Powder Metallurgy

<u>Unit I</u>

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INTRODUCTION

- Historical and modern developments in P/M.
- Advantages,
- Limitations and
- Applications of P/M

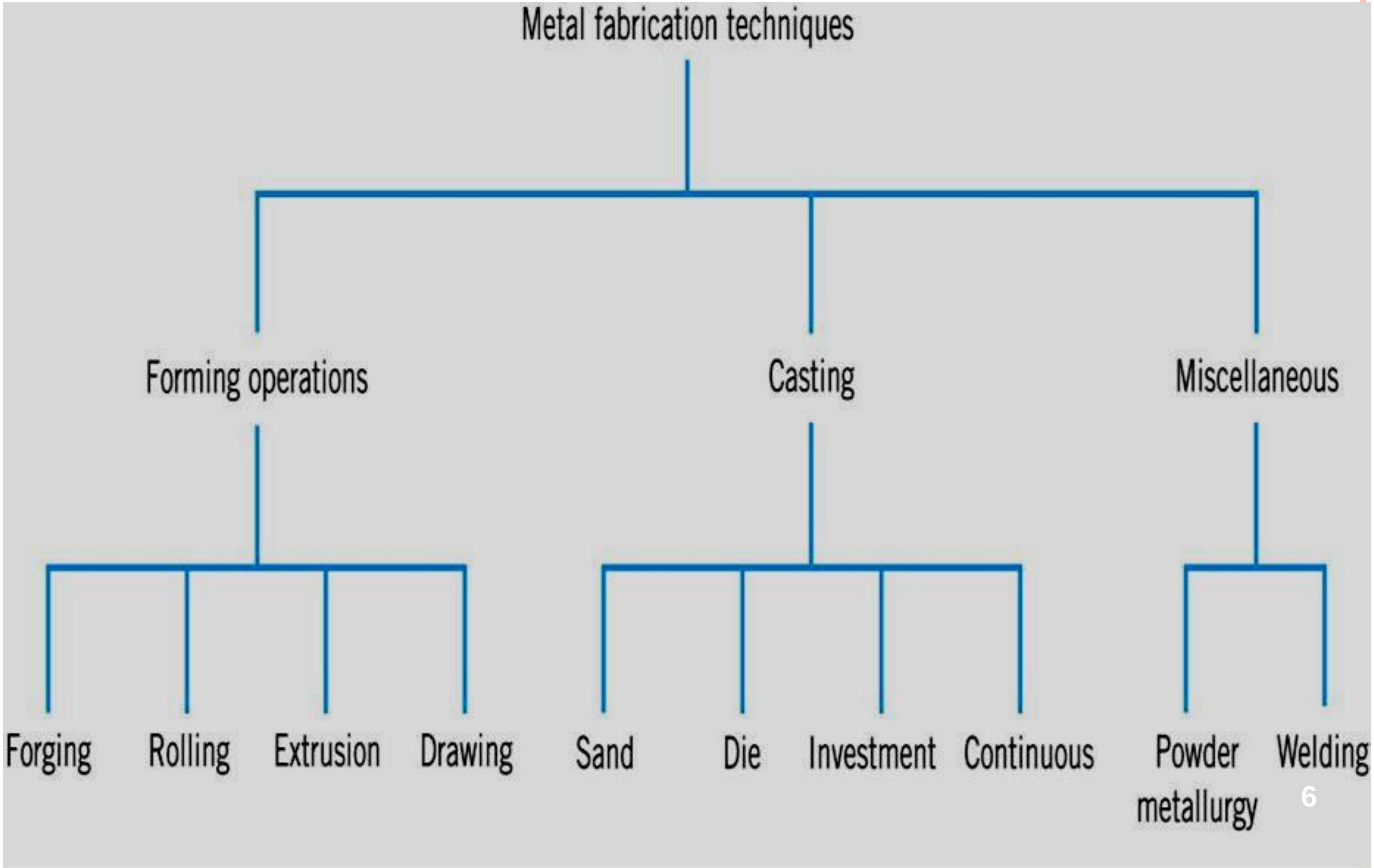
Historical and Modern Developments in P/M

Traditional Manufacturing Processes

- Casting
- Forming
- Sheet metal processing
- **Powder- and Ceramics Processing**
- Plastics processing
- Cutting
- Joining
- Surface treatment

- 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.

Classification of Metal Fabrication Techniques



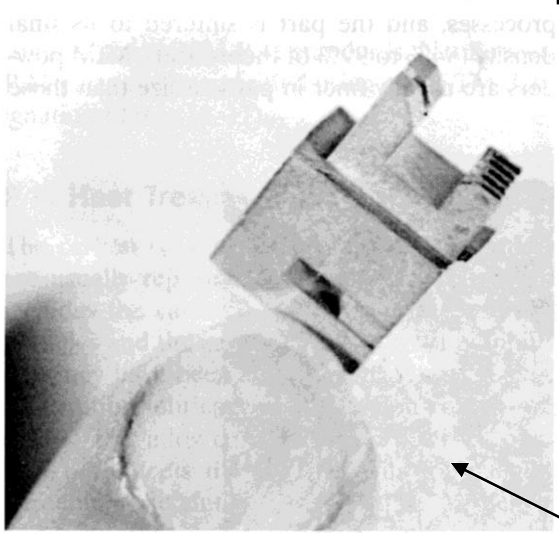
- Pressures of 10-50 tons per square inch are commonly used.
- Also, to attain the same compression ratio across more complex pieces, it is often necessary to use lower punches as well as an upper punch.
- Finally, the end part is formed by applying pressure, high temperature, long setting times (during which self-welding occurs), or any combination thereof.

- Two main techniques used to form and consolidate the powder are sintering and metal injection molding.
- Recent developments have made it possible to use rapid manufacturing techniques

  -which use the metal powder for the products.
- Because with this technique the powder is melted and not sintered, better mechanical strength can be accomplished.

Powder Metallurgy

- Powder metallurgy (P/M) is a process for fabricating metal parts from finely compacted metal powders.



Small detailed P/M Component.

Powder Metallurgy

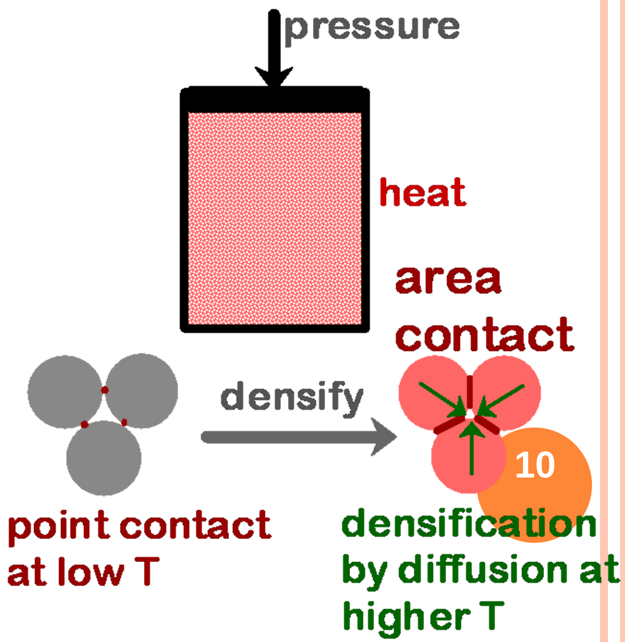
- A fabrication technique that involves the compaction of powdered metal, followed by a heat treatment to produce a more dense piece.
- Powder metallurgy is especially suitable for metals
  - having low ductilities
  - having high melting temperatures

Production of P/M Parts:

→ Preparation of Metal Powders

→ Compaction (pressing)

→ Sintering (densification) at elevated temp.



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

Examples of Powder Metal Products

- Gears
- Cams
- Connecting rods
- Crank shafts
- Bushings & Bearings
- Piston rings
- Light bulb filaments
- Cutting tools

Scope of PM process

- Components can be made from pure metals, alloys, or mixture of metallic and non-metallic powders

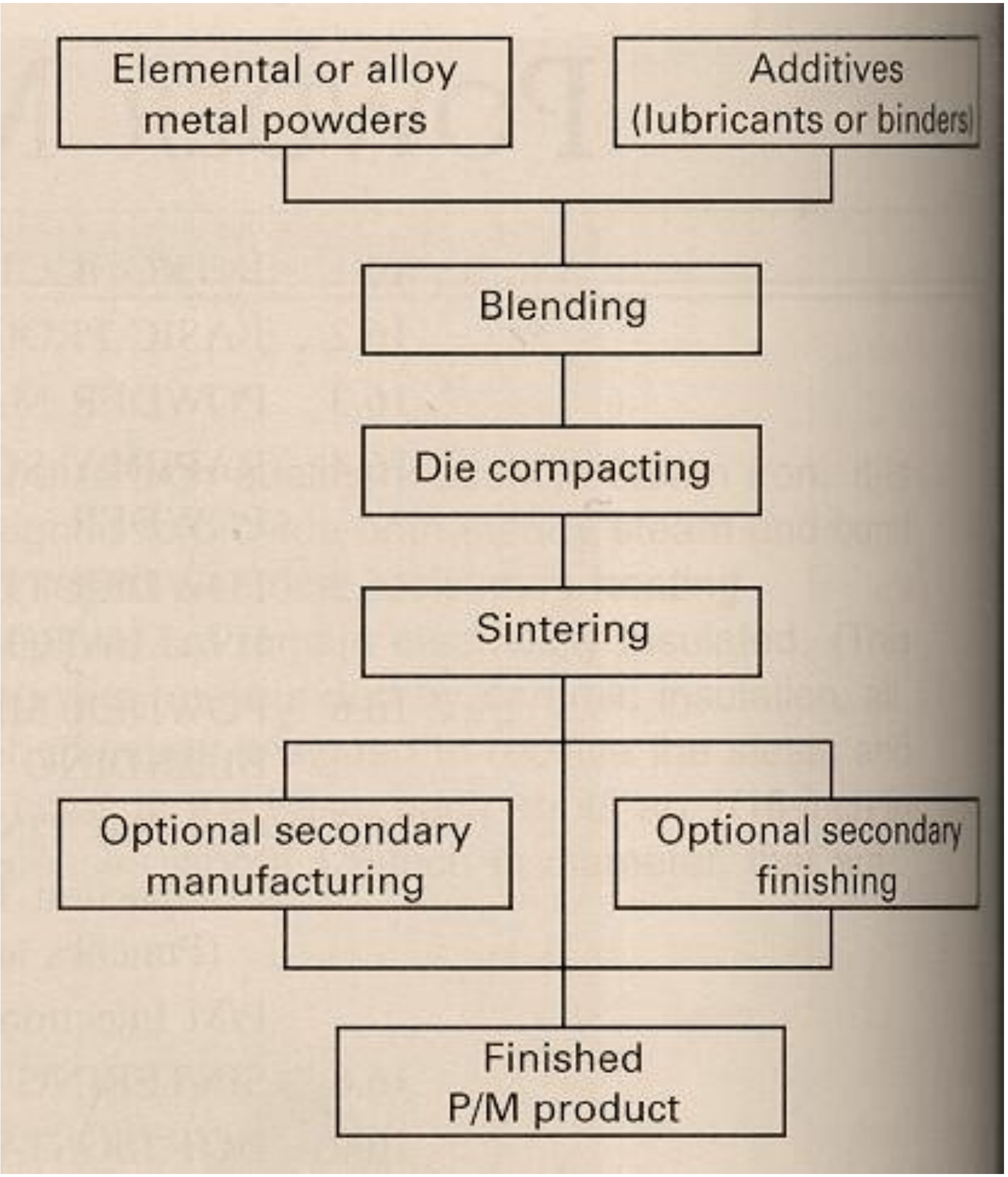
- Commonly used materials ar iron, copper, aluminium, nickel, titanium, brass, bronze, steels and refractory metals, etc.

CopperTin and Bronze Powders

PM PROCESS STEPS

- Powder production
- Blending
- Compaction
- Sintering
- Finishing / secondary Operations.
- PM Visuals

POWDER METALLURGY PROCESS

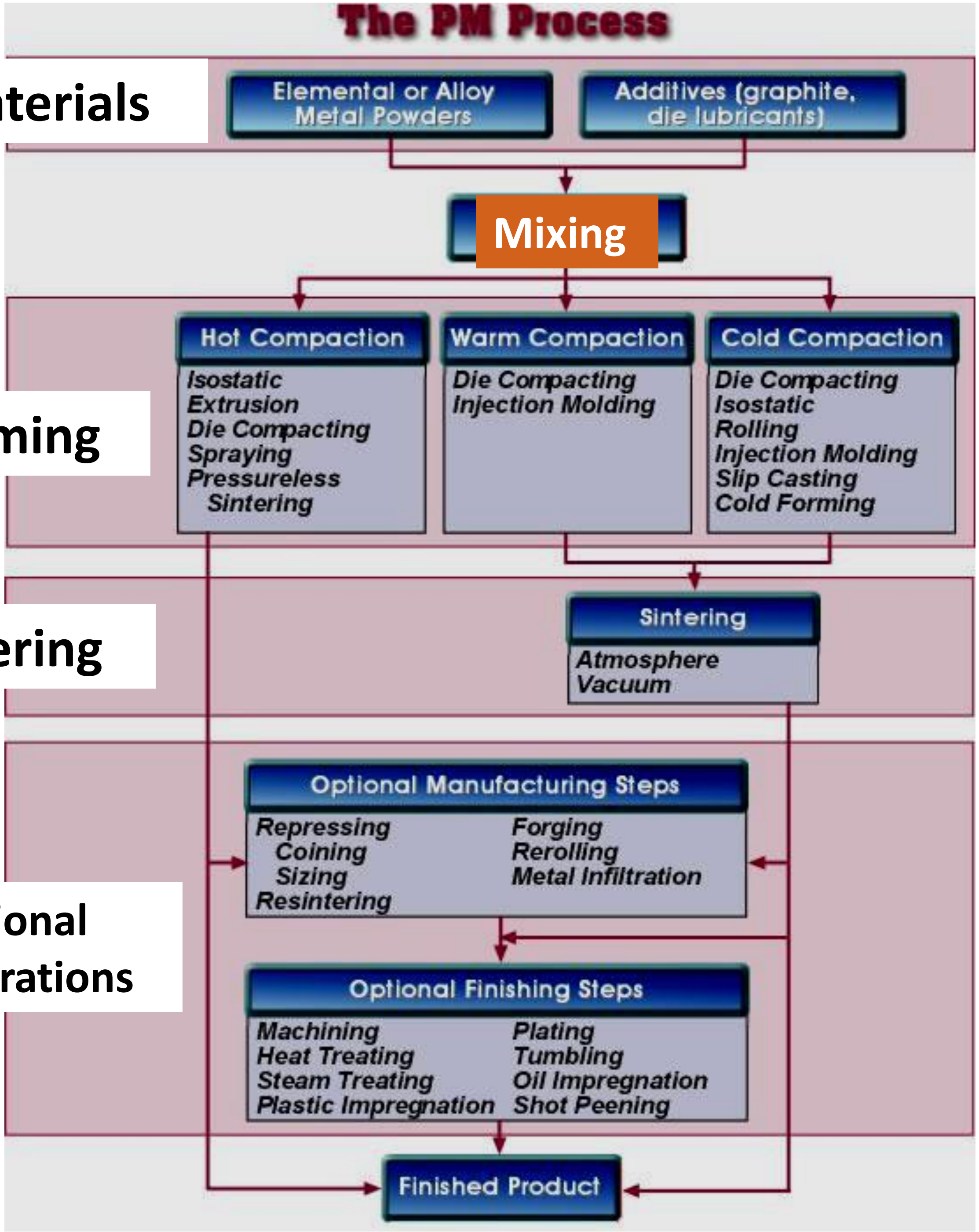


Raw Materials

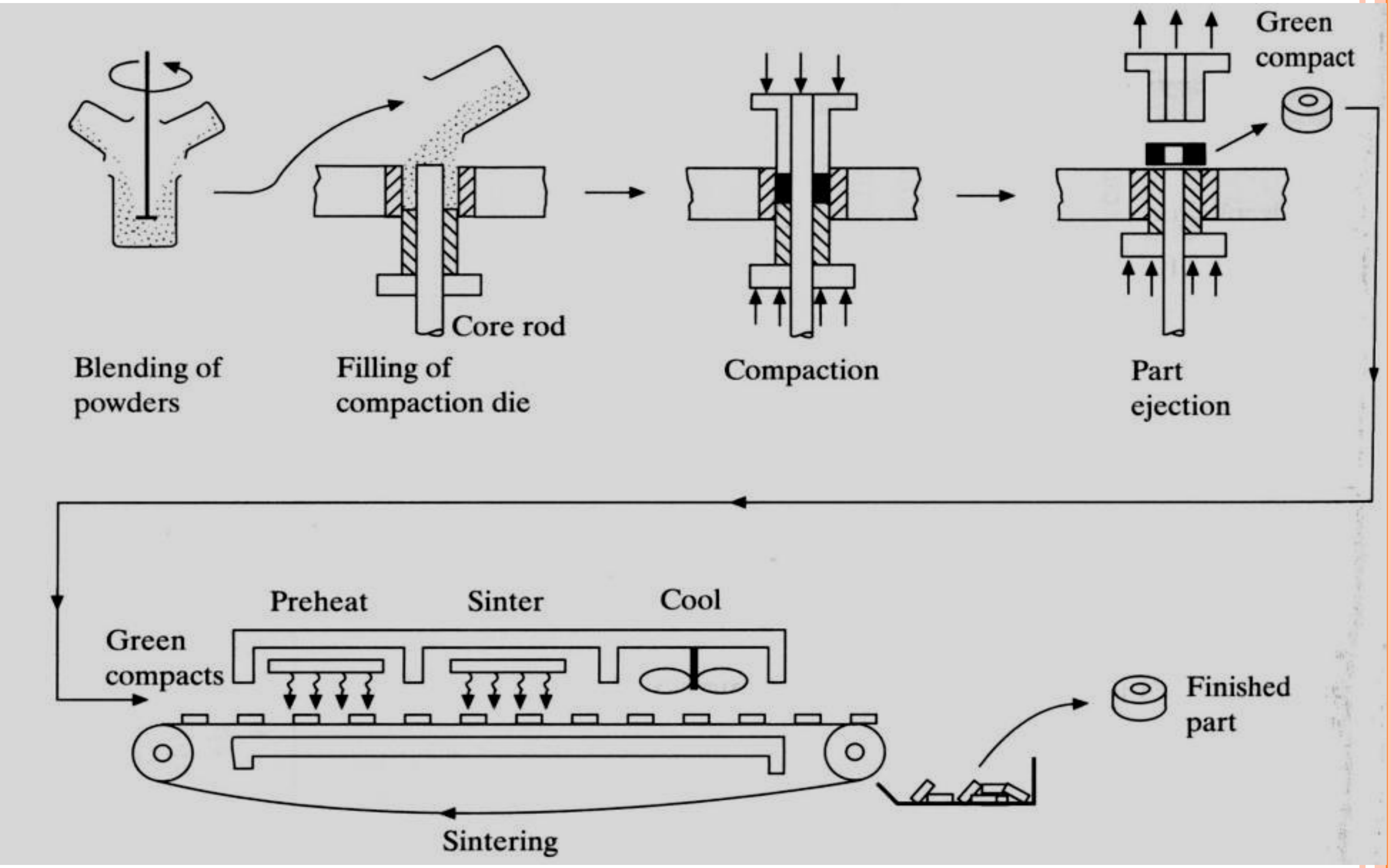
Forming

Sintering

Optional Operations



BASIC PROCESSING STEPS



History and capabilities

- The history of powder metallurgy and the art of metals and ceramics sintering are intimately related.
- Sintering involves the production of a hard solid metal or ceramic piece from a starting powder.
- There is evidence that iron (Fe) powders were fused into hard objects as early as 1200 B.C.
- In these early manufacturing operations, iron was extracted by hand from metal sponge following reduction and was then reintroduced as a powder for final melting or sintering.

- A much wider range of products can be obtained from powder processes than from direct alloying of fused materials.
- In melting operations the "phase rule" applies to all pure and combined elements and strictly dictates the distribution of liquid and solid phases which can exist for specific compositions.

- In addition, whole body melting of starting materials is required for alloying

  -thus imposing unwelcome chemical, thermal, and containment constraints on manufacturing.
- Unfortunately, the handling of aluminium/iron powders poses major problems.
- Other substances that are especially reactive with atmospheric oxygen, such as tin -are sinterable in special atmospheres or with temporary coatings.

- In powder metallurgy or ceramics it is possible to fabricate components which otherwise would decompose or disintegrate.
- All considerations of solid-liquid phase changes can be ignored -so powder processes are more flexible than casting, extrusion, or forging techniques.

- Controllable characteristics of products prepared using various powder technologies include

  -mechanical, magnetic, and

  -other unconventional properties of such materials as porous solids, aggregates, and intermetallic compounds.
- Competitive characteristics of manufacturing processing (e.g., tool wear, complexity, or vendor options) also may be closely regulated.

- Powder Metallurgy products are today used in a wide range of industries

  -from automotive and aerospace applications to

  -power tools and household appliances.
- Each year the international PM awards highlight the developing capabilities of the technology.

ADVANTAGES, LIMITATIONS AND APPLICATIONS OF P/M

Advantages of P/M

- The major advantages of P/M process include process, metallurgical and commercial advantages.

Process Advantages

Powder metallurgy offers the following important process advantages:

1. Eliminates or minimizes machining (little or no scrap).
2. Efficient materials utilization-above 95 % material utilization.

3. Enables close dimensional tolerances- near-net shapes possible.

4. Produces good surface finish.

5. Provides option for heat-treatment, for increasing strength or enhanced wear resistance and plating for improving corrosion resistance.

6. Facilitates manufacture of complex shapes which would be impractical with other metal working processes.

7. Suited to moderate to high-volume component production requirement.
8. Components can be produced at reduced cost as compared to many other processes, i.e. cost-effective.
9. Components of hard materials which are difficult to machine can be readily manufactured, e.g. tungsten wires for incandescent lamps.

10. It is possible to produce components in pure form. Purity of the starting materials can be preserved throughout the process, a requirement for many critical applications.
11. Energy-efficient.
12. Environment-friendly.

Metallurgical Advantages

Powder Metallurgy enables the production of:

1. Powders with uniform chemical composition with the desired characteristics, resulting from the absence of segregation during solidification. These characteristics will be reflected in the finished part.
2. Elemental and prealloyed powders.
3. Unique compositions including non-equilibrium compositions and microstructures (crystalline, nanocrystalline and amorphous).

4. Wide variety of materials-metals and alloys of miscible and immiscible systems, refractory metals like tungsten and molybdenum, ceramics, polymers and composites.
5. Parts with controlled porosity.
6. Materials with improved magnetic properties.

Commercial Advantages/Special Characteristics of Powder Metallurgy parts

Important commercial advantages of P/M include:

1. Ferrous and nonferrous powder metallurgy parts can be oil-impregnated to function as self-lubricating bearings.

   Similarly, parts can be resin-impregnated to seal interconnected porosity to improve density, or

   they can be infiltrated with a lower melting point metal for greater strength and shock resistance, and for making electrical contacts.

2. Parts can be heat-treated and plated if required. P/M parts are also amenable to processing by conventional metal forming processes like rolling and forging.
3. Cost-effective production of simple and complex parts, very close to final dimensions at production rates that can range from a few hundreds to several thousand parts per hour.
4. Offers long-term performance reliability in critical applications.

Advantages of Powder Metallurgy Processing over Conventional Material Processing

The main advantages of P/M processing over conventional material processing methods such as casting, forging, rolling may be classified as follows:

1. Improved microstructure resulting in property improvements as well as materials with novel microstructures.

2. Materials such as cemented carbides, refractory metals, oxide dispersion strengthened materials, friction materials, porous materials can be produced by P/M route alone.

3. Improved product economics.

4. Energy conservation and high level of material utilization.

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

Limitations of P/M

There are numbers of limitations of Powder Metallurgy process as given below:

1. In general, the principal limitations of the process are those imposed by the size and shape of the part, the compacting pressure required and the material used.
2. The process is capital intensive and initial high costs mean that the production ranges in excess of 10,000 are necessary for economic viability (cost of dies is very high).
3. The configuration of the component should be such that it can be easily formed and ejected from a die, undercuts and re-entrant angles can not be molded and have to be machined subsequently.

4. The capacity and stroke of the compacting press and the compacting pressure required limit the cross-sectional area and length of the component.
5. Spheres cannot be molded and hence a central cylindrical portion is required.
6. All materials which can be satisfactorily cold-worked by conventional methods have been produced (e.g. brass up-to 30 % Zn and bronzes up-to 10 % tin). Copper-based materials which are hot-worked have not so far been made by P/M successfully.

Design Considerations for P/M Components:

1. Avoid sharp corners and thus the corners have to be either radiused or chamfered.
2. As under-cuts and re-entrant angles cannot be molded into the component, these have to be machined subsequently.
3. The inability of the powder metallurgy process to introduce cross holes. Such features would have to be machined using a post processing step.

4. To prevent excessive wear of the tools chamfers greater than 45 degrees are preferred, but in case of less than 45 degrees lands are required.
5. Punches less than 1 mm be avoided.
6. Large sectional changes should be avoided as far as possible as they may lead to the cracking of the green component at the change in section through transfer of metal powder into the wide section during the compaction processes.

7. The practical minimum diameter which can be easily molded is about 2 mm and holes running parallel to the direction of pressing should normally have a length to diameter ratio of 4 : 1.
8. Groves are generally molded into the top face of the component and these should not extend to more than 30 % of the total length.
9. Tolerances on sintered components can be improved by sizing at extra cost as per design requirements.

- Tolerances after sintering are generally equivalent to those obtained by turning, milling, etc.
- But after sizing these may be considered equivalent to medium grinding or broaching.

Applications of P/M

- Powder Metallurgy (P/M) is an improved alternative method as compared to Industrial Metallurgy (I/M) being more economical for large production series with precision of design and savings of energy, material and labor.
- Further it is a unique method for producing cermets, cutting tools, nuclear fuel elements, self- lubricating bearings, copper-graphite brushes, automobile parts, etc.

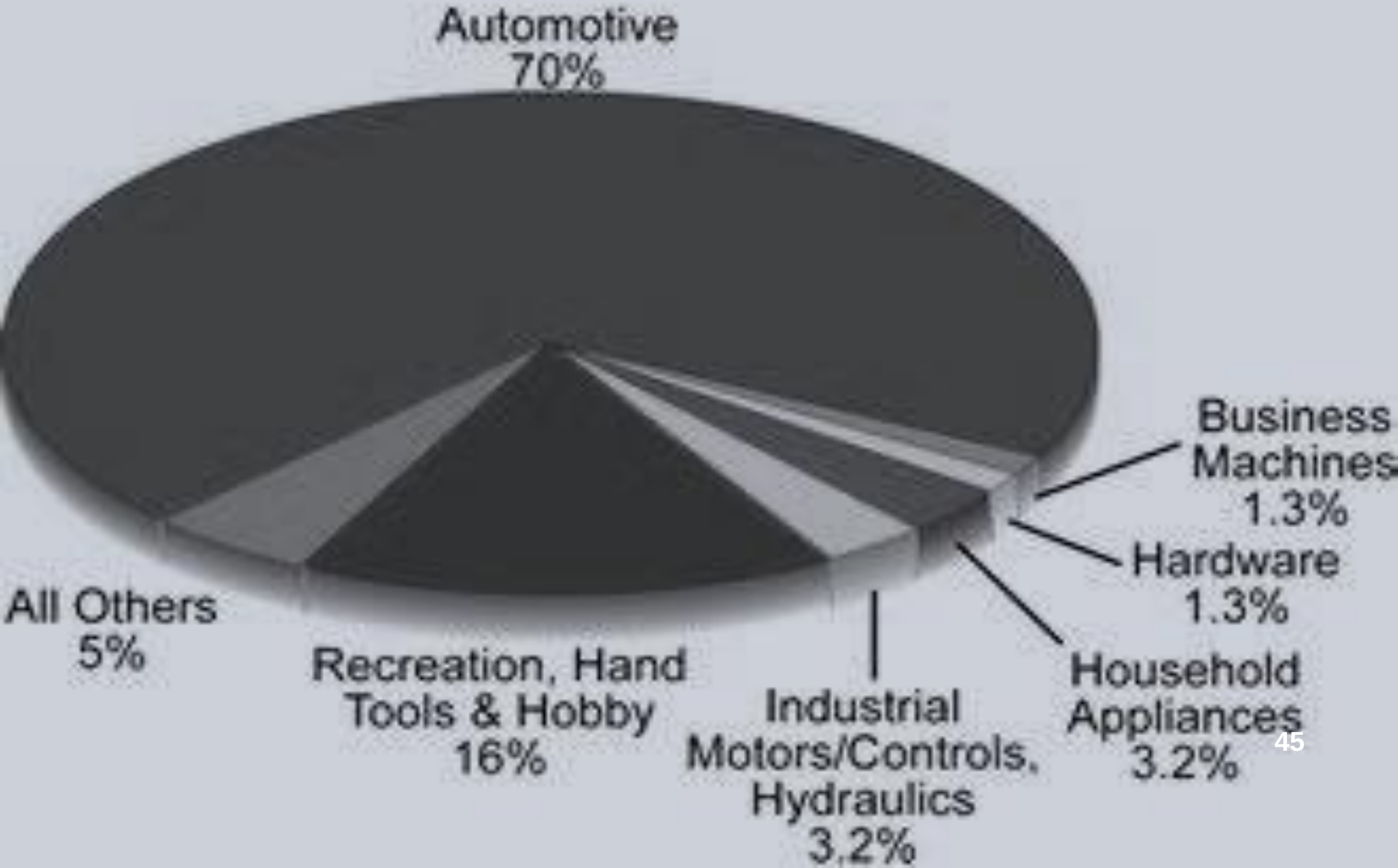
PM markets

- PM components are used in a variety of markets (see figure below)

  -with the automotive industry being the predominant one, consuming approximately 70% of the ferrous products the industry produces annually.

  -Other important markets include recreation, hand tools, and hobby products; household appliances; industrial motors and controls; hardware; and business machines.

PM Structural Components Markets



- In the automotive applications engine and transmission components are particularly important, accounting for at least 70% of total automotive usage.
- Engine applications include:

  -Engine timing pulleys, sprockets and hubs.

  -Valve train parts, valve seat inserts, valve guides, valve timing control and coupling devices.

  -Balancer gears

  -Main bearing caps

  -Engine management sensor rings

  -Oil and water pump gears.

- Transmission applications feature in both manual and automatic transmissions:

  -Synchronizer system parts

  -Clutch hubs

  -Gear shift components

  -Planetary gears and carriers

  -Turbine hubs

  -Clutch and pocket plates.

PM parts feature in other automotive systems:

- Shock absorber components - piston rod guides, piston valves and end valves
- Anti-lock Braking System (ABS) sensor rings
- Exhaust flanges and oxygen sensor bosses (a major application for PM stainless steel parts)
- Gears and bearings in small electric motors
- Door lock parts.

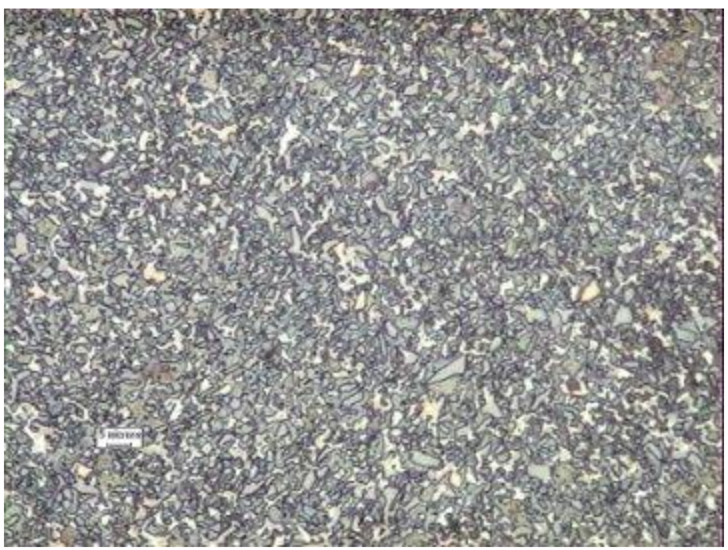
Typical gears manufactured by Stackpole Ltd.

P/M net-shape gears are common, save machining time

- Powder Metallurgy:
- Cermet cutting tools
- (Ceramic-Metal composite)

Cermet cutting inserts for lathe

Microstructure: ceramic particles in metal matrix



Cermet-tipped saw blade for long life

- Powder Metallurgy:
  Porous Metals

Slightly porous appearance is common

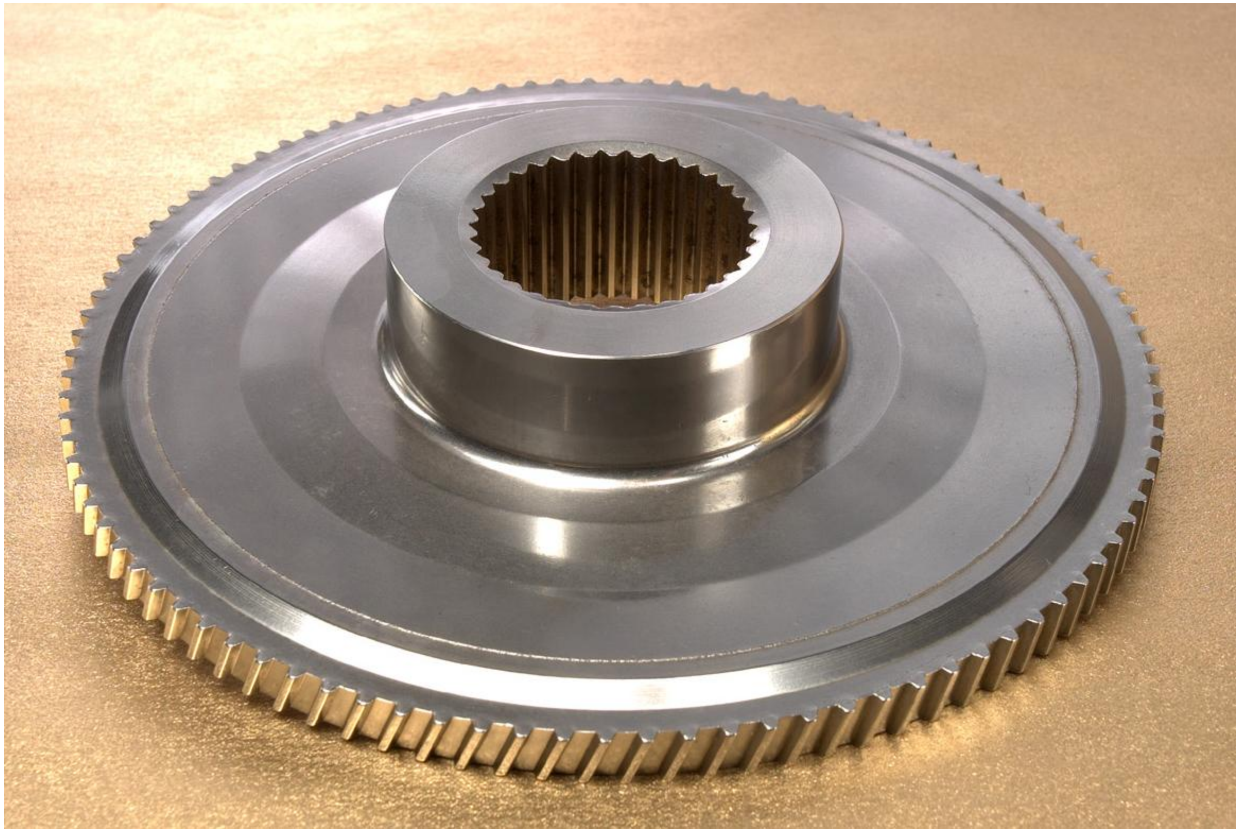
Oil-impregnated Porous Bronze Bearings

Metal filters

- Powder Metallurgy: Connecting Rods

Forged on left; P/M on right

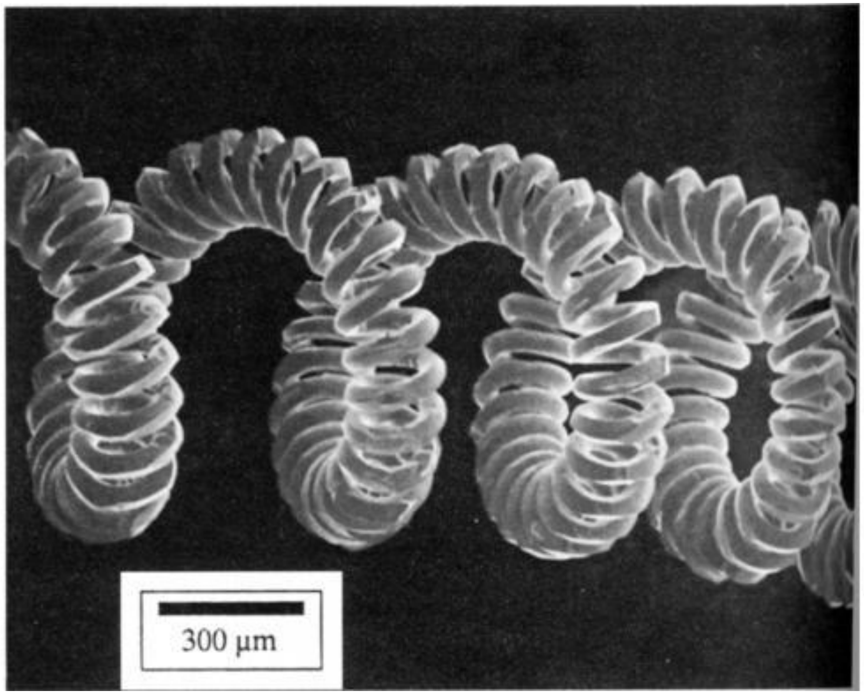
Powdered Metal Transmission Gear

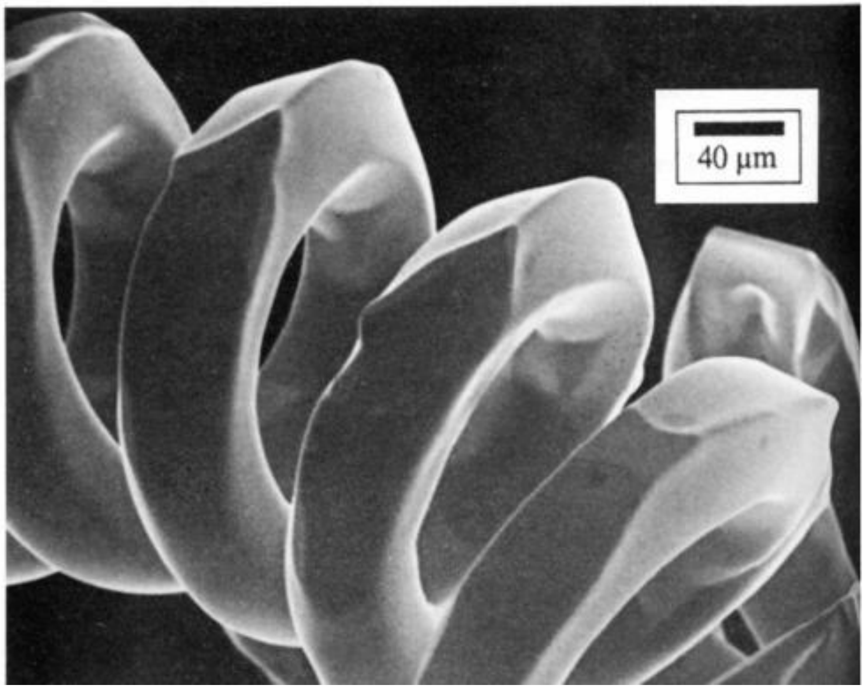


- Warm compaction method with 1650-ton press
- Teeth are molded net shape: No machining
- UTS = 155,000 psi
- 30% cost savings over the original forged part

- Powdered Metal Turbine blade-disk ("blisk"): 1 piece!

•P/M Tungsten Light bulb Filament





Motor Cycle Parts

Vehicles Engine Parts

INDUSTRIAL MACHINES PARTS

Industrial Machines Parts

Industrial Machines Parts

Industrial Machines Parts

For Electric Motors

Characteristics of metal powder

- Particle size, shape and size distribution.
- Characteristics of powder mass such as:
  - Apparent density
  - Tap density
  - Flow rate
  - Friction conditions.
- Properties of green compacts and sintered compacts.

Particle size, shape and size distribution

Introduction:

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.

Powder Characteristics:

- The further processing and the final results achieved in the sintered part are influenced by the characteristics of the powder:

  -particle size,

  -size distribution

  -particle shape,

  -structure

  -and surface condition.

Effect of powder characteristics :

- For a good compaction,

  1) irregular shaped particles are preferred as they give better interlocking and hence high green strength,

  2) apparent density of powders decides the die fill during compaction. Hence powder size, shape & density affect the apparent density,

  3) flow rate affects the die fill time, and once again powder size, shape & density affect the flow rate.

Particle size

- The particle size has a great importance in P/M because it affects most of the properties such as

  -mould strength,

  -density of compact,

  -porosity,

  -expulsion of trapped (occluded) gases,

  -dimensional stability,

  -agglomerations

  -Flow and mixing characteristics.

- *Particle size* is controlled by passing the metal powder through screens of various mesh sizes, called *screening*.
- Other methods for particle-size analysis are:

1. Sedimentation
2. Microscopic analysis
3. Light scattering
4. Optical methods
5. Suspending particles

<u>Measuring Particle Size</u>

- 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

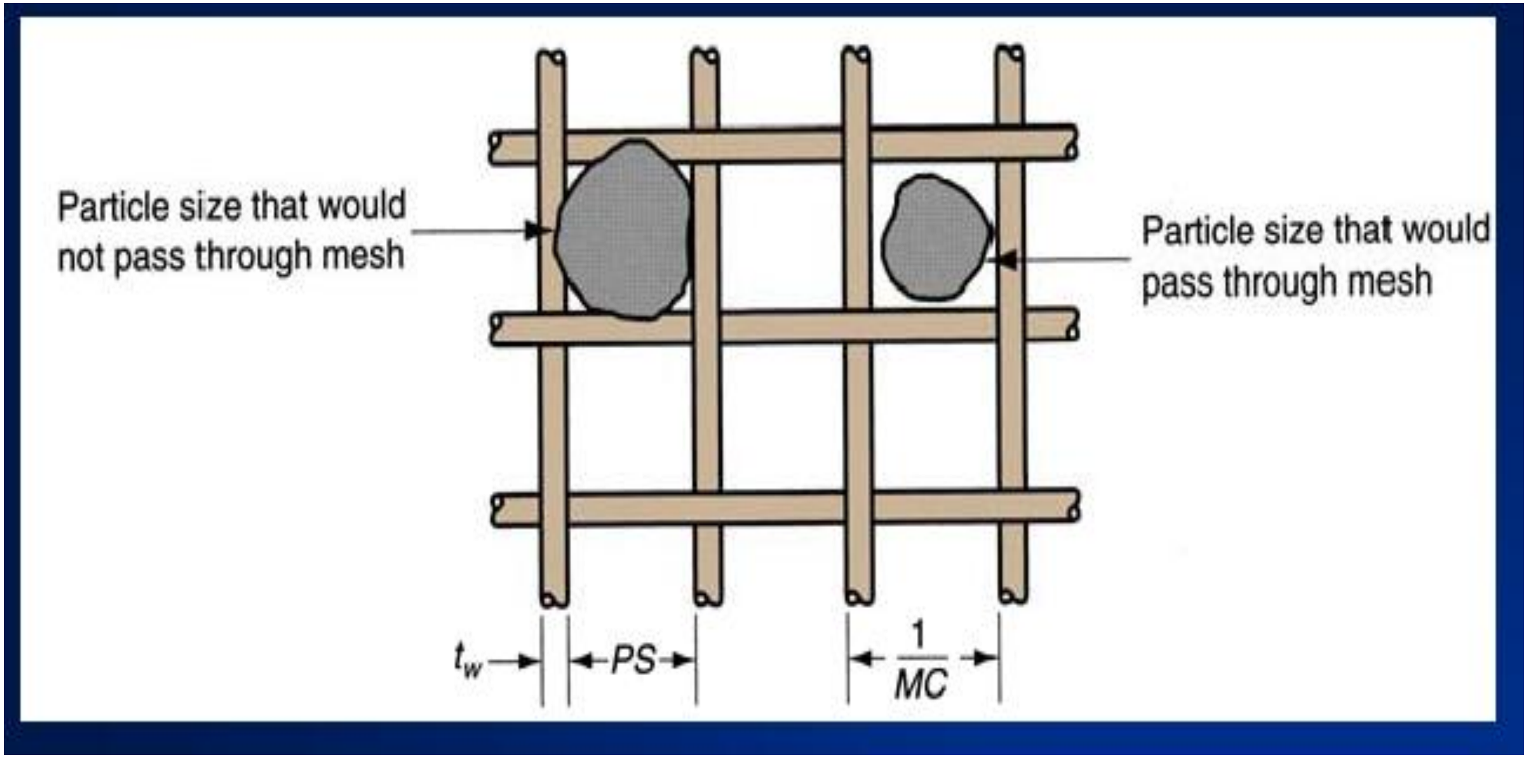


Fig. 2.1 Screen mesh for sorting particle sizes

- In practical P/M metal powders are divided into three distinct classes:

  1. Sieve
  2. Sub-sieve
  3. Sub-micron (or ultrafine).

- The screen with the opening of finest standard mesh-sieve for production purposes is the 325 mesh screen having the aperture of 44 micron.

- Sub-sieve particles are smaller than the aperture of such a screen but greater than 1μ.
- This class of powder is used for the production of refractory metals, hard carbides and magnetic cores.
- As the name suggests, the sub-micron powder particle size is smaller than 1μ and

  -it is used for the manufacture of dispersion strengthened high temperature alloy, bearing and micro porous components, magnetic materials, nuclear reactor fuels.

- Sieve size powders are used for most ordinary mass production because of their good flow ability and lack of further processing requirement such as granulation.
- Majority of metal powders employed in powder metallurgy industry vary in size from 4 to 200 microns.
- Powders of sub-micron size have been developed and used for the production of many powder metallurgical parts particularly dispersion strengthened materials, etc.

Other Screening Methods

- Sedimentation
  - Involves measuring the rate at which particles settle in a fluid
- Microscopic Analysis
  - Includes the use of transmission and scanning electron microscopy
- Optical
  - Particles block a beam of light and then sensed by a photocell
- Light Scattering
  - A laser that illuminates a sample consisting of particles suspended in a liquid medium
  - The particles cause the light to be scattered, and a detector then digitizes and computes the particle-size distribution
- Suspending Particles
  - Particles suspended in a liquid and then detected by electrical sensors

METHODS OF MEASUREMENT - ADVANTAGES AND DISADVANTAGES

- ***Sieves***
- An old fashioned, but cheap and readily usable technique for large particles, such as those found in mining and some food processing applications. It allows separation into some size bands if required.
- Using this technique it is not possible to measure sprays or emulsions and dry powders under 38μm are difficult. Cohesive and agglomerated materials, such as clays, are also difficult to measure and materials like 0.3 μm TiO_2 are impossible.

- The longer the measurement times the smaller the answer, as particles orient themselves to fall through the sieve.
- It is a low-resolution method and usually only four to five size classes are provided.

Sedimentation

- This is the traditional method in the paint and ceramics industries and uses wide range of equipments.
- However, as the density of the material is needed, it is no good for emulsions where the material does not settle, or for very dense material that settles too quickly.
- Temperatures also require close monitoring in order to control viscosity. A 1°C change in temperature will produce a 2% change in viscosity.

- Other disadvantages include slowness of measurement, which makes repeat measurements tedious.
- Irregularly shaped particles, such as disc-shaped kaolins, take even longer to settle due to their increased drag compared with spherical particles.
- The technique also has a limited range, with particular difficulties below 2 μm and above 50 μm.

ELECTROZONE SENSING

- This technique was originally developed for sizing blood cells. For industrial materials it has many drawbacks.
- It works on the principle of measurement of change in capacitance as the charged particles flow through a small orifice.
- It is difficult to measure emulsions and impossible to measure sprays.

- Dry powders require suspension.
- Measurement must take place in an electrolyte, which creates difficulties for organic materials, and the method requires calibration standards that are expensive and change size in distilled water and electrolyte.
- It is slow for materials of relatively wide particle size and it is not easy to measure particles below 2μm.
- Porous particles and dense materials pose additional problems

Microscopy

- This is an excellent technique that allows direct examination of the particles in question, and one that is relatively cheap.
- However, it is not suitable as a quality or production control technique beyond the level of simple judgement.
- Also, as relatively a few particles are examined, there is a real danger of unrepresentative sampling and if weight distribution is measured results are magnified.
- Missing one 10 µm particle has the same effect as missing one thousand 1m m particles.

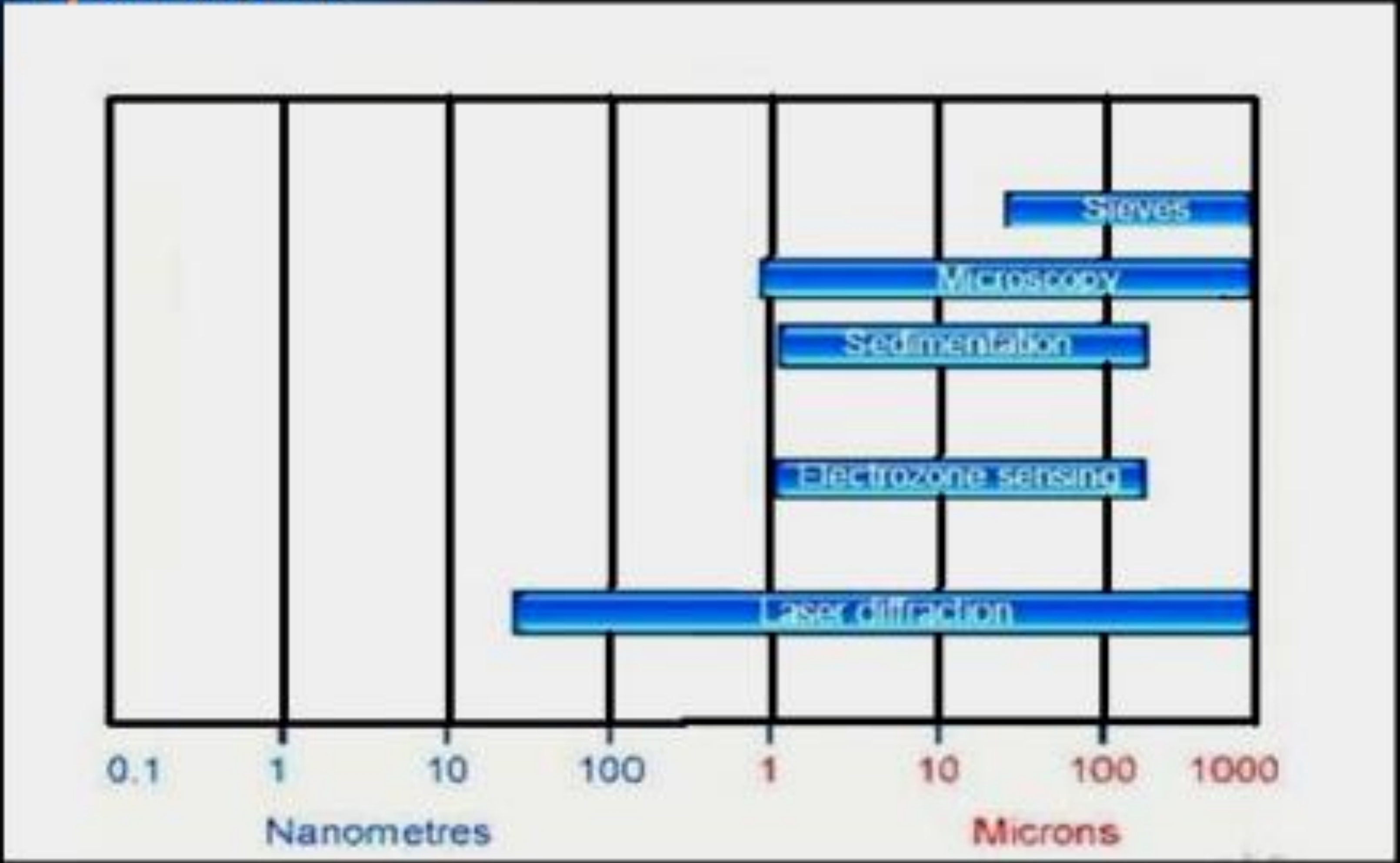
- The National Bureau of Standards (NBS) recommends that a minimum of 10,000 images (not particles!) must be examined for statistical validity.
- Sample preparation for electron microscopy is laborious and slow, and for manual methods fewer particles are examined.

Laser diffraction

- More accurately called low angle light scattering (LALLS), laser diffraction is becoming the preferred standard in many industries for characterization and quality control.
- It offers a wide dynamic range and is very flexible.
- Dry powders can be measured directly and liquid suspensions and emulsions can be measured in a re-circulating cell.
- This gives high reproducibility and enables the use of dispersing agents and surfactants for the determination of primary particle size.

- LALLS in non-destructive and non-intrusive and a volume distribution is generated which is equal to the weight distribution where density is constant, making it of direct relevance to chemical engineers.
- Other benefits are rapidity, with answers in under a minute; repeatability for reliable results; and high resolution. There is no need to calibrate against a standard, but equipment performance can be easily verified.

Methods applied for the size range of particles:



Disadvantages of other methods:

- **<u>Sieves</u>:** This is readily usable for large particles such as are found in mining.Not possible to measure sprays or emulsions. Cohesive and agglomerated materials e.g. clays are difficult to measure.
- **<u>Sedimentation</u>:** This has been the traditional method of measurement in the paint and ceramics industry and gives relatively low answers!

The applicable range is 2-50 microns.

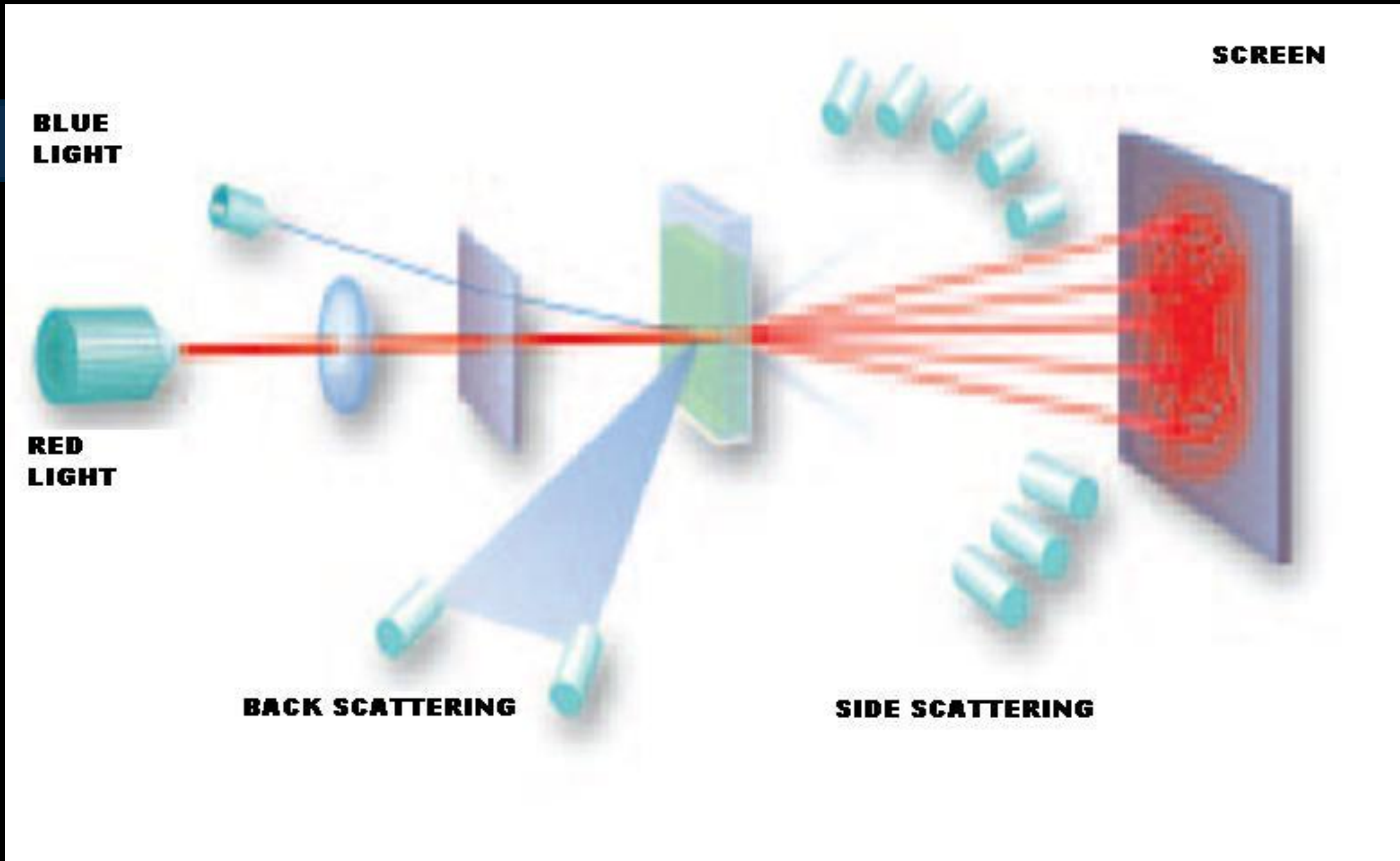
- **<u>Electrozone sensing</u>:** This technique was developed in the mid 1950's for sizing blood cells. The method requires calibration standards which are expensive, difficult to measure emulsions and Porous particles give significant errors.
- **<u>Microscopy</u>:** It is not suitable as a quality or production control technique.

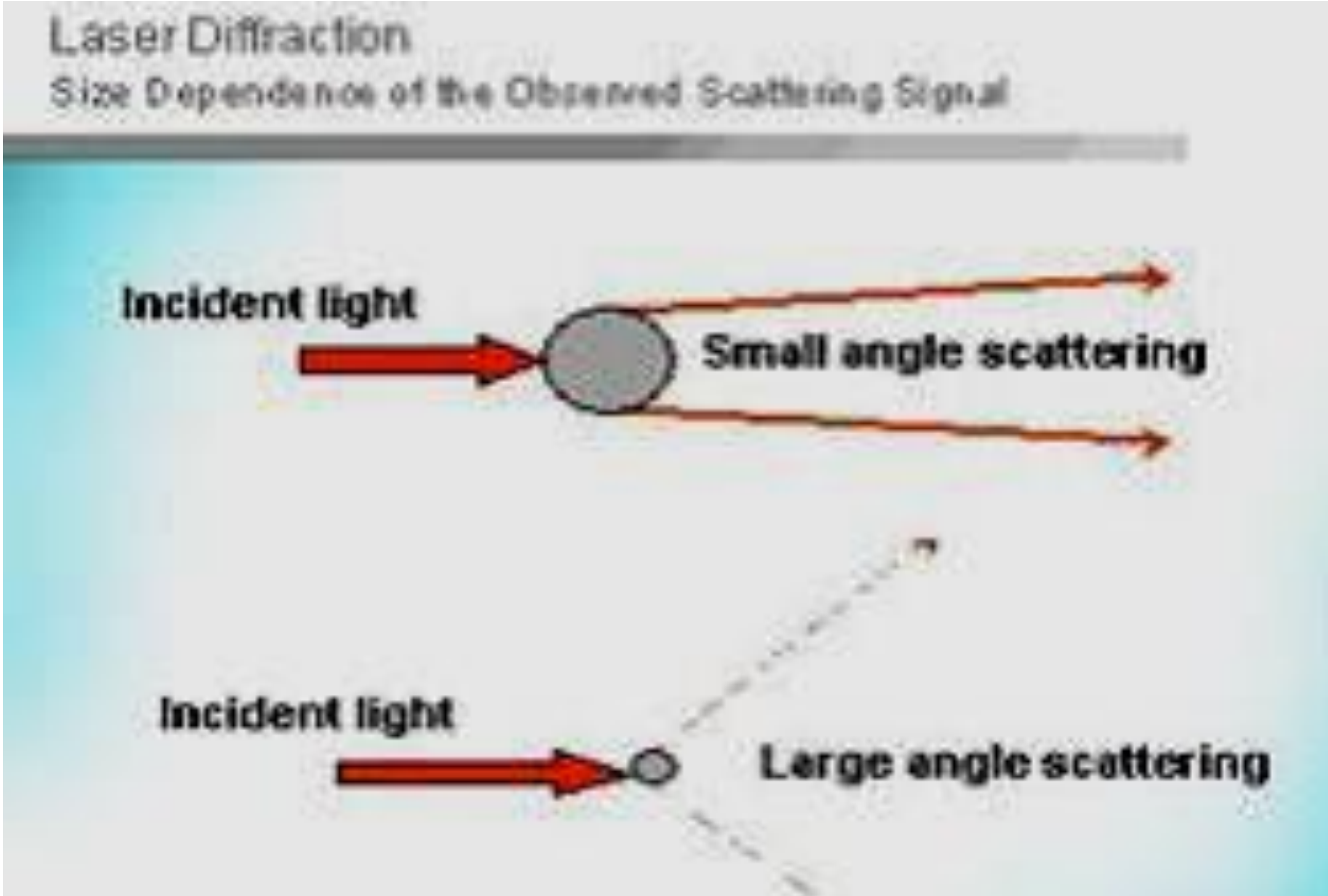
- On this basis these days the preferred Particle Size Analysis technique in industries as well as research laboratories is Laser Diffraction or Laser Particle Size Analysis.
- Laser Particle Size Analyser are becoming a method of choice for Particle Size Analysis in most industries due to:
  - Extremely wide dynamic range : 1nm~6000nm
  - Extremely wide sample concentration range measurement: (ppm~40%)

- High Resolution and precision
- Quick and Easy sample handling and measurement
- Sample preparation system removes large contaminants .

- Laser Particle Size Analyser may be used for measuring the size of particles (in the form of dry powders, sprays, suspensions and emulsions) using the effects produced by the diffraction and diffusion of a laser beam.

- Laser diffraction (LD) is a method used for particle size measurement that is based on the property of the particles to scatter light.


SCREEN
BLUE LIGHT
RED LIGHT
BACK SCATTERING
SIDE SCATTERING


Laser Diffraction
Size Dependence of the Observed Scattering Signal
Incident light
Small angle scattering
Incident light
Large angle scattering

- During the laser diffraction measurement, particles are passed through a focused laser beam.
- These particles scatter light at an angle that is inversely proportional to their size.
- The angular intensity of the scattered light is then measured by a series of photosensitive detectors.
- The map of scattering intensity versus angle is the primary source of information used to calculate the particle size.

Laser diffraction gives the following advantages:

- Flexibility.
- This method is rapid producing an answer in less than one minute, unlike other techniques.
- A wide dynamic range(0.1- 2000 microns)
- The method is non-destructive and non-intrusive. Hence samples can be recovered if they are valuable.
- **Dry powders** can be measured directly, although this may result in poorer dispersion than using a liquid dispersing medium.
- This method gives more detailed particle size distributions than the other techniques stated.

Contd…

- **Speed of measurement** -- single measurements can be made in 400 [micro]sec, allowing the dynamics of drug delivery from aerosol devices to be followed.
- **Measurement repeatability** -- the ability to acquire data rapidly allows many thousands of measurements to be averaged when reporting a single result, delivering excellent repeatability when compared with techniques that deliver results based on one-off measurements.
- **Range of applicability** -- sprays, dry powders, suspensions and sprays can all be characterized using the same technique, allowing different formulation types to be compared in a realistic way.

Particle Shape

- Particle shape is described in terms of aspect ratio or shape factor
- *Aspect ratio* is the ratio of the largest dimension to the smallest dimension of the particle

Shape Factor

- A measure of the ratio of the surface area of the particle to its volume

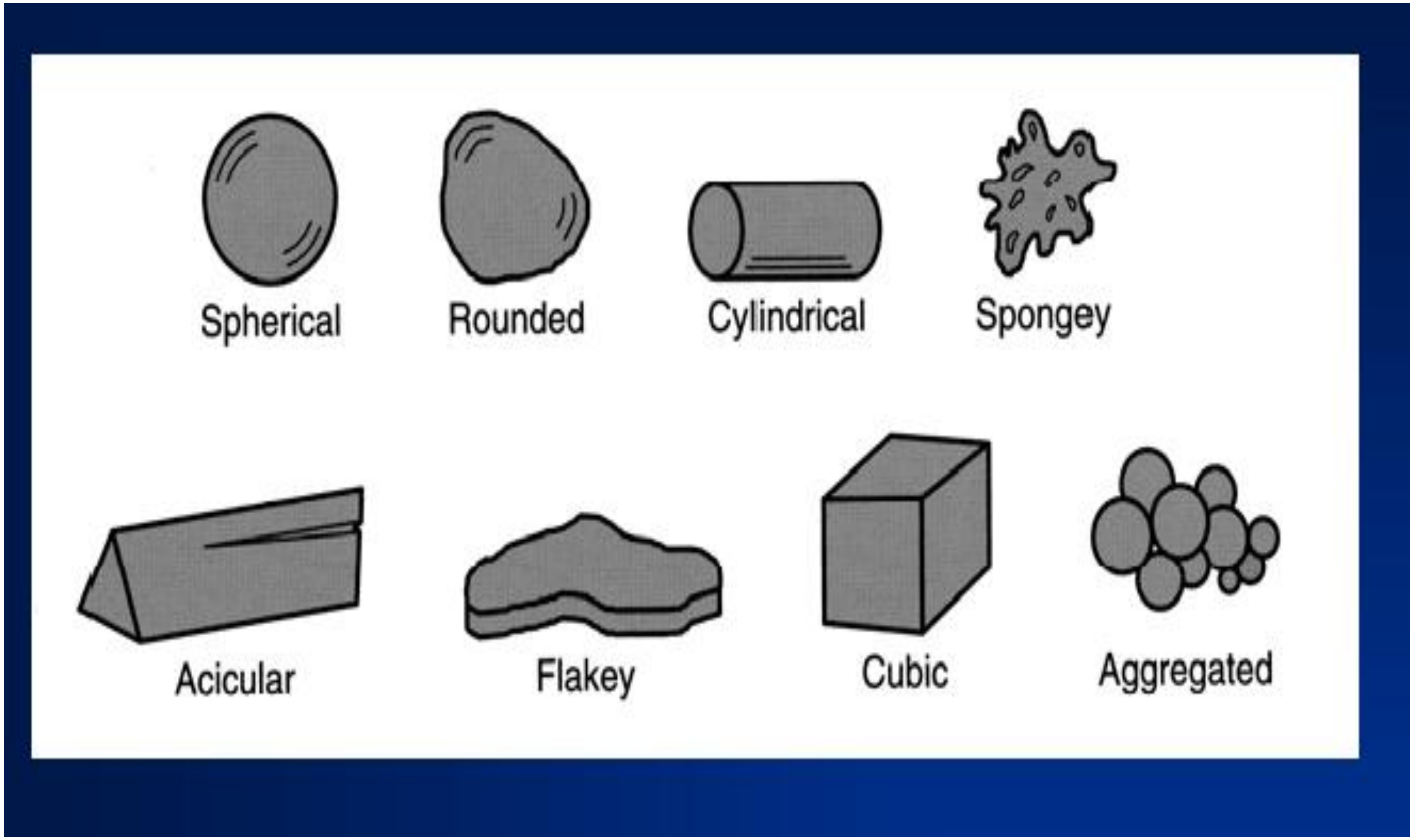
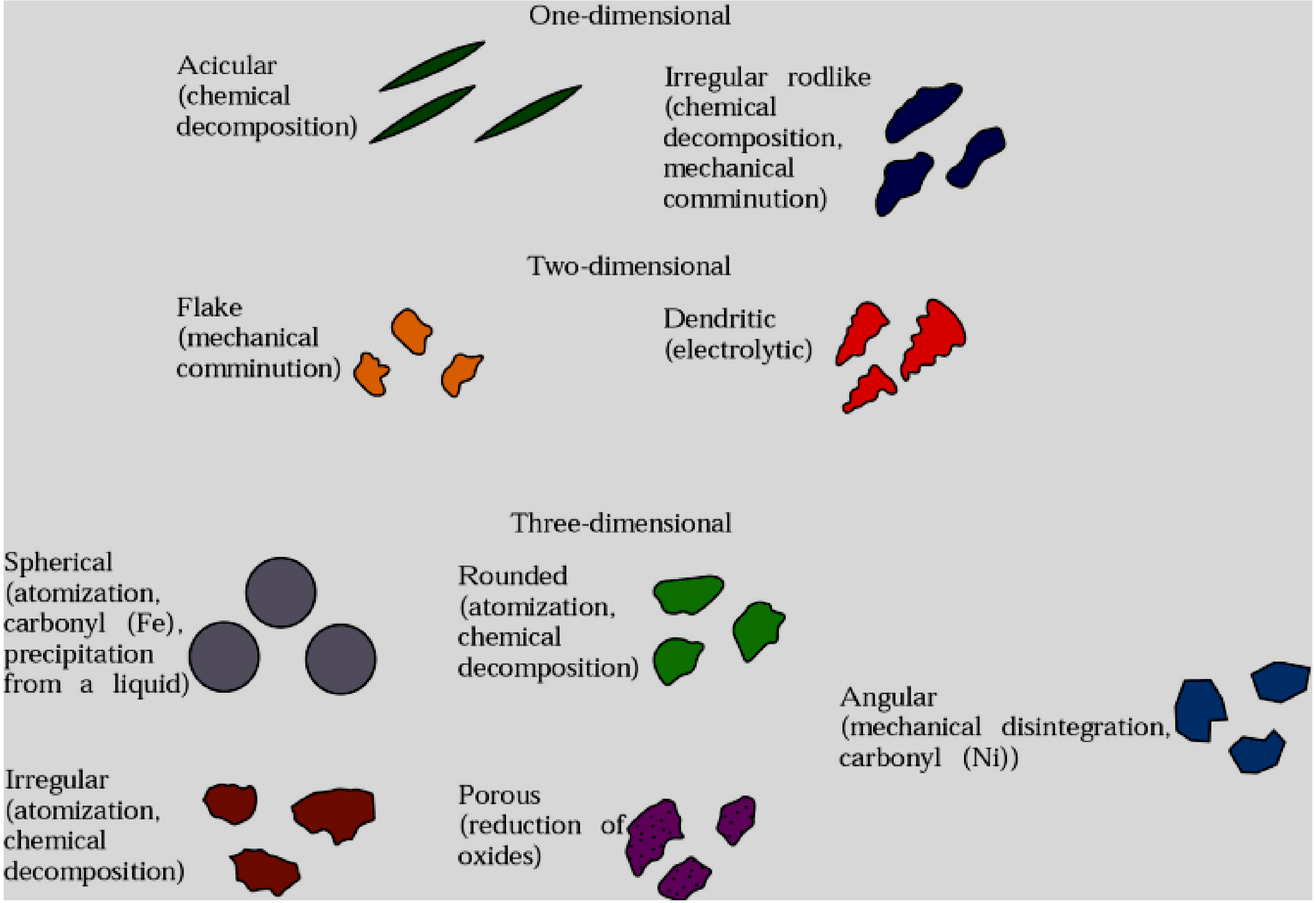


Fig. 2.2 Several of the possible (ideal) particle shapes in powder metallurgy

METAL POWDER PARTICLE SHAPES



Metal powder particle shapes and the processes by which they are produced

Particle Shape and Shape Factor

- Major influence on processing characteristics
- Usually described by aspect ratio and shape factor
- Aspect ratio is the ratio of the largest dimension to the smallest dimension
- Ratio ranges from unity (spherical) to 10 (flake-like, needle-like)

- Shape factor (SF) is also called the shape index
- Is a measure of the ratio of the surface area to its volume
- The volume is normalized by a spherical particle of equivalent volume
- The shape factor for a flake is higher than it is for a sphere

Size Distribution

- Affects the processing characteristics of the powder
- Distribution of particle size is given in terms of a *frequency-distribution* plot
- Properties of metal powders that affect their behaviour in processing are:
  1. *Flow properties*
  2. *Compressibility*
  3. *Density*

Size Distribution and Other Properties

- Size distribution is important because it affects the processing characteristics of the powder
- Flow properties, compressibility and density are other properties that have an affect on metal powders behavior in processing them
- Flow
  - When metal powders are being filled into dies
- Compressibility
  - When metal powders are being compressed
- Density
  - Theoretical density, apparent density, and the density when the powder is shaken or tapped in the die cavity

Characteristics of powder mass such as:

Apparent density
Tap density
Flow rate
Friction conditions.

Apparent density

- The apparent density of a powder is defined as the mass per unit volume of loose or unpacked powder.
- Thus it includes internal pores but excludes external pores.
- It is governed by chemical composition, particle shape, size, size distribution, method of manufacture of metal powders as well as shape and surface conditions which can vary from 20-50% of the theoretical density.
- Apparent density is important in pressing operations because the die is generally filled by volume.

Relation between Various Types of Powder and Apparent Density

Types of Powder	Apparent Density
Electrolytic or atomized powders	High
Reduction of oxides or Chemical precipitation	Low
Spherical	Maximum
Dendritic	Reduced
Irregular	Lower
Flake	Very poor
Coarse	Good
Fine	Poor
Uniform sized powder	Lower
Mixed sized Powder	Optimum

- The main factor is not the particle size but the particle size distribution for altering the apparent density.
- Thus the uniform and identical particles occupy a constant fraction of the available space but various sized particles increase the density to an optimum extent.

- An increase in apparent density is obtained with additions of fine particles and results from the ability of fines to fill the inter particle voids.
- Because of their more brittle behavior, oxides present on the surface result in the lowering of strength and altering the apparent density of the metal powder.

Tap density

- Tap density (or load factor) is the apparent density of the powder after it has been mechanically shaken down or tapped until the level of the powder no longer falls.
- It appears to be widely used for storage, packing or transport of commercial powders and also a control test on mixed powder.

- Tapped density is the term used to describe the bulk density of a powder (or granular solid) *after* consolidation/compression prescribed in terms of "tapping" the container of powder a measured number of times, usually from a predetermined height.
- The method of "tapping" is best described as "lifting and dropping".

Measuring tapped density :

- In general, any graduated container can serve as a means to determine tapped density.
- In practice, graduated glass measuring cylinders are most often used.
- In the standard methods below, the total capacity of the cylinder to be used, and the readability of its scale are stated.
- The cylinder can be tapped manually or by mechanical device.

Manual tapping:

- The raising and lowering of the cylinder by hand is done

  -either (i) without reference to the height traversed and arbitrary acceleration in both upward and downward directions

    -the hand remaining in contact with the cylinder at all times (hand tapping),

  -or (ii) by constraining the upwards distance traveled and allowing free-fall of the cylinder under gravity (drop box).

- In hand tapping the cylinder containing the powder is tapped by repeatedly striking its base down onto a hard surface

Mechanical devices:

- *Tap density analyzers* (tap density testers) use an electric motor to turn a cam under a specially constructed cylinder holder.
- The holder secures the cylinder to a vertical shaft which runs in a low friction bearing.
- The *tapping rate* is normally expressed in taps per minute; the rate being typically a few hundred.
- The actual rate is determined by the rotational speed of the cam under the shaft/platform.

- Digital or electromechanical counters are usually incorporated in the device to automatically stop the cam rotation after a predetermined (yet adjustable) number of taps.
- The height through which the container falls is known as the *drop height* or *stroke*.
- It is set by the distance between the highest point on the cam and the striking surface.
- In the standard methods, the drop height is one of two values, 3mm (or 1/8") or 14mm, within tolerances specified therein.

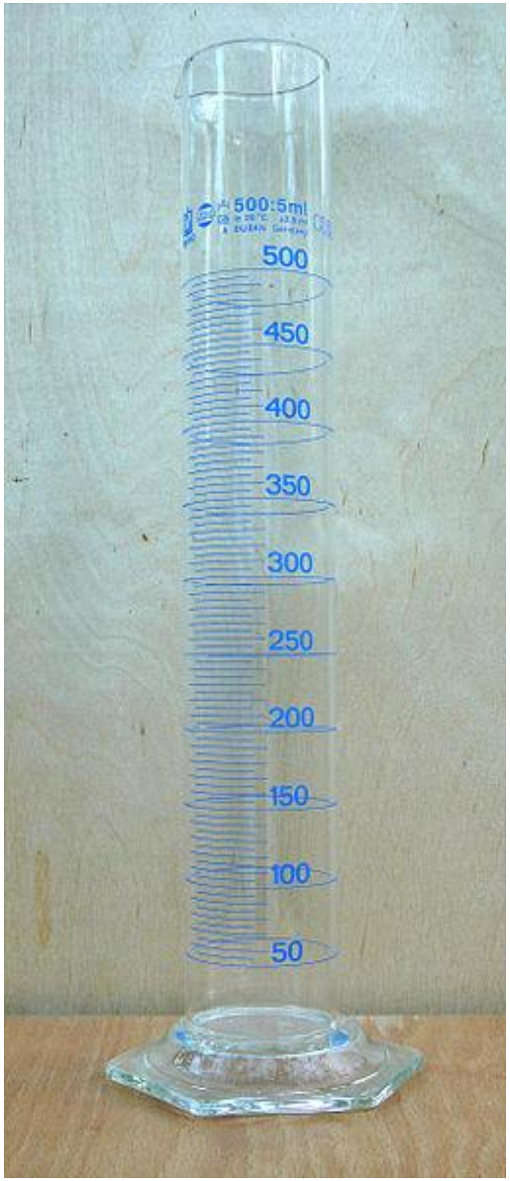


Fig. 2.3 A glass measuring cylinder that can be used for tapped density measurements

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 s*tate 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.

2.2.3 Flow rate

- The flow rate is a very important characteristic of powders which measures the ability of a powder to be transferred.
- It is defined as the rate at which a metal powder will flow under gravity from a container through an orifice both having the specific shape and finish.
- The powder filling of die must be rapid and uniform without bridge formation for obtaining a rapid rate of production, consistent compacts and economy.

- On the other hand poor flow properties of the powder result in the slow and uneconomical feeding of the die cavity and the possibility during pressing of uneven filling of the die cavity.
- It is affected not only by particle size, size distribution and shape, but also by absorbed air or gas, moisture, lubricant, coefficient of inter particle friction, etc.
- In general, fine or dendritic, irregular, coarse and spherical powders have poor, reduced, good and maximum flow rates respectively.

- Flow rate increases with decreased particle irregularly and increased particle size, specific gravity, and apparent density.
- It can also be increased by tapping or vibrating.
- The standard apparatus, known as Hall Flowmeter, is generally used for the determination of flow rate.
- It consists of a standard and accurately machined conical funnel made of brass with smooth finish having an internal angle of 60º.

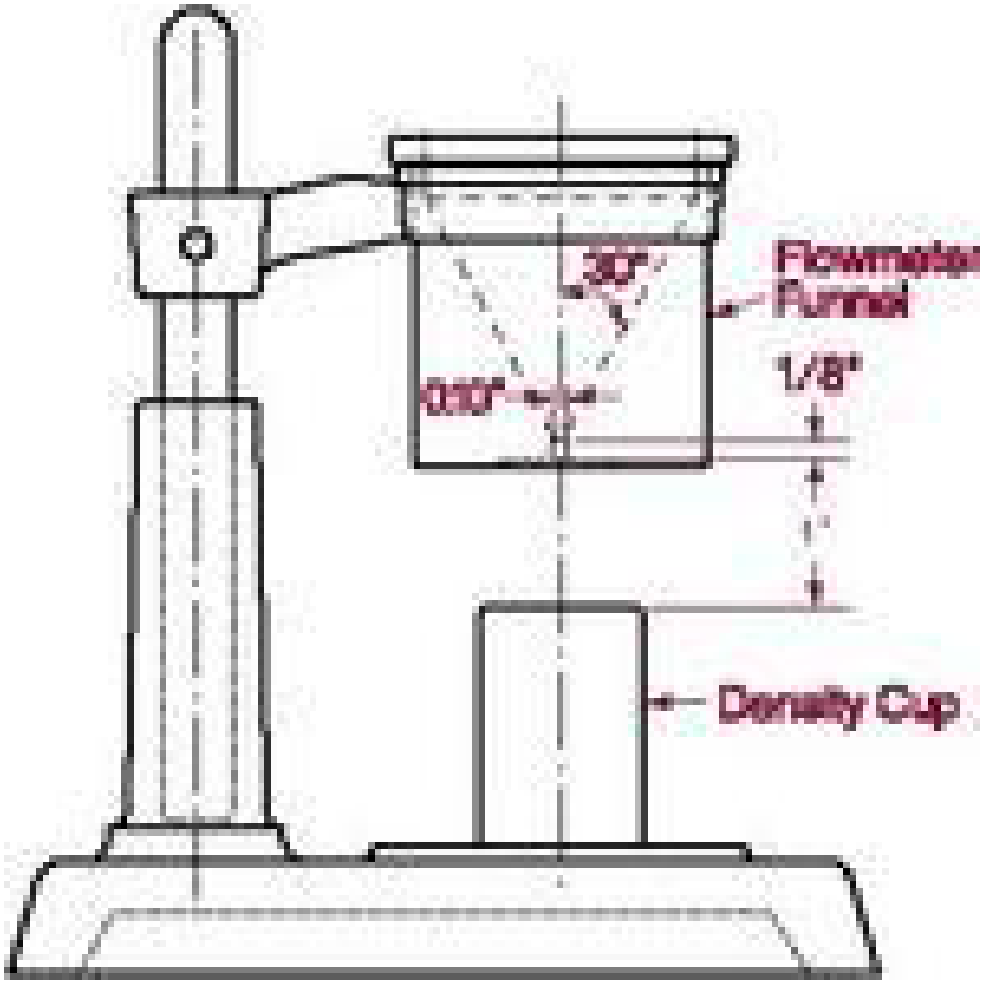


Fig. 2.4 Hall Flowmeter

- The orifice situated at the bottom of the funnel is either 1/8" for ferrous powders or 1/10" in diameter for non-ferrous powders.
- The time required to flow the weighed sample of powder (usually 50 gm)

  -from the funnel into a cup held at a fixed distance below the orifice

  -is a measure of flow rate

  -which is expressed in seconds or

  -gm/minute in case a non- standard weight of the sample is employed.

- There is such a close relationship between apparent density and flow properties that is very difficult to vary one without altering the other.
- Flow rate, apparent density, and tap density are essential processing factors since they affect the transporting and pressing of powders.

- 2.2.4 Friction conditions

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

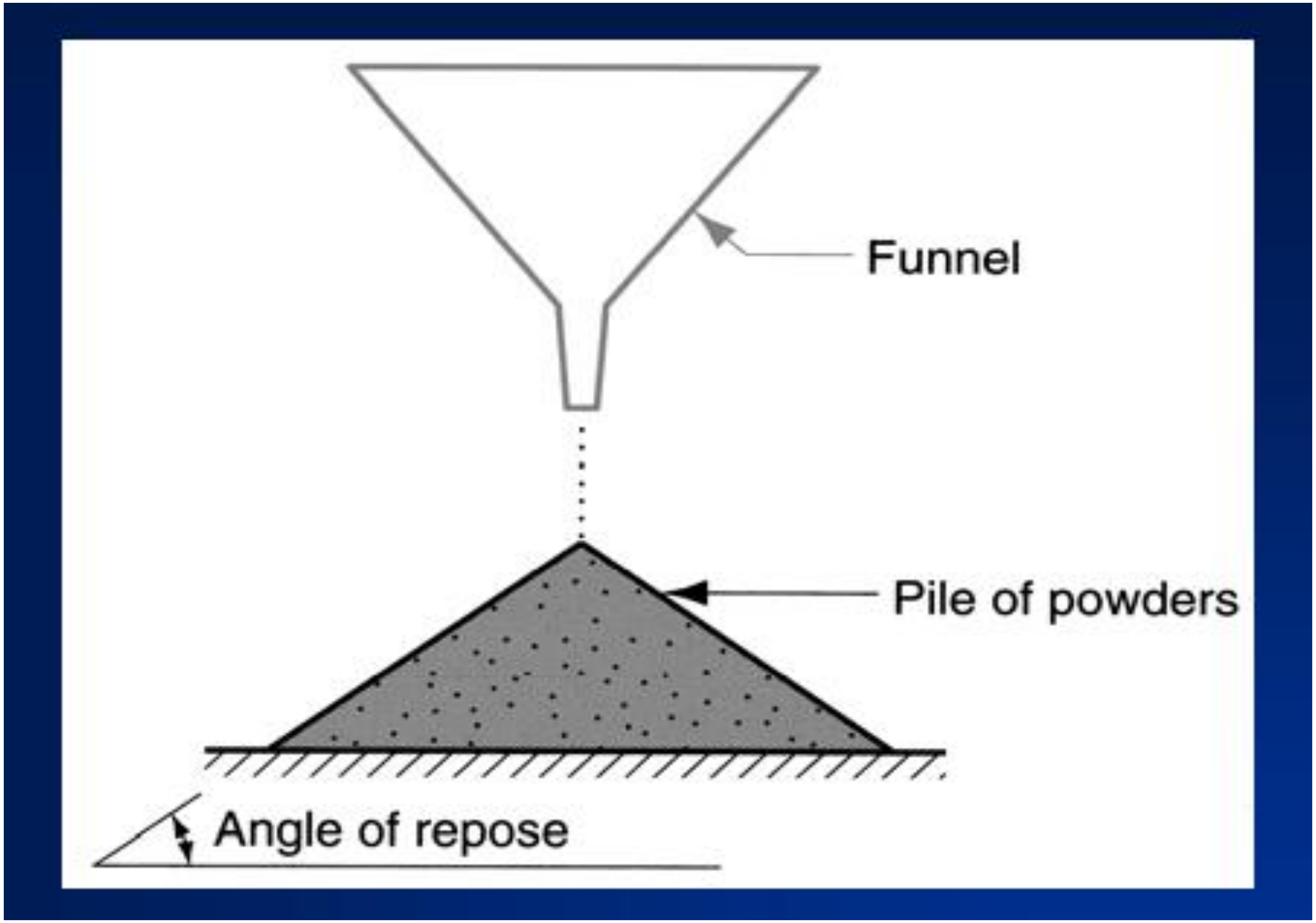


Fig. 2.5 Interparticle friction as indicated by the angle of repose of a pile of powders poured from a narrow funnel. Larger angles indicate greater interparticle friction.

Observations

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

Properties of green compacts and sintered compacts.

- A very important parameter is the apparent density (AD) of the powder.

  -since this strongly influences the strength of the compact obtained on pressing.

  -The AD is a function of particle shape and the degree of porosity of the particles.

- The choice of powder characteristics is normally based on compromise

  -since many of the factors are in direct opposition to each other.

- An increase in the irregularity and porous texture of the powder grain,

  -i. e., decrease in apparent density

  -increases the reduction in volume that occurs on pressing

  -and thus the degree of cold welding

  -which, in turn

  -gives greater strength to the green compact.
- This increase in contacting surfaces also leads to more efficient sintering.

- Additionally the greater reduction in volume necessary to give the required green density

  -may require greater pressure, and

  -consequently larger presses and stronger dies.

- The ease and efficiency of packing the powder in the die

  -depends to a large extent on a wide particle size distribution

  -so that the voids created between large particles can be progressively filled with those of smaller size.

- Fine particle sizes tend to leave smaller pores

  -which are easily closed during sintering.
- An excess of fines , however, reduces flow properties.
- Fine particle size is, however, an important requirement, of the Metal Injection Moulding process.
- The purity of the powder is critically important.
- Impurity levels that can be tolerated depend to a large extent

  -on the nature and state of combination of the substances concerned.

- For example, the presence of combined carbon in iron

  -tends to harden the matrix

  -so that increased pressures are required during compaction.

- Free carbon, however, is often an advantage

  -acting as a lubricant during the pressing operation.

- Most metal powders are coated by thin oxide film

  -but in general these do not interfere with the process

  -since they are ruptured during the pressing operation

  -to provide clean and active metal surfaces

  -which are easily cold-welded.
- Their final reduction under the controlled sintering atmosphere is essential for
  - complete metal bonding, and
  - maximum strength.

- Stable oxide films or included oxide particles

  -such as SiO_2 or Al_2O_3 are more serious

  -since these are generally abrasive, and

  -lead to increased tool wear.
- Furthermore they cannot be reduced during subsequent sintering

  -and their presence may adversely affect the mechanically properties

  -especially impact strength of the finished part.
- This is of major importance when high integrity, high density parts are required-notably powder forgings.