MME 3518
POWDER METALLURGY

- 2 Midterm Exams- 40 %
- Pop-quizes-10 %
- Final Exam- 50 %

COURSE MATERIAL

- Lecture Notes
- G.S. Upadhyaya, Powder Metallurgy Technology

Suggested Readings

- S. A. Tsukerman, Powder Metallurgy
- R.M. German, Powder Metallurgy Science

Every lecture attanence

Make-up exams definitely will not be easier than the regular exams!

If you have sensitivity about your final grade, I may have advices to you in the beginning of the course. At the end of the course, I will not be able to help you.

No smart-phone usage during lecture

MEMORIZING	UNDERSTANDING
• Limits learning of ideas and concepts to word for word recall.	• Converts ideas and concepts into own words.
• Limits ability to generate insight or creative ideas.	• Creates a basis for generating insights and creative syntheses.
• Limits learning to actual words recalled.	• Advances the depth of learning.
• Inability to deduce or induce.	• Develops insights that come from deduction or induction.
• Has trouble seeing beyond the basic concept or idea.	• Can see meaning, effects, results, consequences beyond the basic idea or concept.

• Difficult to explain ideas to someone else other than word for word.	• Able to use own words to explain something clearly to someone else.
• Difficult to see how ideas apply in real-life situations.	• Can apply ideas to real life situations.
• Relevance of ideas outside the classroom is difficult to see.	• Ability to seek connections between knowledge learned in classroom and the outside world.
• Does not see differences, similarities, and implications of ideas.	• Can identify differences, similarities between ideas and implications of these ideas.
• Interprets ideas literally.	• Realizes that there can be figurative as well as literal interpretations of ideas.

• Strives for rote learning and has trouble solving problems when numbers or components are changed.	• Strives for understand and can solve problems even when numbers or components are changed.
• Believes there is one right answer to every question.	• Accepts that there may be more than 1 "right" answer to a question depending on circumstances.

Definition of Powder Metallurgy

- Powder metallurgy may defined as, “the art and science of producing metal powders and utilizing them to make serviceable objects.”

OR

- It may also be defined as “material processing technique used to consolidate particulate matter i.e. powders both metal and/or non-metals.”

OR

- is a process whereby a solid metal, alloy or ceramic in the form of a mass of dry particles is converted into an engineering component of predetermined shape and possessing properties which allow it to be used in most cases without further processing.

- Powder metallurgy is a forming and fabrication technique consisting of three major processing stages.
  - First, the primary material is physically powdered, divided into many small individual particles.
  - Next, the powder is injected into a mold or passed through a die to produce a weakly cohesive structure (via cold welding) very near the dimensions of the object ultimately to be manufactured.
  - Finally, the end part is formed by applying pressure, high temperature, long setting times during which self-welding occurs.

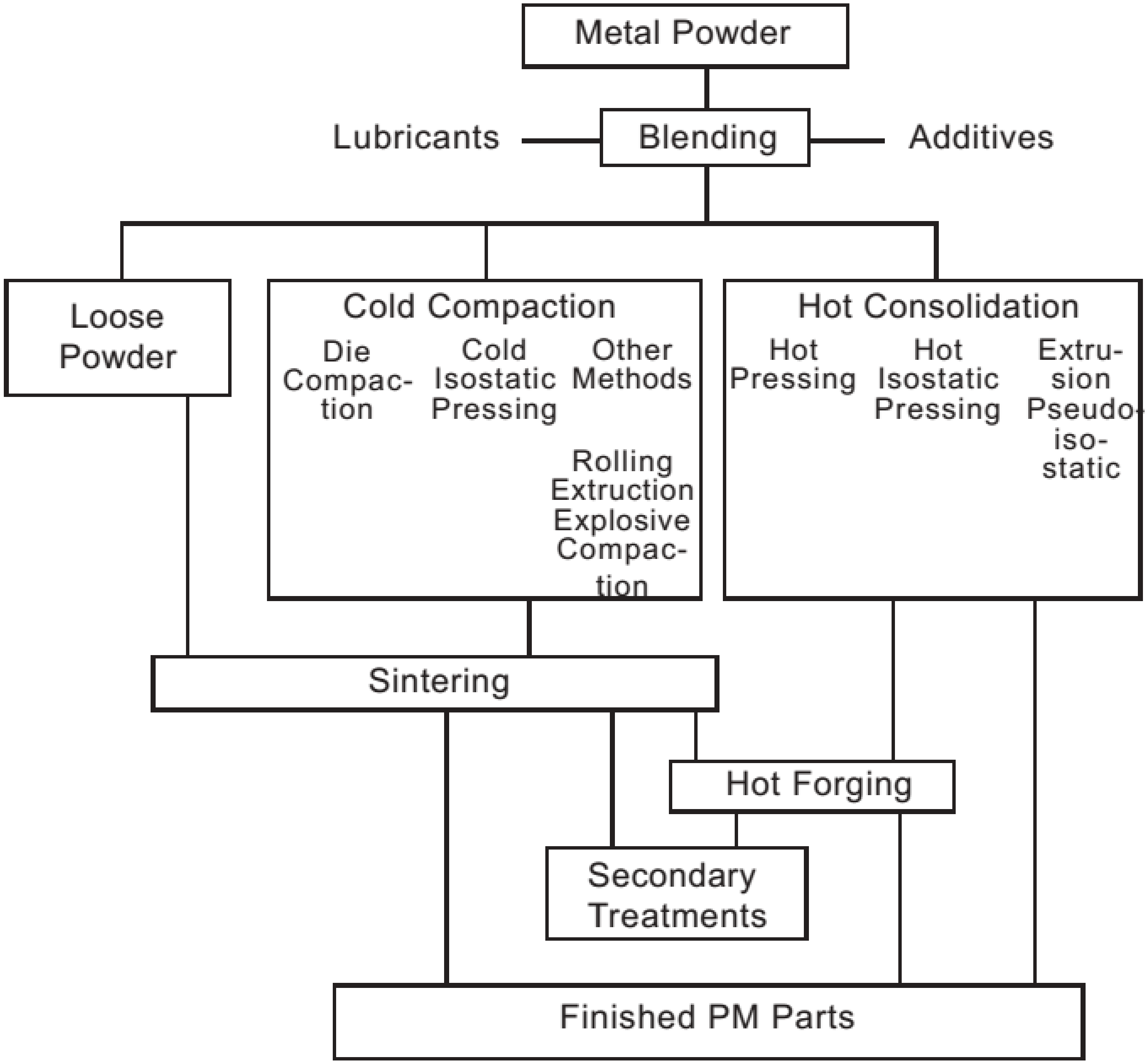
Powder Metallurgy

- Subject Matter
  - Powder metallurgy (PM) is the art and science of manufacturing complex shaped objects from powders
  - It includes all manufacturing steps to produce the final product
    - Powder production
    - Blending
    - Shaping and compaction
    - Sintering
  - This course covers all these aspects of this manufacturing process with emphasis on structure-processing-properties relationships.
- Objectives
  - To learn the technology
  - To gain insight into scientific principles underlying design and operation of PM processes
  - To be able to select and design the optimal processing route for any given product properties.

Powder Metallurgy (PM)

Metal processing technology in which parts are produced from metallic powders

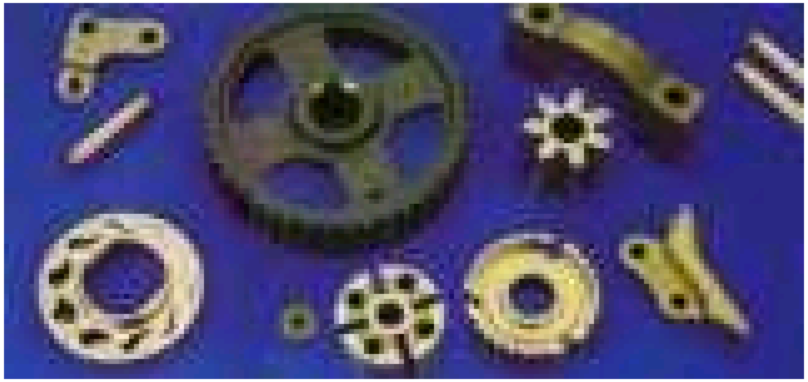
- PM parts can be mass produced to net shape or near net shape, eliminating or reducing the need for subsequent machining
- Certain metals that are difficult to fabricate by other methods can be shaped by PM
- Tungsten filaments for lamp bulbs are made by PM
- PM process wastes very little material ~ 97% of 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

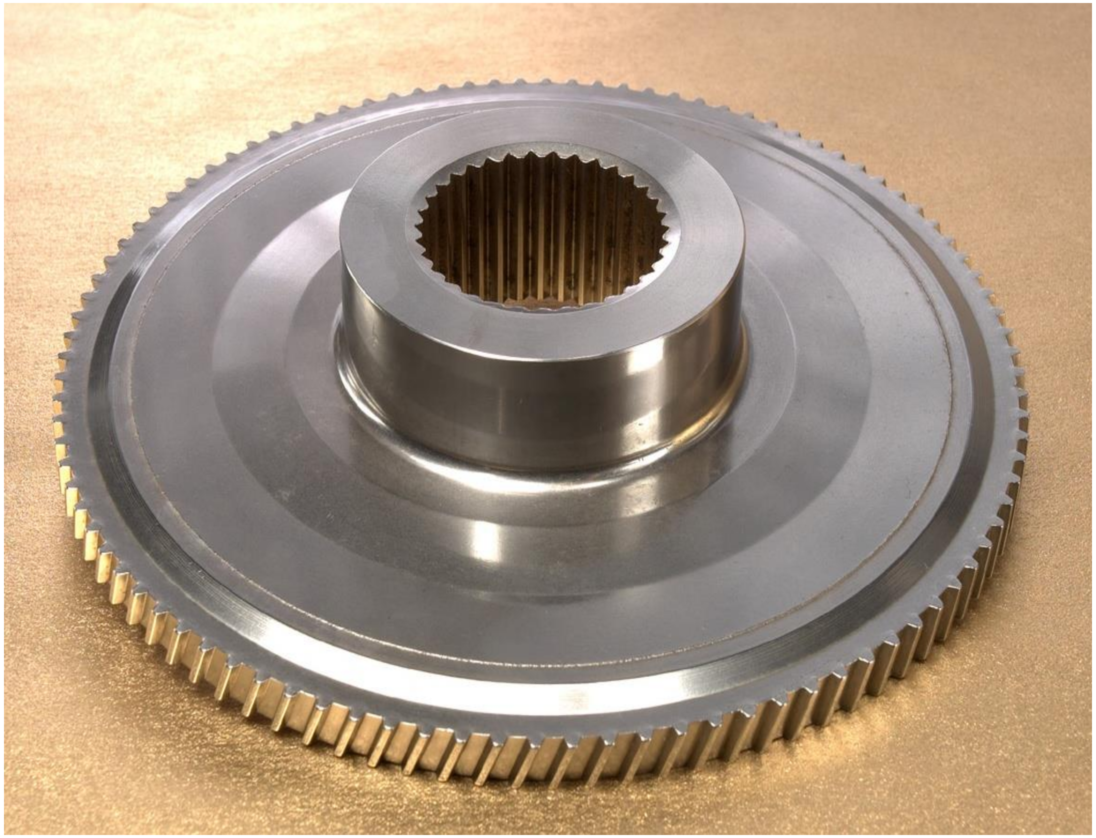


Basic steps of the Powder Metallurgy Process.

PM Parts

A collection of powder metallurgy parts.





Connecting Rods:
Forged on left; P/M on right

Powdered Metal Transmission Gear

- ***Warm compaction method with 1650-ton press***
- ***Teeth are molded net shape: No machining***
- ***UTS = 155,000 psi***
- ***30% cost savings over the original forged part***

Industrial Machines Parts

For Electric Motors

PM vs. Other Fabrication Methods
(casting, stamping or machining)

- PM is the choice when requirements for strength, wear resistance or high operating temperatures exceed the capabilities of die casting alloys.
- PM offers greater precision, eliminating most or all of the finish machining operations required for castings.
- It avoids casting defects such as blow holes, shrinkage and inclusions. Powder injection molding is coming out as a big challenge for investment casting.
- However the PM process is economical only when production rates are higher, since the tooling cost is quite appreciable

- The powder metallurgy methods starts with powders and the properties of the manufactured parts depend to a large extent on the properties of the initial powders.

  Amongst powder properties, composition, size, form and structure of particle, specific surface, porosity and volume characteristics, fluidity, strength, hardness, permeability regarding liquids and gases, electric conductivity, compressibility and sinterability are of great importance in powder metallurgy.

  Metal powders consist of separate small bodies—the so-called particles—from 0.1 μ up to several millimeters in size.
- In the majority of powders the size of particle varies from several microns to 0.5 mm.
  Particles usually have internal pores, cracks and impurities.

- Particle shape is widely varied and determined by the methods of production; the desired particle size is obtained by regulating the conditions of manufacture. Particles are divided according to their shape into three basic groups:

(1) hair or needle-shaped, the lengths of which considerably exceed their other dimensions;
(2) flat (flakes or leaves) whose length and breadth are many times greater than their thickness;
(3) equiaxed, which are roughly identical in all dimensions.

Powders of the same chemical composition, but with different physical characteristics, are sharply distinguished by technological properties, i.e. by their behaviour during processing.

Production methods and the fields of application for powders are determined with powder properties (shape,size)

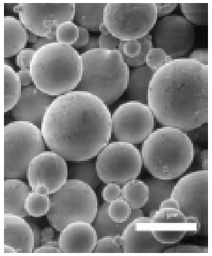
Example: copper powder with particles in the form offtakes (flat) up to 1 μ thick and up to 50μ in diameter are used only as a pigment since any articles made from it contain cracks after pressing.

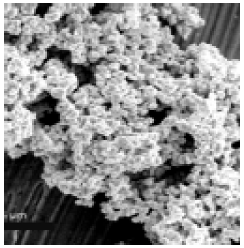
Copper powder with particles of spherical form (globules) from 100 to 700μ in diameter is pressed only at very high pressures.

A powder with irregularly shaped particles, so called dendritic, 40-45μ in size is easily pressed even at low pressures.

Powder Metallurgy Technology

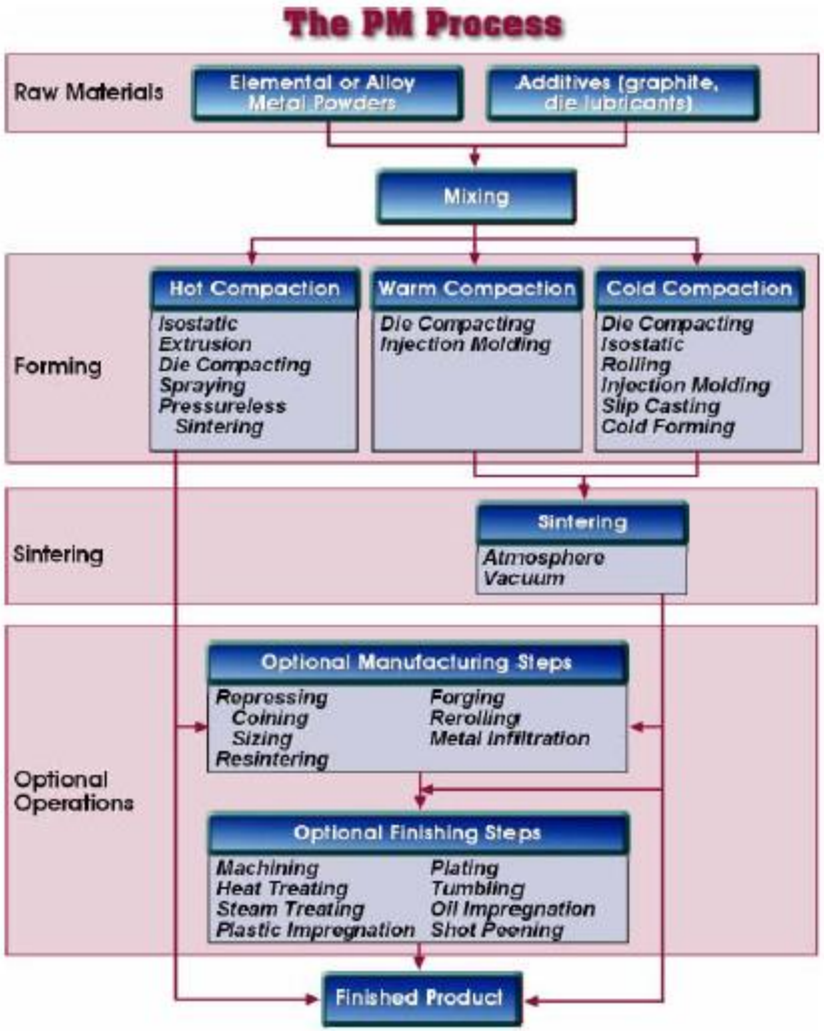
- General Classification
  - Powder Technology
  - Powder Processing
- Powder technology
  - It involves all processing operations to prepare the particles in the 100 µm range for subsequent shaping and consolidation processes.
    - Powder fabrication
      - Mechanical
      - Atomization
      - Electrolysis
      - Chemical synthesis
    - Particle classification
    - Particle handling, modification and mixing
  - Particle characterization and microstructure control are essential components of powder technology





Powder Metallurgy Technology (cont.)

- Powder Processing
  - It involves all operations to consolidate the particles to the final product
    - Shaping and compaction
    - Sintering
    - Densification
    - Finishing operations
      - Machining
      - Heat treatment
      - Joining
      - Coating
  - Selection of processing methods depends on desired properties of final product.



Why Powder metallurgy?

It the only near net-shape manufacturing technology capable of fabricating parts for all types of materials

- Metals and intermetallics
- Ceramics
- Engineered materials: Composites and porous materials

- Advantages
  - Achieves a wide variety of alloy systems
  - Facilitates manufacture of complex or unique shapes which would be impractical or impossible with other metalworking processes
  - Maintains close dimensional tolerances
  - Produces good surface finishes and eliminates or minimizes machining
  - Provides controlled porosity for self-lubrication or filtration applications
  - Suited to moderate-to-high volume component productions requirements

Applications

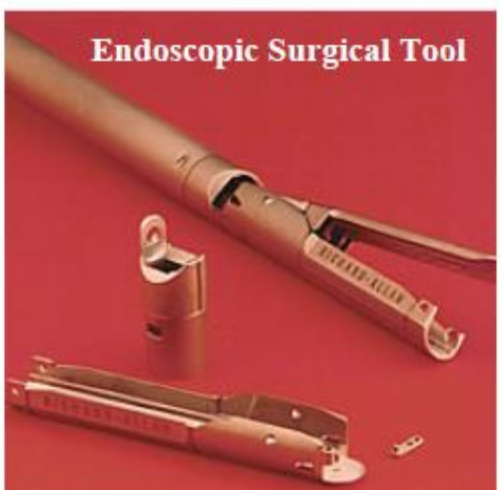
Powder metallurgy is used in various industrial sectors:

- Automobile industry (motors, gear assemblies, brake pads)
- Abrasives (polishing and grinding wheels)
- Manufacturing (cutting and drilling tools)
- Electric and magnetic devices (magnets, soft magnetic cores)
- Medical and dental (implants, prostheses, amalgams)
- Aerospace (motors, heat shields, structural parts)
- Welding (solder, electrodes)
- Energy (electrodes, fuel cells)
- Other (porous filters, sporting goods)

Example Applications

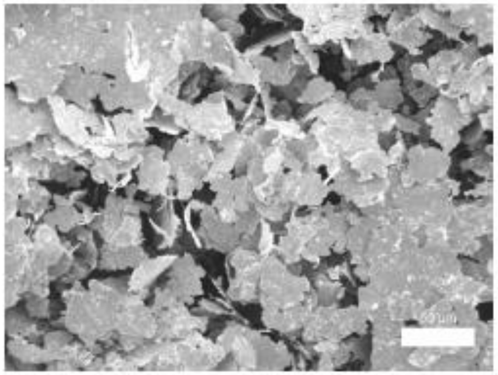
- Automotive

- Biomedical components

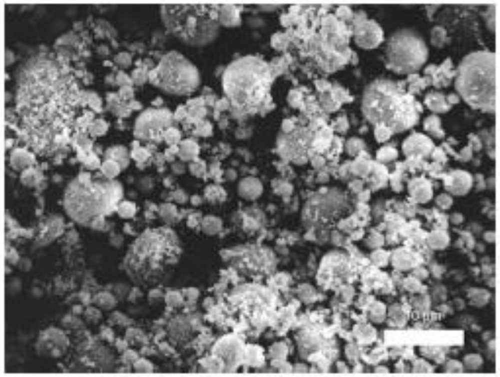


Powders and Particles

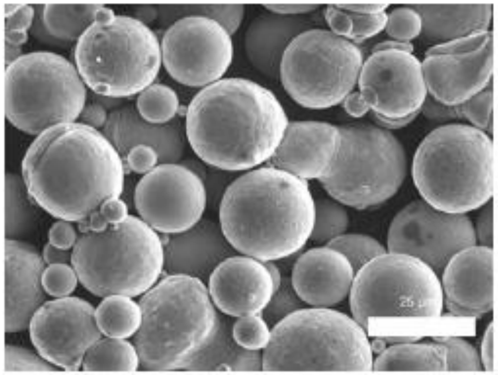
- A powder is a collection of finely dispersed solid particles smaller than 100 µm.
- The particle size of powders used in powder metallurgy ranges from 0.1 to 100 µm.
- The size and shape of the particles depends on
  - Materials chemistry
  - Powder production technique



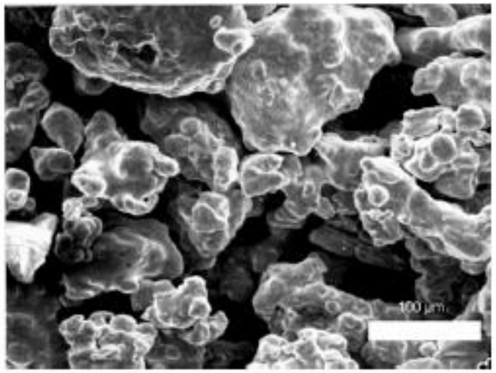
Tantalum flakes
50 µm width



Silicon nitride
Agglomerate
2 µm spheres



Stainless Steel
20 µm spheres



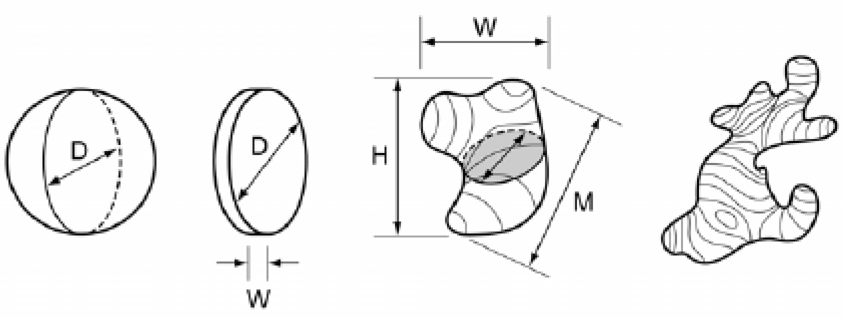
Iron irregular particles
100 µm long

Powder Characteristics

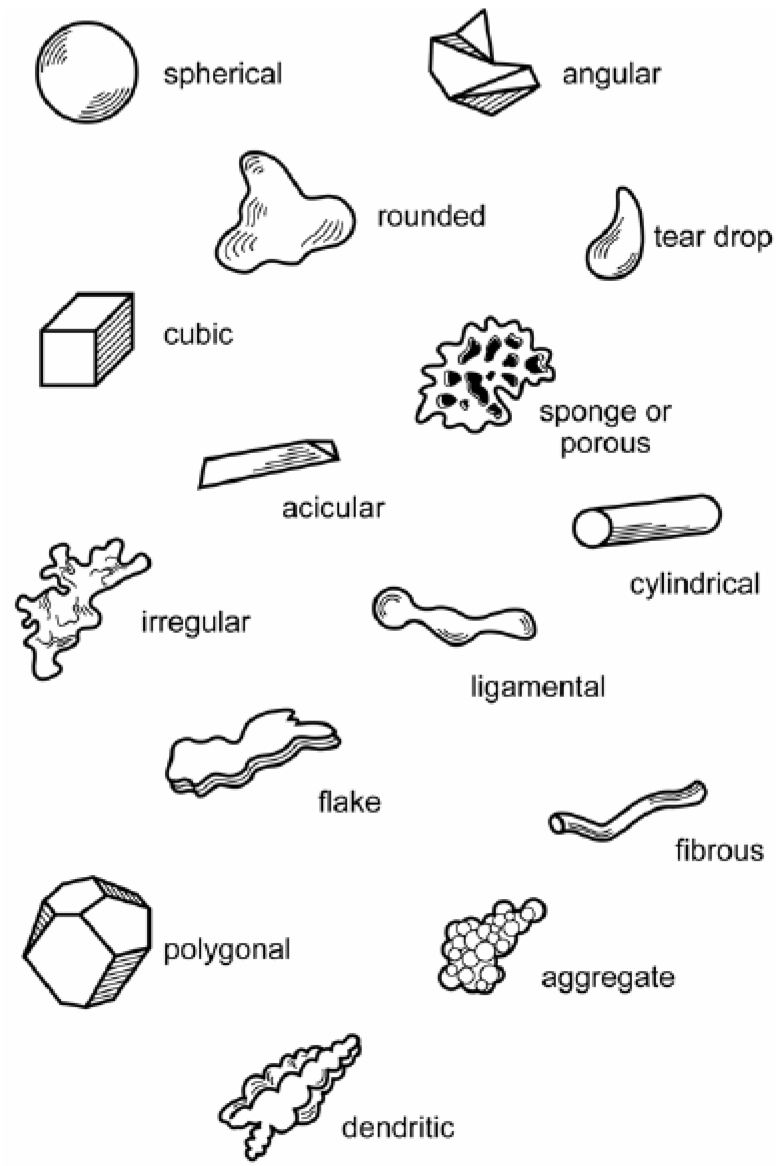
- Powder characteristics relevant to powder processing are:
  - Particle size and its distribution
  - Particle agglomeration
  - Surface area of particles
  - Interparticle friction
  - Particle flow and packing
  - Crystal Structure of the particles
  - Composition, homogeneity and contamination
- These characteristics must be measured and quantified to
  - Optimize powder fabrication process
  - Select powder processing route
  - Specify operating conditions of compacting, sintering and finishing processes.

Particle Size and Shape

- Most fabricated particles have complex shapes
- Particles size and shape influence packing, flow and compressibility of the powder.
- Characteristic dimensions of the particle depends on the shape of the particle

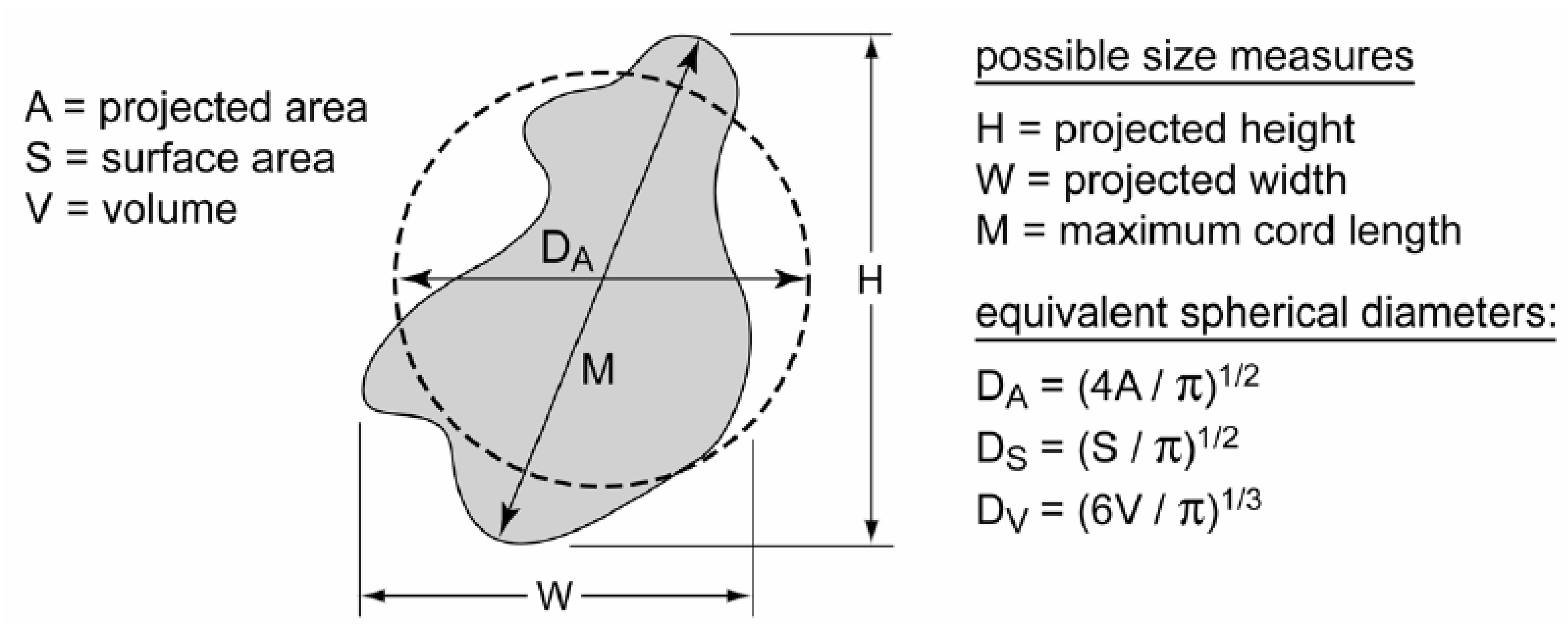


a) sphere b) flake c) rounded irregular d) irregular



Particle Size

- Several metrics are used to describe particle size. They are based on
  - Characteristic length of projected particle
    - Projected height
    - Projected width
    - Maximum cord length
  - Diameter of an equivalent sphere of the same
    - Projected area (Projected equivalent diameter, D_A)
    - Surface area of actual particle (Surface equivalent diameter, D_S)
    - Volume of actual particle (Volume equivalent diameter, D_V)

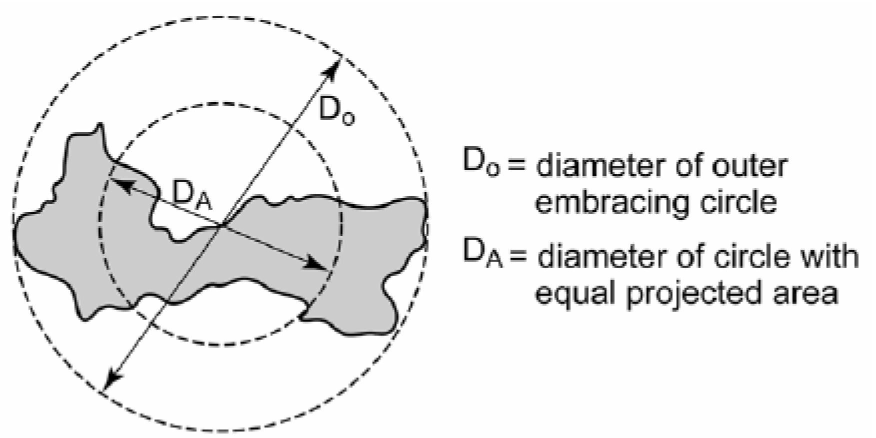


Particle Shape

- Most common descriptors of particle shape are main particle features (see figure of particle shapes), shape factor and aspect ratio.
- The shape factor, k, is defined as the particle surface area divided by the surface area of the same volume
  - The shape factor for a spherical particle is unity, and greater than one for other shapes
  - It is used to calculate specific surface area S (area per unit mass m^2/kg)

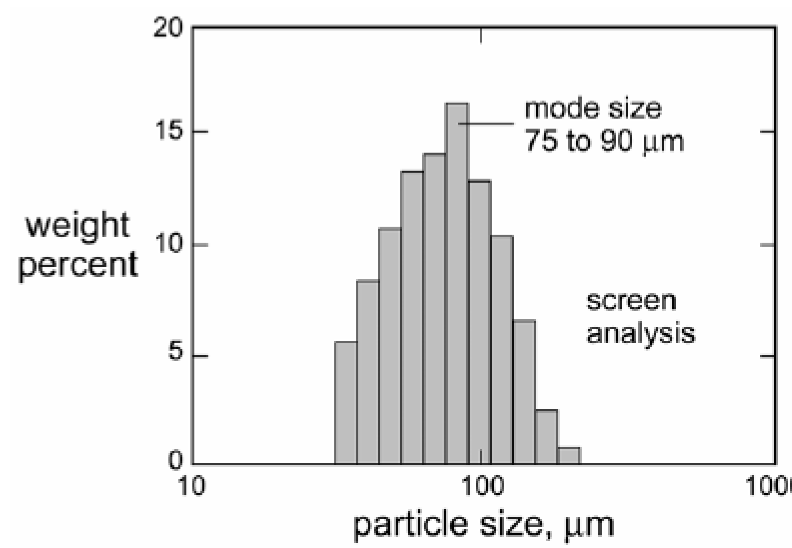
$$S = 6\,k / (\rho\, D_V)$$

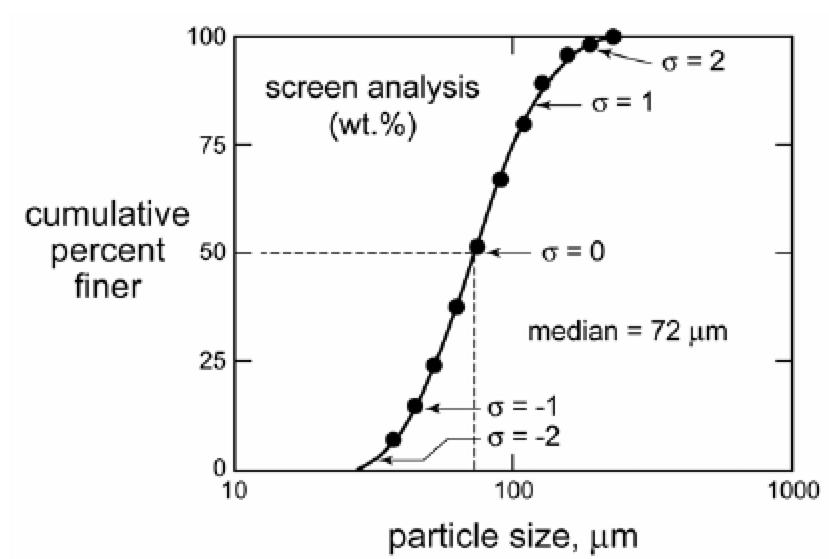
- The aspect ratio is described in terms of
  - Linear dimensions of projected particle (M/W)
  - Equivalent diameters of projected particle (D_O/D_A)



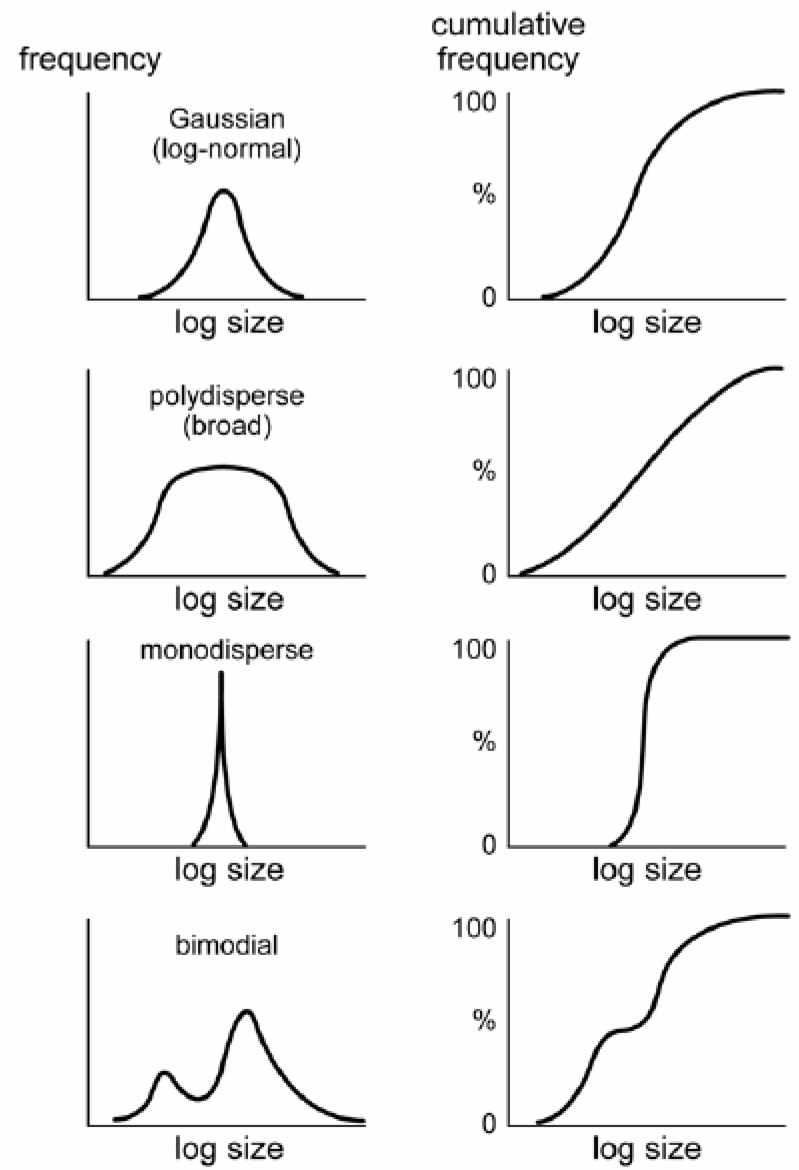
Particle Size Distribution

- The variation of particle size in a powder is described by a distribution function.
- The key parameters in the distribution function are a mean particle size and a standard deviation σ^2
- These two parameters are determined from measured amounts of all particle sizes in the powder





Types of Particle Distribution



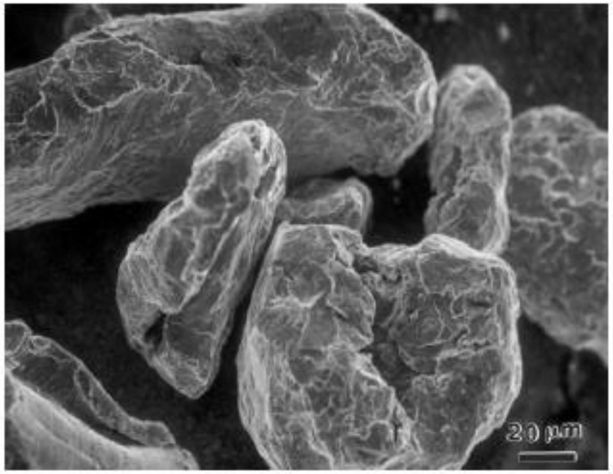
POWDER FABRICATION METHODS

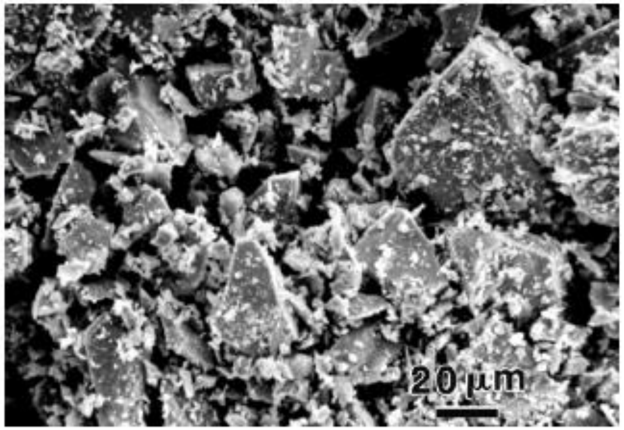
Powder Fabrication

- Powder manufacturing revolves around transforming bulk materials into finely dispersed pieces
- Powder manufacturing techniques
  - Mechanical Comminution
  - Chemical Synthesis
  - Electrolytic deposition
  - Liquid atomization
  - Vapor Condensation
- Energy efficiency (actual energy consumption/surface energy of particles) of these techniques is generally low, less than 5%.
- Selection Criteria
  - Type and properties of the material
  - Reactivity of the material
  - Desired characteristics of the produced powder
  - Rate of production and costs

Mechanical Powder Fabrication

- Powder production methods
  - Machining
    - Uses shear forces to chip bulk materials
    - Produced chips are quite large (mms in size)
  - Impaction
    - Disintegrate of bulk materials is by impact
    - It produce powders in mm size range
  - Attritioning
    - It involves grinding the material with another a harder material
    - Produce fine particles in 1 to 100 mm size range
  - Compression
    - Involves compressing the material to its breaking point
    - It is hardly used in powder fabrication





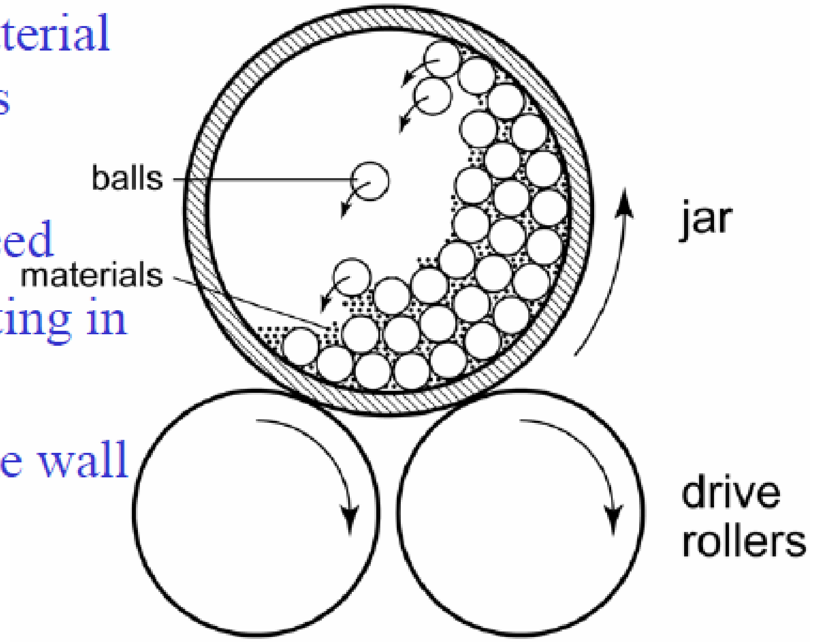
- Mechanical powder fabrication involves one or more of these techniques
- Powders produced by mechanical techniques are irregular in shape.

Machining

- Metalworking by traditional metal cutting processes such as turning on a lathe, and drilling produces large powder as a byproduct
- It is the cheapest method for producing large quantities of powders
- It lacks control of particle size and shape, and material structure.
- Powders produced by this method is generally not suitable for powder processing
- They are used as the feed material for other mechanical fabrication processes

Impaction Processes

- Milling
  - Milling refers to processes that use hard balls and rods to fracture particulate materials upon collision.
  - It is used for crushing brittle materials, such as carbides, oxides and intermetallics or embrittled metals such as saturated niobium with hydrogen.
  - The crushing system is essentially a cylindrical drum filled with balls or rods and the material and the drum rotates to produce collisions between falling balls and particles
  - The key process parameter is rotation speed
  - Slow rotation cause the balls to roll resulting in low impact forces
  - Fast rotation cause the balls to stick on the wall of the drum by centrifugal forces.



Milling

It is a mechanical method for powder production, where the initial material is pulverized without any change in chemical composition. Reduction of particle size is beneficial for sintering, which depends on diffusion of atoms.

Most common milling method is ball milling

- Generally balls are used for milling. Hardness of the balls must be equal or greater than the hardness of the powder will be milled.
- Amount and size of the balls are critical for the final powder size.
- Wet or dry milling can be applied.
- From balls or barrel impurities may added to the powder

(milling time and ball hardness)