POWDER METALLURGY

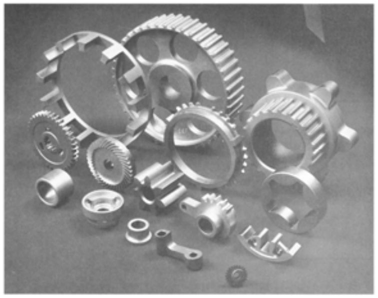
- Characterization of Engineering Powders
- Production of Metallic Powders
- Conventional Pressing and Sintering
- Alternative Pressing and Sintering Techniques
- Materials and Products for PM
- Design Considerations in Powder Metallurgy

Introduction

- Feasible when
  (1) the melting point of a metal is ……….. such as W, Ta, Mo
  (2) the reaction with the melt becomes a problem. eg. Zr and superhard tool materials
- Powder Metallurgy (PM) (around 1800s)
  – Pressing - Powder compressed into the desired shape.
  – Sintering – Heating at a temperature well below melting.
- Advantage
  – Near-net shape, No waste, Inherent porosity,
  – Dimension control ……………………
  – PM production methods can be automated for economical production
- Disadvantage
  – …………., Powder harder to handle
  – Geometric & Size limitation, Density variation

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



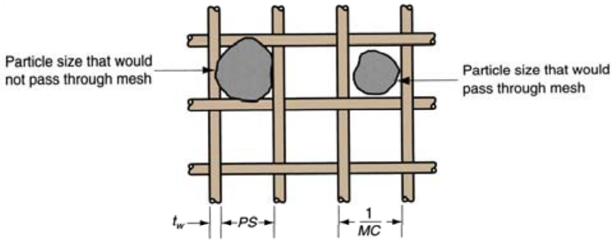
A collection of powder metallurgy parts

A *powder* can be defined as a finely divided solid particulates.

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

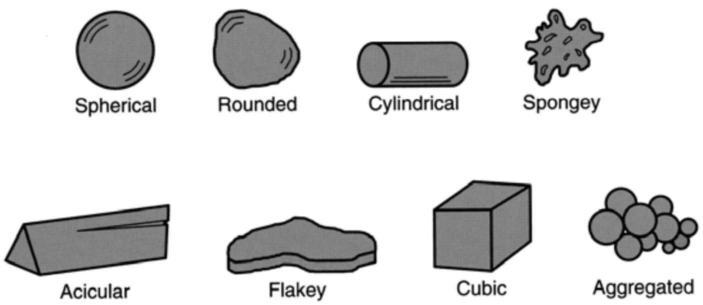
- Interparticle friction and flow char.
- Packing density and porosity
- Chemistry and surface film

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 ……………………….

Particles Shapes

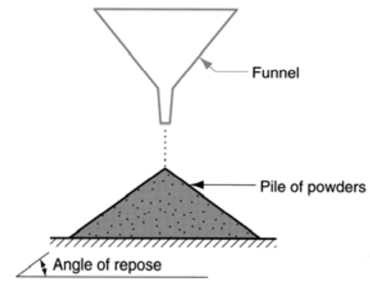


Several of the possible (ideal) particle shapes in powder metallurgy

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

- Smaller particle sizes generally show greater friction and steeper angles
- Spherical shapes have the ………. interparticle 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 ……… 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 …………..… in some of the particles
- If internal pore volumes are included in above porosity, then equation is exact.

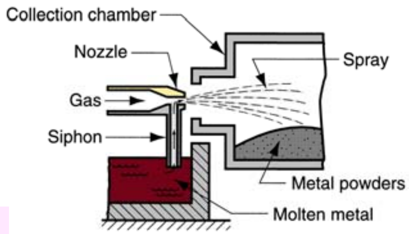
Chemistry and Surface Films

- 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

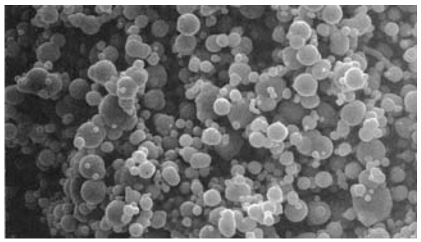
1. Atomization
   - *Centrifugal, gas or water*
2. Chemical
   - *Decomposition or precipitation*
3. Electrolytic

Mechanical methods are occasionally used to reduce powder sizes

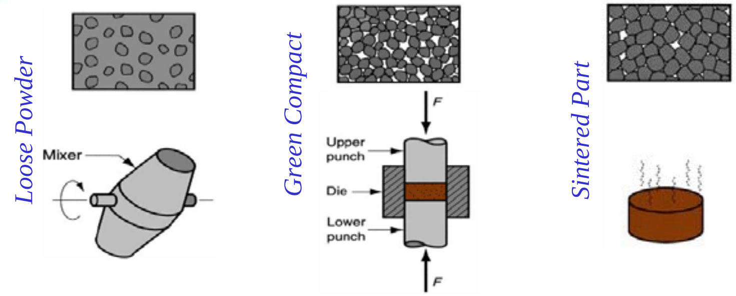


gas atomization method

e.g. iron powders produced by decomposition of iron pentacarbonyl; particle sizes range from about 0.25 - 3.0 microns

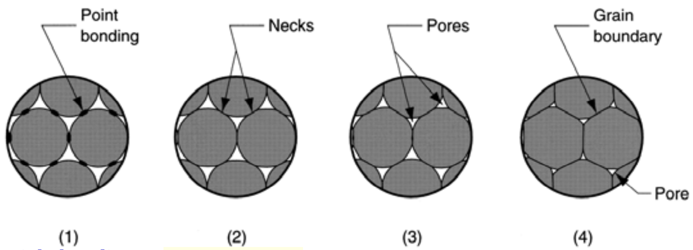


Conventional Pressing and Sintering



- 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, …………………, and for other reasons.

Sintering

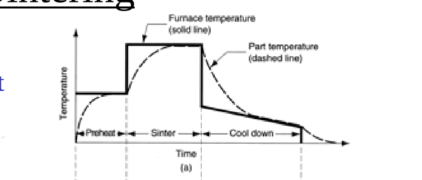


(1) *particle bonding is initiated at contact points* (2) *contact points grow into "necks";* (3) *the pores are reduced in size* (4) *grain boundaries develop in place of the necked regions*

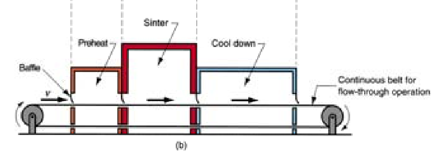
- Heat treatment to bond the metallic particles, thereby increasing strength and hardness
- Usually carried out at between 70% and 90% of the metal's melting point
- Generally agreed among researchers that the primary driving force for sintering is …………………………..
- **Part shrinkage** occurs during sintering due to pore size reduction

Sintering

Typical heat treatment cycle in sintering



schematic cross-section of a continuous sintering furnace



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

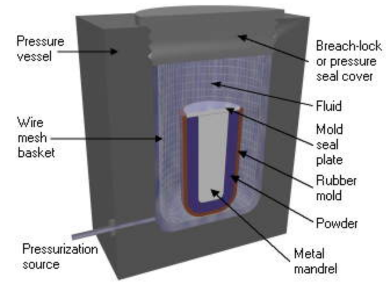
- *Repressing* - pressing the sintered part in a closed die to increase density and improve properties
- *Sizing* - pressing a sintered part to improve dimensional accuracy
- *Coining* - pressworking operation on a sintered part to press details into its surface
- *Machining* - creates geometric features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

Impregnation and Infiltration

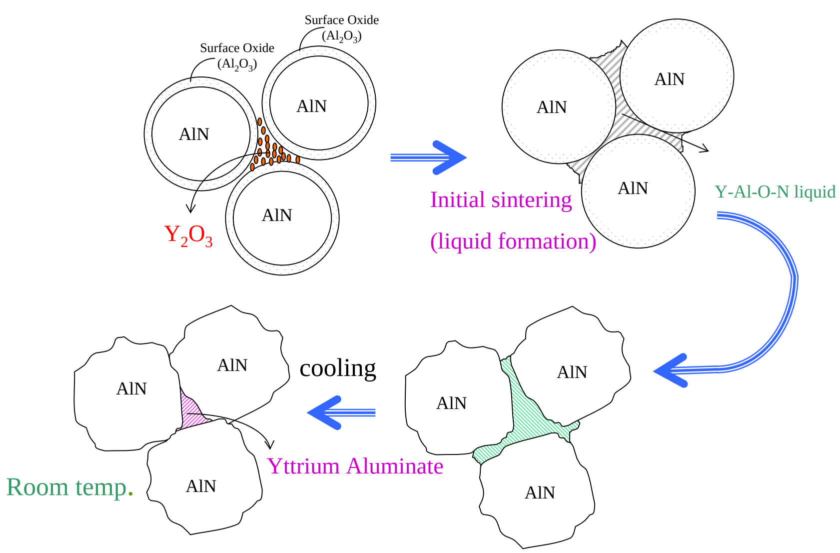
- Porosity is a unique and inherent characteristic of PM technology
- It can be exploited to create special products by filling the available pore space with oils, polymers, or metals
- Impregnation: The term used when oil or other fluid is permeated into the pores of a sintered PM part
  - *Common products are oil-impregnated bearings, gears, and similar components*
  - *An alternative application is when parts are impregnated with polymer resins that seep into the pores 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 lower*
  - *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 ………….. toughness and strength*

Alternative Pressing and Sintering Techniques

- The conventional press and sinter sequence is the most widely used shaping technology in powder metallurgy
- Isostatic Pressing
  - Cold Isostatic Pressing (CIP)
  - Hot Isostatic Pressing (HIP)
- Powder Injection Molding (Metal & Ceramics)
  - *Powder mixed with binder to form granular pellets*
  - *Pellets are heated to remove binder*
  - *Sintering and Secondary operation*
- Powder Rolling, Powder Extrusion (powder in a container) and Powder Forging
- Hot pressing and Spark pressing (high electric current)
- Liquid-phase sintering

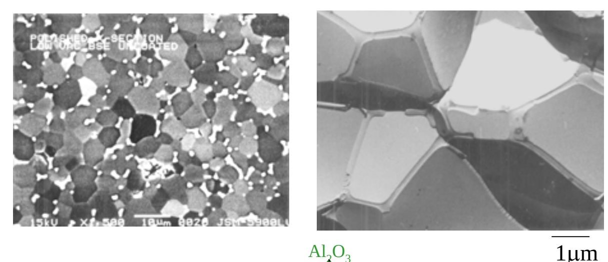


Liquid Phase Sintering of AlN



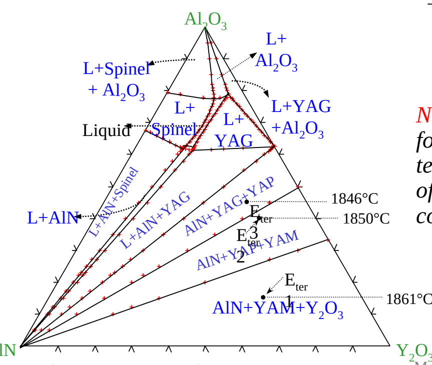
Liquid Phase Sintering of AlN

With yttria



Without yttria

AlN-Al_2O_3-Y_2O_3 Isothermal Section at 1800°C

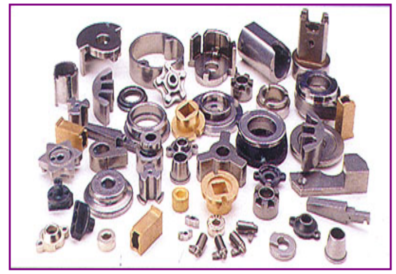


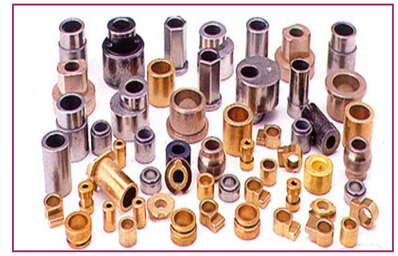
Note that liquid forms at a lower temp. than the Tm of any of the components

Materials and Products for PM

- Raw materials for PM are …………….. 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 PM?
- Common elemental powders:
  - *Iron, Aluminum and Copper*
- Used in applications where high purity is important
- Elemental powders are also mixed with other metal powders to produce special 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
- Used for alloys that cannot be formulated by mixing elemental powders
- Common pre-alloyed powders:
  - *Stainless steels, Certain copper alloys and High speed steel*

PM Products





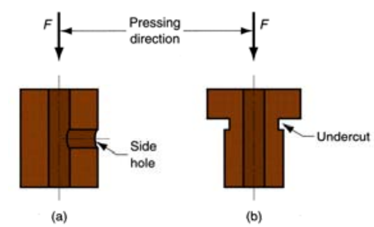
- Gears, bearings, sprockets, fasteners, electrical contacts, cutting tools, and various machinery parts
- Advantage of PM: parts can be made to ………………… or ……………
  - *They require little or no additional shaping after PM processing*
- When produced in large quantities, gears and bearings are ideal for 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*

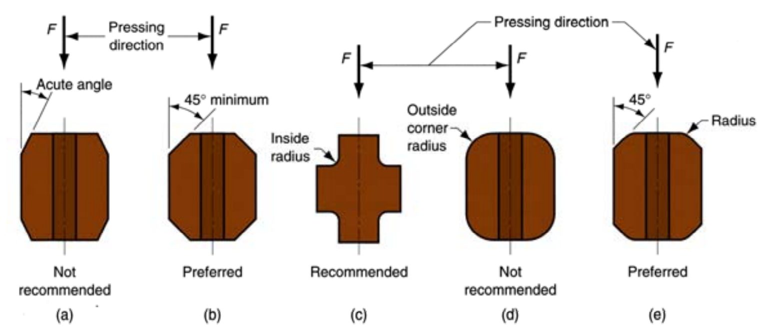
Design Guidelines for PM Parts

- Economics usually require large quantities to justify cost of equipment and special tooling
  - *Minimum quantities of ……….. units are suggested*
- PM is unique in its capability to fabricate parts with a controlled level of porosity
  - *Porosities up to …….. are possible* (e.g. Metal foams)
- 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
- 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

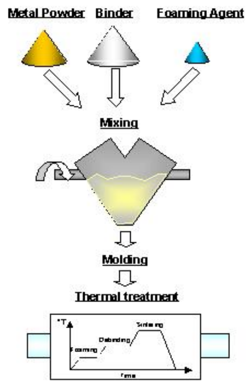
Design Guidelines for PM Parts

- 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



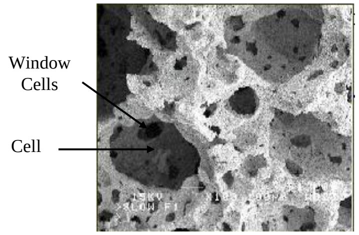


Metal Foams Produced by PM



Production Steps of IMI metal foam

This process can produce a very porous structure



Microstructure of the metal foam produced at IMI-NRC

Next time

Processing of Ceramics