MSE 440/540: Processing of Metallic Materials

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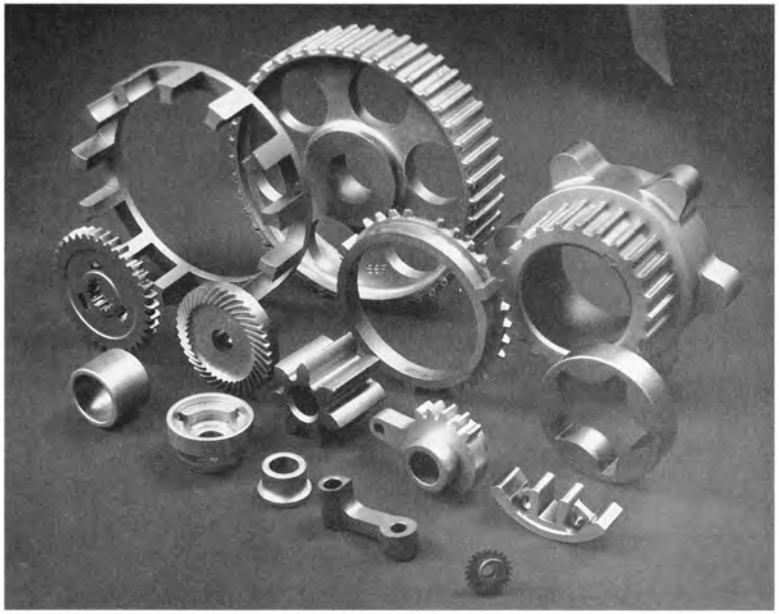
Lecture 15: Powder Metallurgy

Powder Metallurgy (PM)

- <u>Usual PM production sequence:</u>
  1. Pressing - powders are compressed into desired shape to produce *green compact*
     - Accomplished in press using punch-and-die
  2. Sintering – green compacts are heated to bond the particles into a hard, rigid mass
     - Temperatures are below melting point



Why Powder Metallurgy is Important

- PM parts can be mass produced to *net shape* or *near net shape*
- PM process wastes very little material - ~ 3%
- PM parts can be made with a specified level of porosity, to produce porous metal parts
  - Filters, oil-impregnated bearings and gears
- Difficult to fabricate parts can be shaped by powder metallurgy
  - Tungsten filaments for incandescent lamp bulbs are made by PM
- Certain alloy combinations and cermets can only be made by PM
- PM production can be automated for economical production

Limitations and Disadvantages

- High tooling and equipment costs
- Metallic powders are expensive
- Problems in storing and handling metal powders
  - Degradation over time, fire hazards with certain metals
- Limitations on part geometry because metal powders do not readily flow well
- Variations in density may be a problem, especially for complex geometries

Production of Metallic Powders

- Any metal can be made into powder form
- Three principal methods by which metallic powders are commercially produced
  1. <u>Atomization</u>
  2. <u>Chemical</u>
  3. <u>Electrolytic</u>
- In addition, mechanical milling is occasionally used to reduce powder sizes

Gas Atomization Method

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

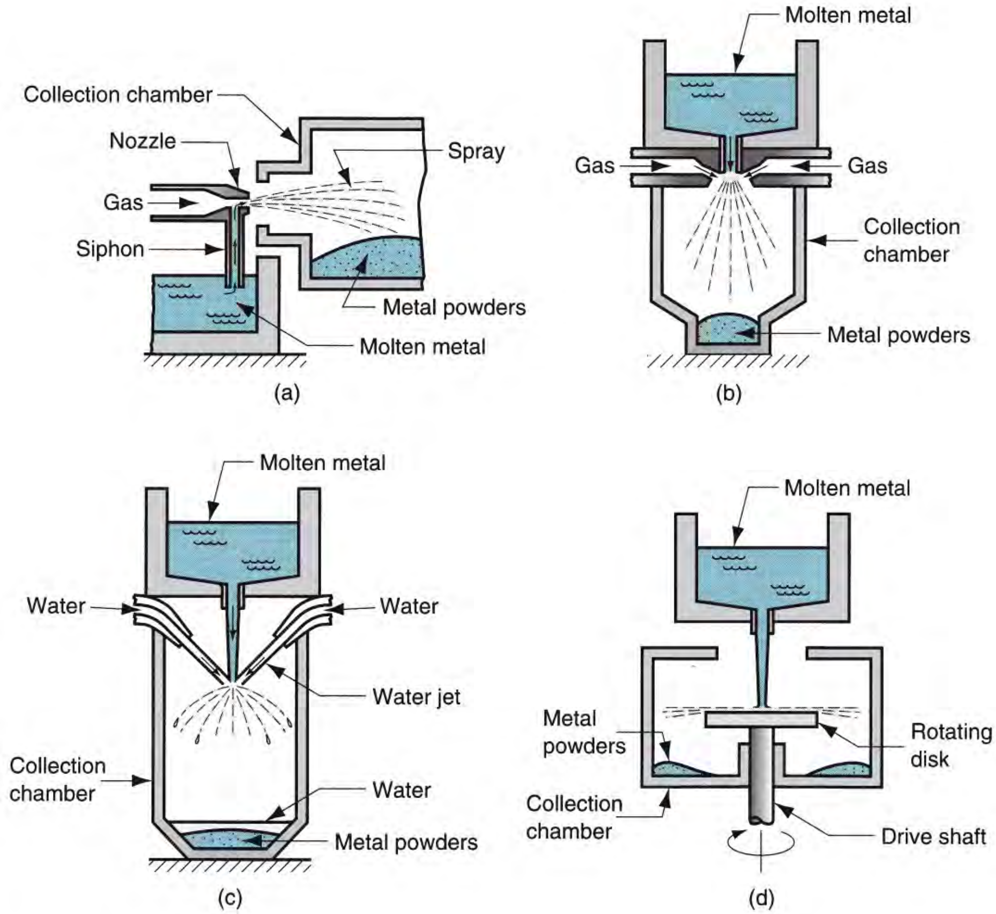
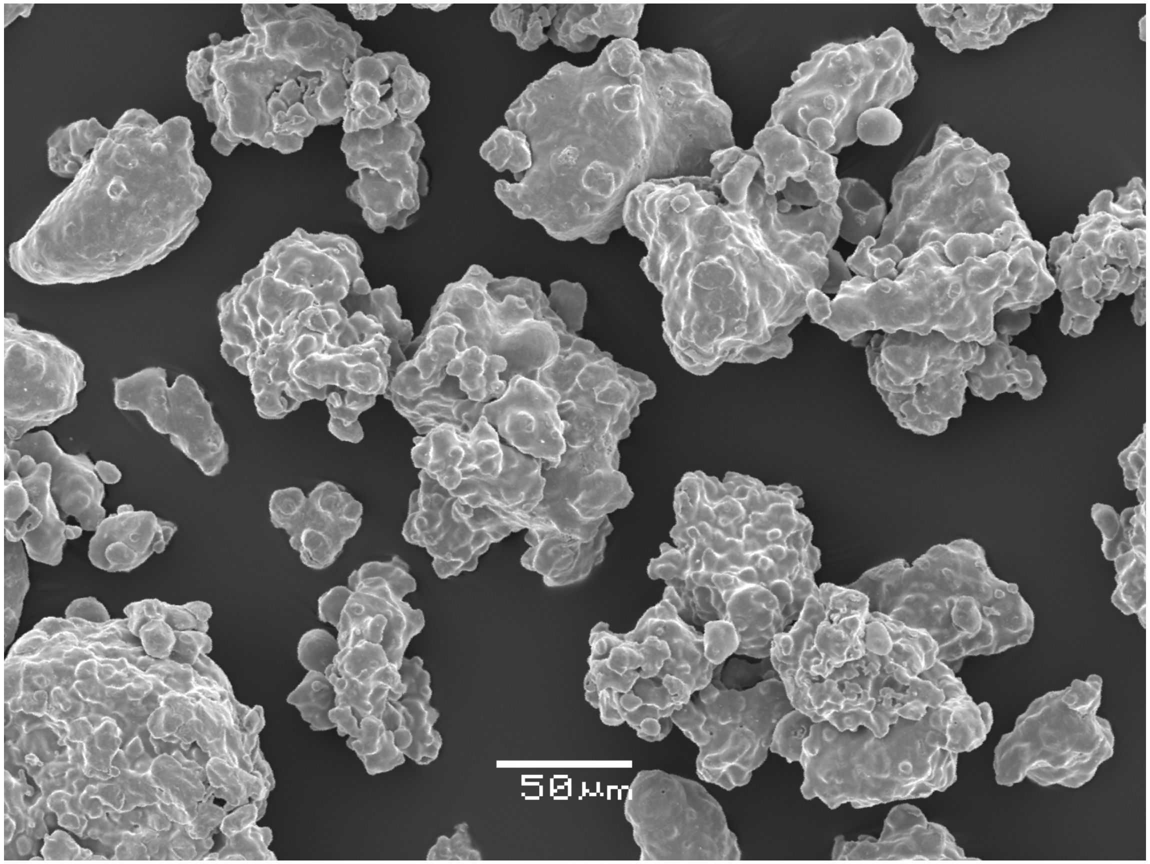


Figure 10.2

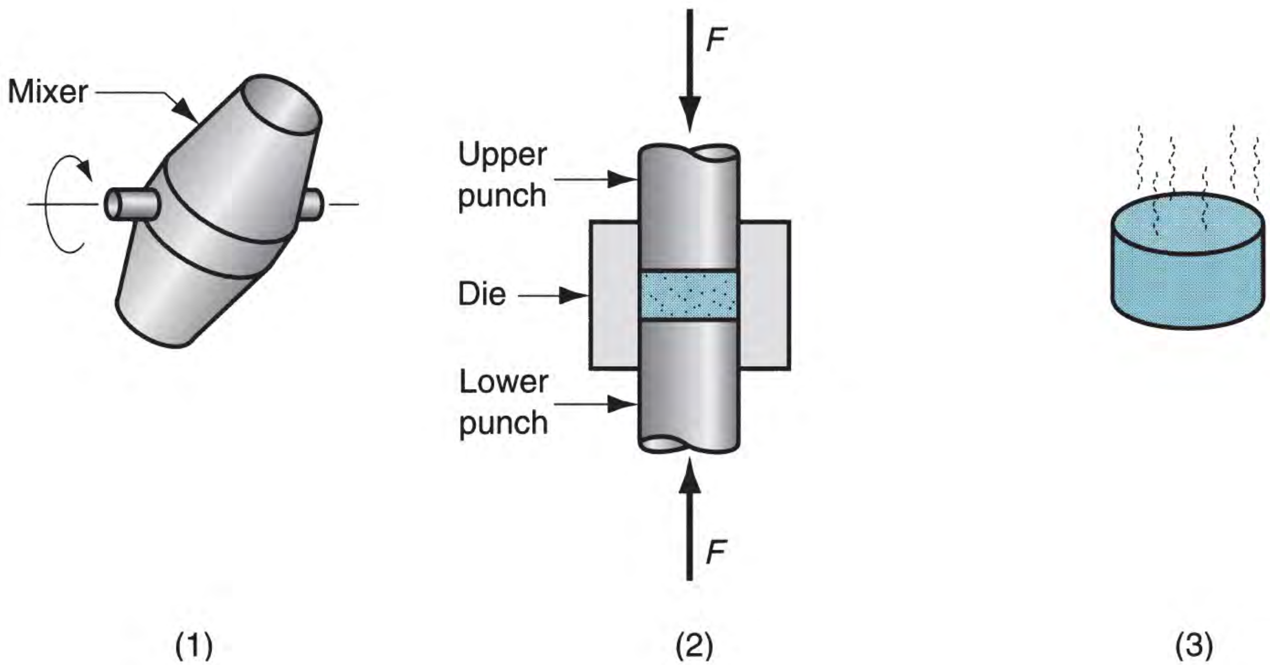
Iron Powders for PM



Powders produced by water atomization

Conventional Press and Sinter Steps

1. Blending and mixing of powders
2. Compaction - pressing into desired shape
3. Sintering - heating to temperature below melting point to cause solid-state bonding of particles and strengthening of part



Blending and Mixing of Powders

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

http://www.youtube.com/watch?v=1Mjsi2F2MrY

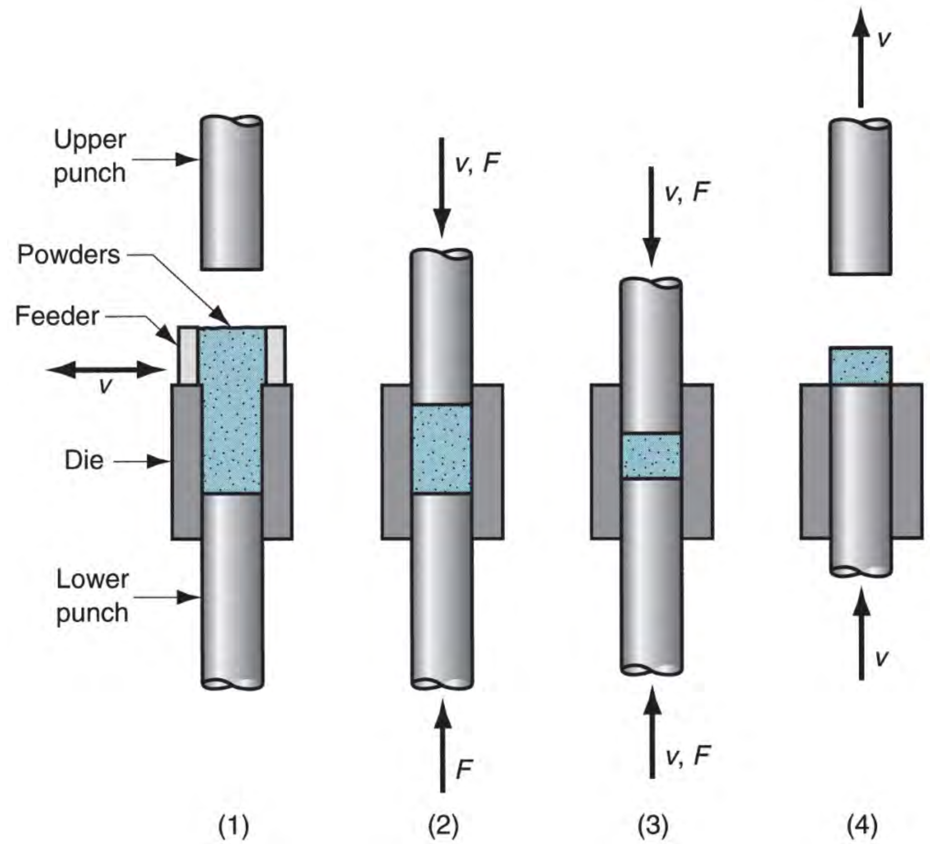
Compaction

High pressure to form the powders into the required shape

- 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 *green strength* of the part should be adequate for handling

Conventional Pressing in PM

- 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, (4) part ejection



http://www.youtube.com/watch?v=5VmeIunoyKw

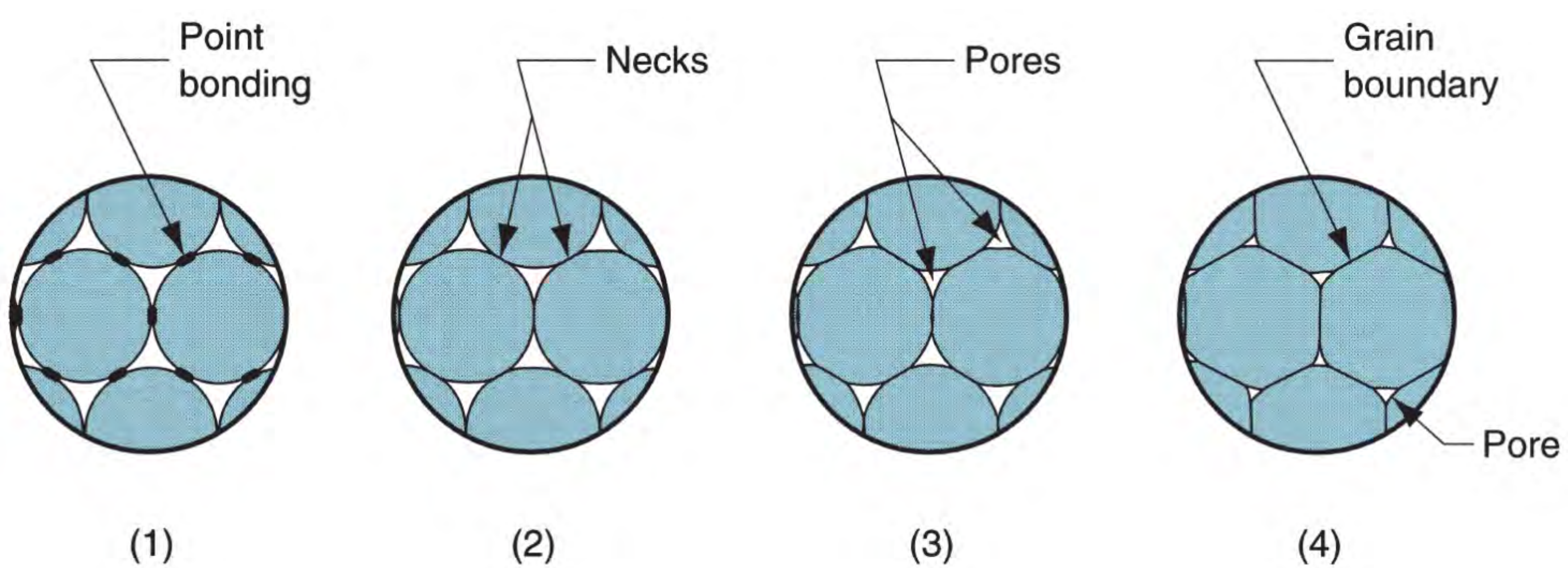
Sintering

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

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

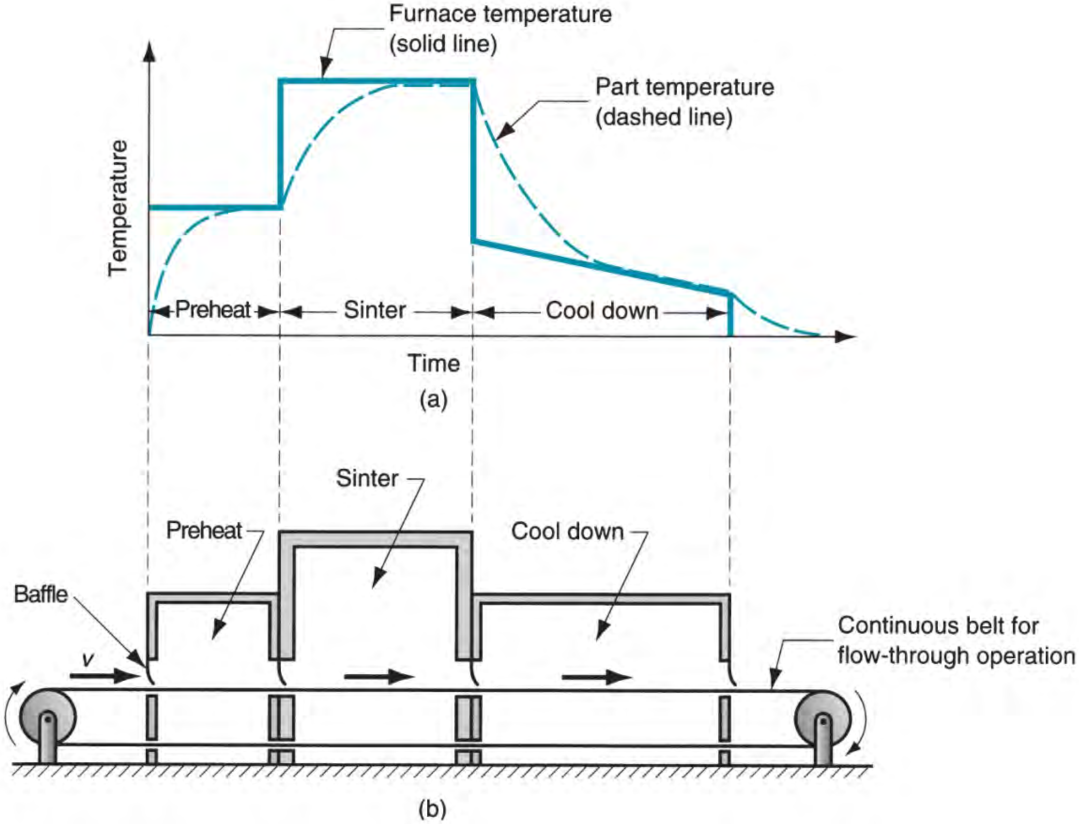
Sintering Sequence on a Microscopic Scale

- (1) Particle bonding is initiated at contact points; (2) contact points grow into "necks"; (3) pores between particles are reduced in size; (4) grain boundaries develop between particles in place of necked regions



Sintering Cycle and Furnace

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



Densification and Sizing

- Secondary operations are performed on sintered part to increase density, improve accuracy, or accomplish additional shaping
  - Repressing - pressing in closed die to increase density and improve properties
  - Sizing - pressing to improve dimensional accuracy
  - Coining - pressing details into its surface
  - Machining - for geometric features that cannot be formed by pressing, such as threads and side holes

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
- 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

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
- Heating the filler metal in contact with the sintered part so capillary action draws the filler into the pores
  - Resulting structure is nonporous, and the infiltrated part has a more uniform density, as well as improved toughness and strength

Alternative Pressing and Sintering Techniques

- Some additional methods for producing PM parts:
  - Isostatic pressing - hydraulic pressure is applied from all directions to achieve compaction
  - Powder injection molding (PIM) - starting polymer has 50% to 85% powder content
    - Polymer is removed and PM part is sintered
  - Hot pressing - combined pressing and sintering

PM Materials – Elemental Powders

A pure metal in particulate form

- Common elemental powders:
  - Iron
  - Aluminum
  - Copper
- Elemental powders can be mixed with other metal powders to produce alloys that are difficult to formulate by conventional methods
  - Example: tool steels

Pre-Alloyed Powders

Each particle is an alloy comprised of the desired chemical composition

- Common pre-alloyed powders:
  - Stainless steels
  - Certain copper alloys
  - High speed steel

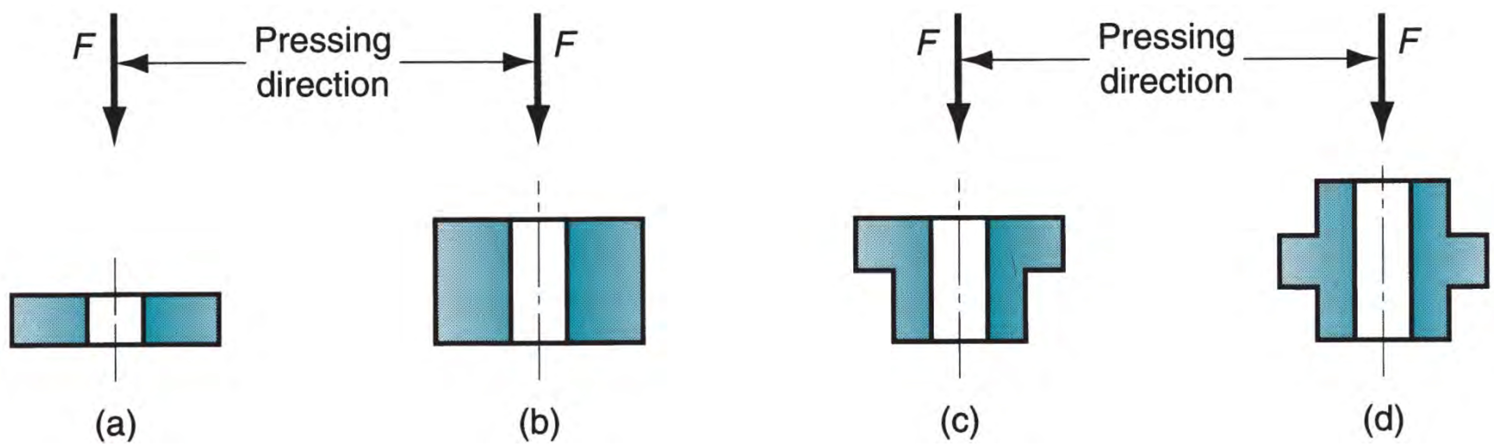
PM Products

- 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
- When produced in large quantities, gears and bearings are ideal for PM because:
  - Their geometries are defined in two dimensions
  - There is a need for porosity in the part to serve as a reservoir for lubricant

http://www.youtube.com/watch?v=n_FW7Q2xO5o&feature=related

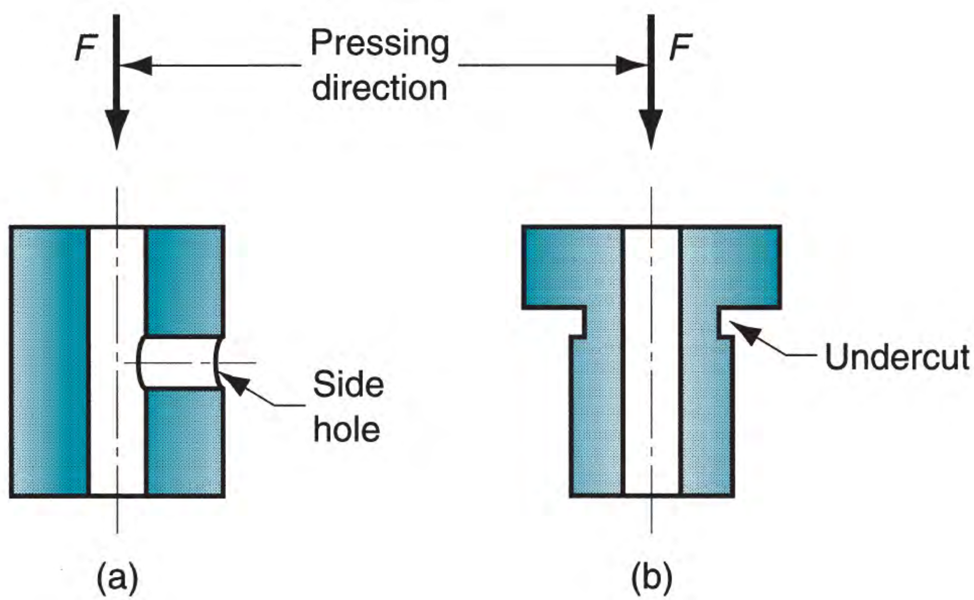
Four Classes of PM Parts

- (a) Class I Simple thin shapes; (b) Class II Simple but thicker; (c) Class III Two levels of thickness; and (d) Class IV Multiple levels of thickness



Side Holes and Undercuts

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

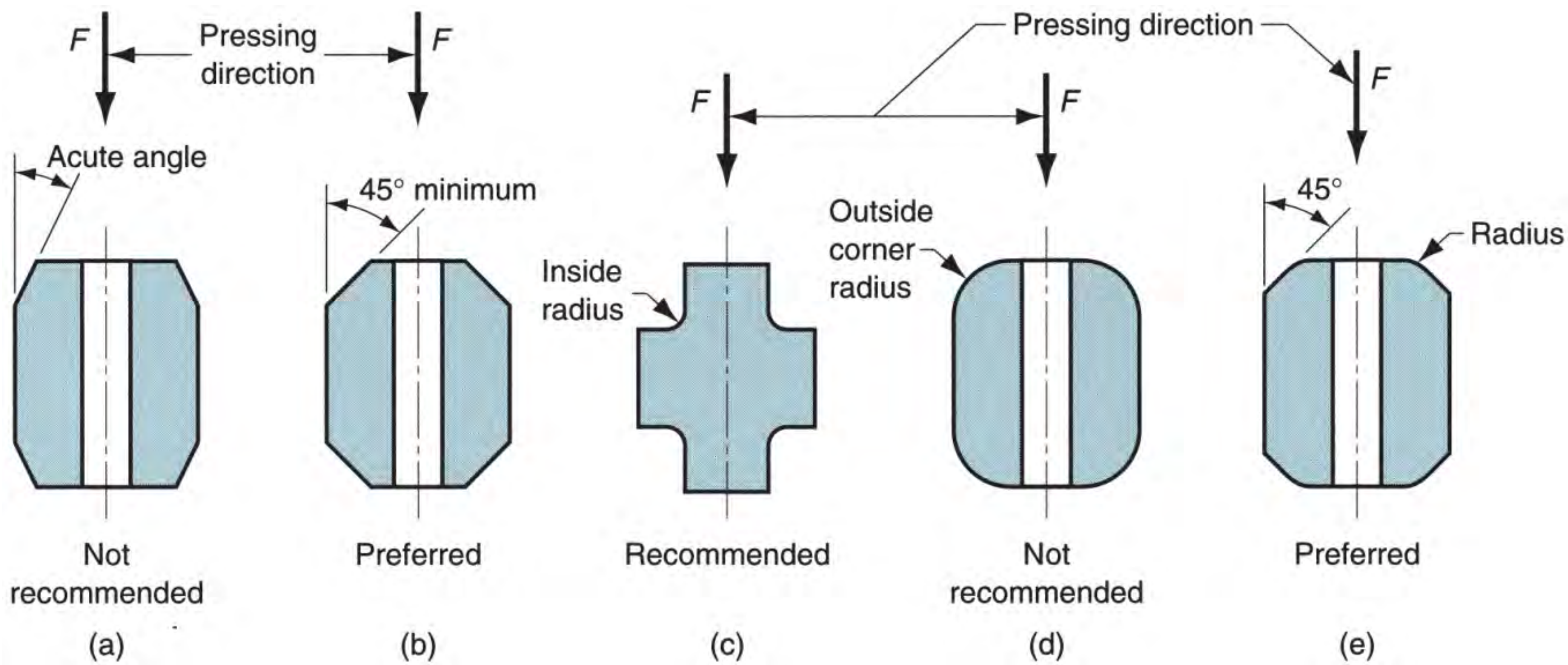


Design Guidelines for PM Parts - III

- Screw threads cannot be fabricated by PM
  - They must be machined into the part
- Chamfers and corner radii are possible in PM
  - But problems occur 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 hole diameter ~ 1.5 mm (0.060 in)

Chamfers and Corner Radii

- (a) Avoid acute angles; (b) use larger angles for punch rigidity; (c) inside radius is desirable; (d) avoid full outside corner radius because punch is fragile at edge; (e) better to combine radius and chamfer



HW assignment

- Reading assignment: Chapters, 20.4, 21

- Review Questions: 10.1, 10.2, 10.3, 10.4, 10.5, 10.7, 10.8, 10.9, 10.11, 10.12, 10.14, 10.15,
- Problems: 10.1,