Lecture 15: Powder Metallurgy
Powder Metallurgy (PM)

- **Usual PM production sequence:**
  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. Atomization
  2. Chemical
  3. Electrolytic
• 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

![Diagram of Gas Atomization Method](image-url)
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 \textit{pressing}, in which opposing punches squeeze the powders contained in a die

• The workpart after pressing is called a \textit{green compact},

• The \textit{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=5VmelunoyKw
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
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,