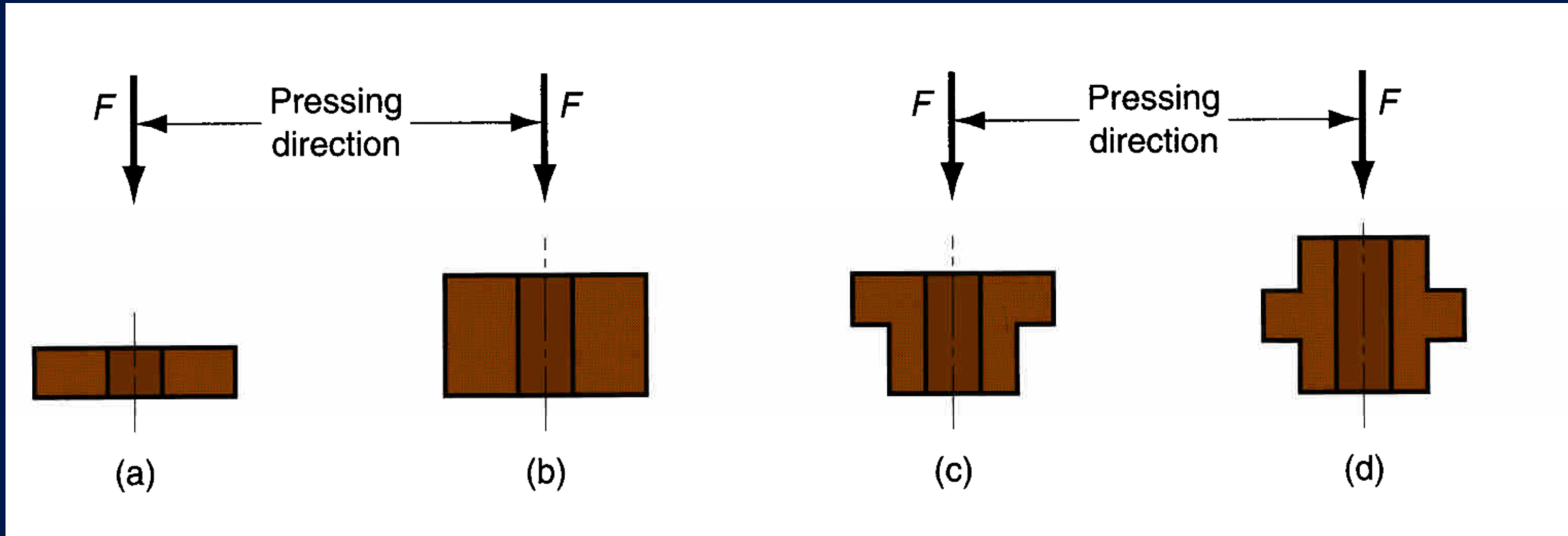

Figure 16.16 - Four classes of PM parts (side view shown; cross-section is circular): (a) Class I - simple thin shapes, pressed from one direction; (b) Class II - simple but thicker shapes require pressing from two directions; (c) Class III - two levels of thickness, pressed from two directions; and (d) Class IV - multiple levels of thickness, pressed from two directions, with separate controls for each level

Design Guidelines for PM Parts - I

- Economics usually require large quantities to justify cost of equipment and special tooling
  - Minimum quantities of 10,000 units are suggested
- PM is unique in its capability to fabricate parts with a controlled level of porosity
  - Porosities up to 50% are possible
- PM can be used to make parts out of unusual metals and alloys - materials that would be difficult if not impossible to produce by other means

Design Guidelines for PM Parts - II

- The part geometry must permit ejection from die after pressing
  - This generally means that part must have vertical or near-vertical sides, although steps are allowed
  - Design features such as undercuts and holes on the part sides must be avoided
  - Vertical undercuts and holes are permissible because they do not interfere with ejection
  - Vertical holes can be of cross-sectional shapes other than round without significant difficulty

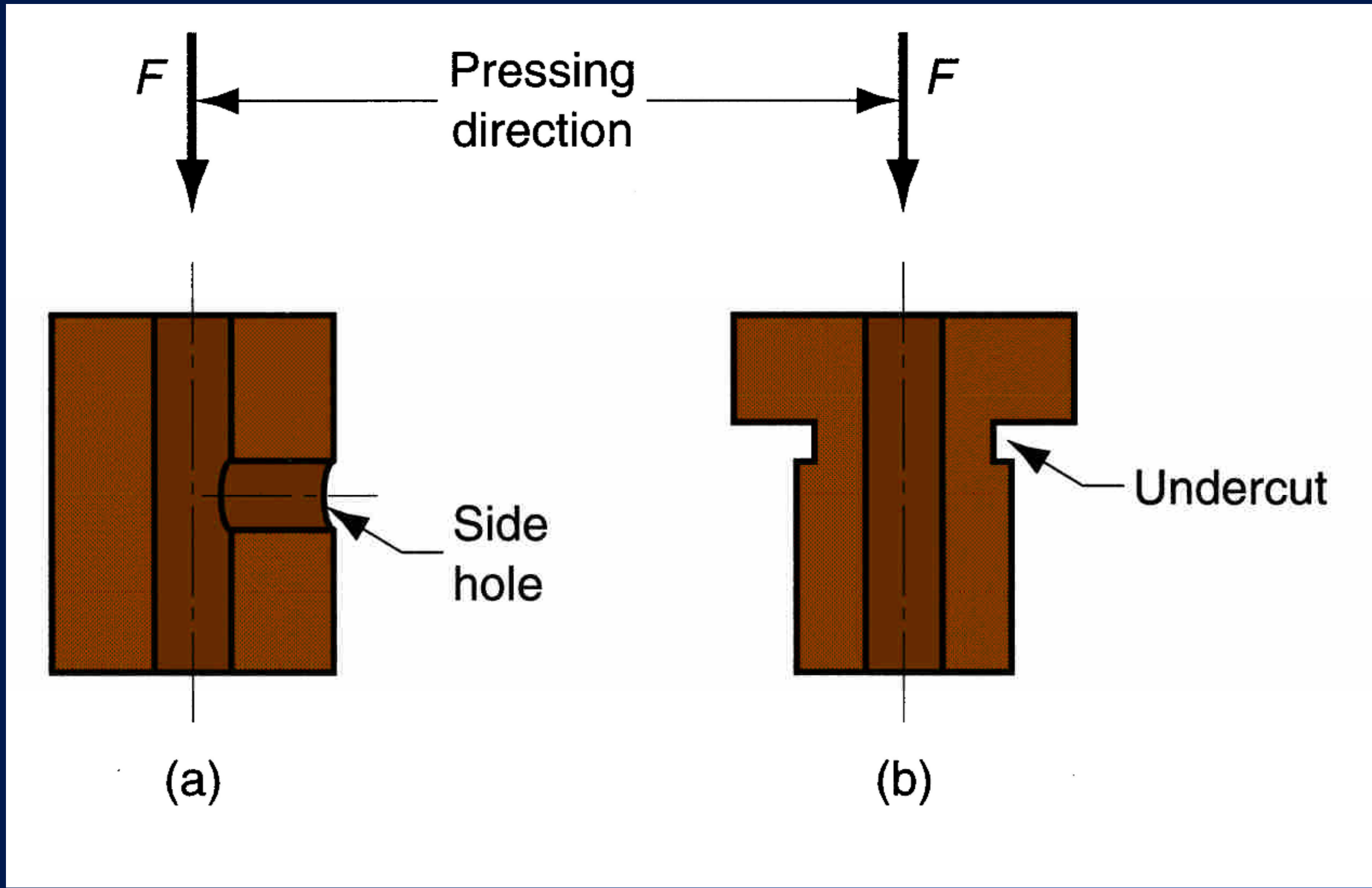

Figure 16.17 - Part features to be avoided in PM: side holes and (b) side undercuts since part ejection is impossible

Design Guidelines for PM Parts - III

- Screw threads cannot be fabricated by PM; if required, they must be machined into the part
- Chamfers and corner radii are possible by PM pressing, but problems arise in punch rigidity when angles are too acute
- Wall thickness should be a minimum of 1.5 mm (0.060 in) between holes or a hole and outside wall
- Minimum recommended hole diameter is 1.5 mm (0.060 in)

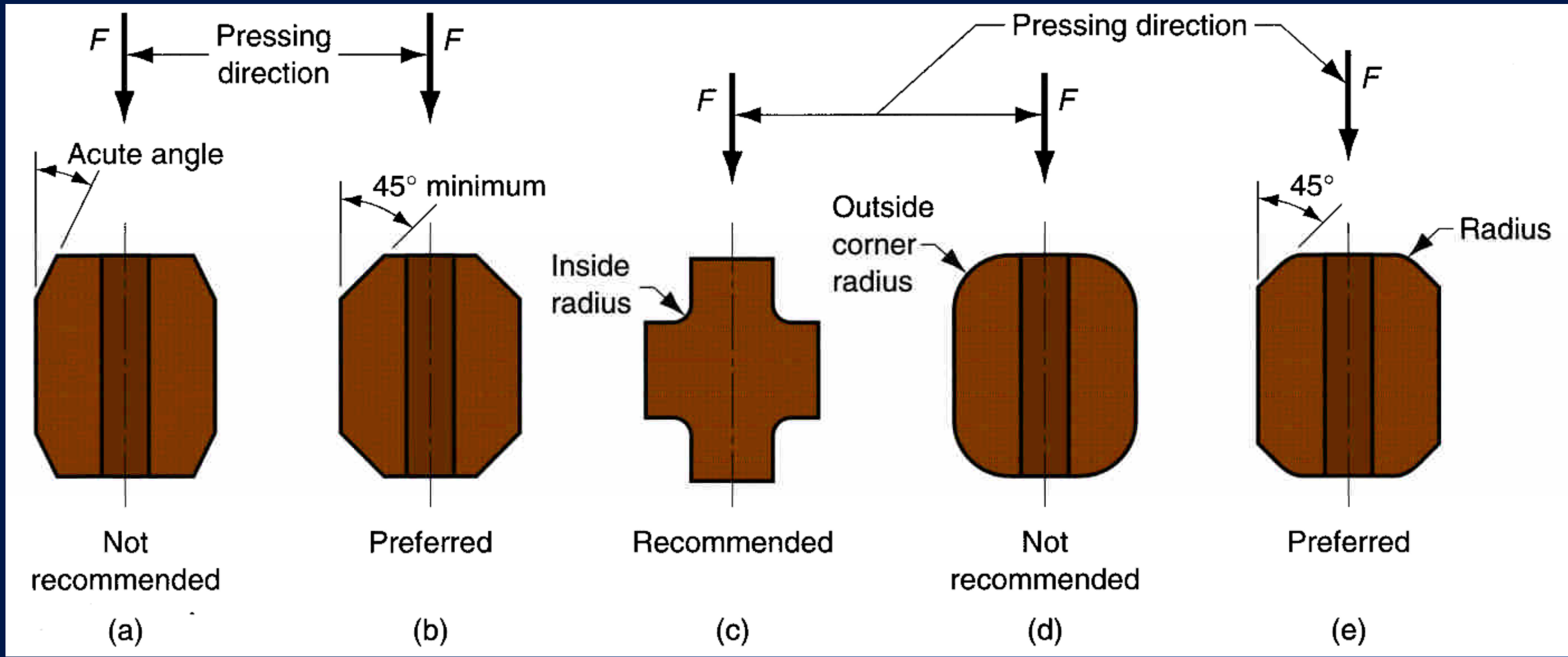

Figure 16.19 - Chamfers and corner radii are accomplished but certain rules should be observed: (a) avoid acute angles; (b) larger angles preferred for punch rigidity; (c) inside radius is desirable; (d) avoid full outside corner radius because punch is fragile at edge; (e) problem solved by combining radius and chamfer