POWDER METALLURGY- UNIT 2

Monil Salot

SYLLABUS

- Important methods of metal powder manufacturing:
  - Machining.
  - Milling.
  - Atomization.
  - Electro deposition.
  - Reduction From Oxide.
  - Carbonyl Process.
  - Production Of Alloy Powders.

- Powder Conditioning.
- Fundamentals Of Powder Compaction.
- Density Distribution In Green Compacts.
- Types Of Compaction Presses.
- Compaction Tooling And Role Of Lubricants.
- Single And Double Die Compaction.
- Isostatic Pressing.
- Hot Pressing.

Introduction.

- The chief raw materials used in the production of powder metallurgy components are the metal powders.
- These consist of fine, high purity metal powders.

- Metal powders => Main constituent of a P/M product
- final properties of the finished P/M part depends on

  -size, shape, and surface area of powder particles.
- Single powder production method is not sufficient for all applications.
- Powder production methods:

  1. Mechanical methods
  2. Physical methods
  3. Chemical methods

- These powders are produced by processes such as
  -atomization
  -pulverization
  -chemical reduction
  -electrolytic techniques
  or
  -mechanical alloying.
- Of these processes, atomization is the most popular technique.

Machining

- Employed to produce

  -filings, turnings, scratching, chips etc.

  -subsequently pulverized by crushing and milling.
- Relatively coarse and bulky powders entirely free from fine particles are obtained.

- Particularly suitable in a very few special cases

  -Production of

  - magnesium powders for pyrotechnique applications
  - explosiveness and malleability of powder prohibit use of other methods.
  - beryllium powders, silver solders and dental alloys (containing up to 70 % silver among its constituents).

- Powder particles produced are of irregular shape.
- Highly expensive method

  -limited application.
- Employed where

  -cost is not excessive in relation to the cost of metals themselves

  or

  -choice of method is considered a necessity as in the case of Mg.

Milling

- During milling, impact, attrition, shear and compression forces are acted upon particles.
- During impact, striking of one powder particle against another occurs.
- Attrition refers to the production of wear debris due to the rubbing action between two particles.
- Shear refers to cutting of particles resulting in fracture.

  -The particles are broken into fine particles by squeezing action in compression force type.

- Main objective of milling:

  -Particle size reduction (main purpose),

  -shape change,

  -agglomeration (joining of particles together),

  - solid state alloying,

  -mechanical or solid state mixing,

  -modification of material properties.

- Mechanism of milling:
- Changes in the morphology of powder particles during milling results in the following events.

  1. Microforging
  2. Fracture
  3. Agglomeration
  4. Deagglomeration

- Microforging => Individual particles or group of particles are impacted repeatedly so that they flatten with very less change in mass
- Fracture => Individual particles deform and cracks initiate and propagate resulting in fracture
- Agglomeration => Mechanical interlocking due to atomic bonding or van der Waals forces
- Deagglomeration => Breaking of agglomerates

- The different powder characteristics influenced by milling are
- Shape
- Texture
- crystalline size
- Hardness
- Flowability
- Sinterability

Size

Particle size distribution

Chemical composition

Density

Compressibility

Sintered density.

- Milling equipment: The equipments are generally classified as crushers & mills (grinding).
- Crushing => for making ceramic materials, oxides of metals.
- Grinding => for reactive metals such as titanium, zirconium, niobium, tantalum.
- Grinding: Different types of grinding equipments/methods are shown in the figure 3.1.

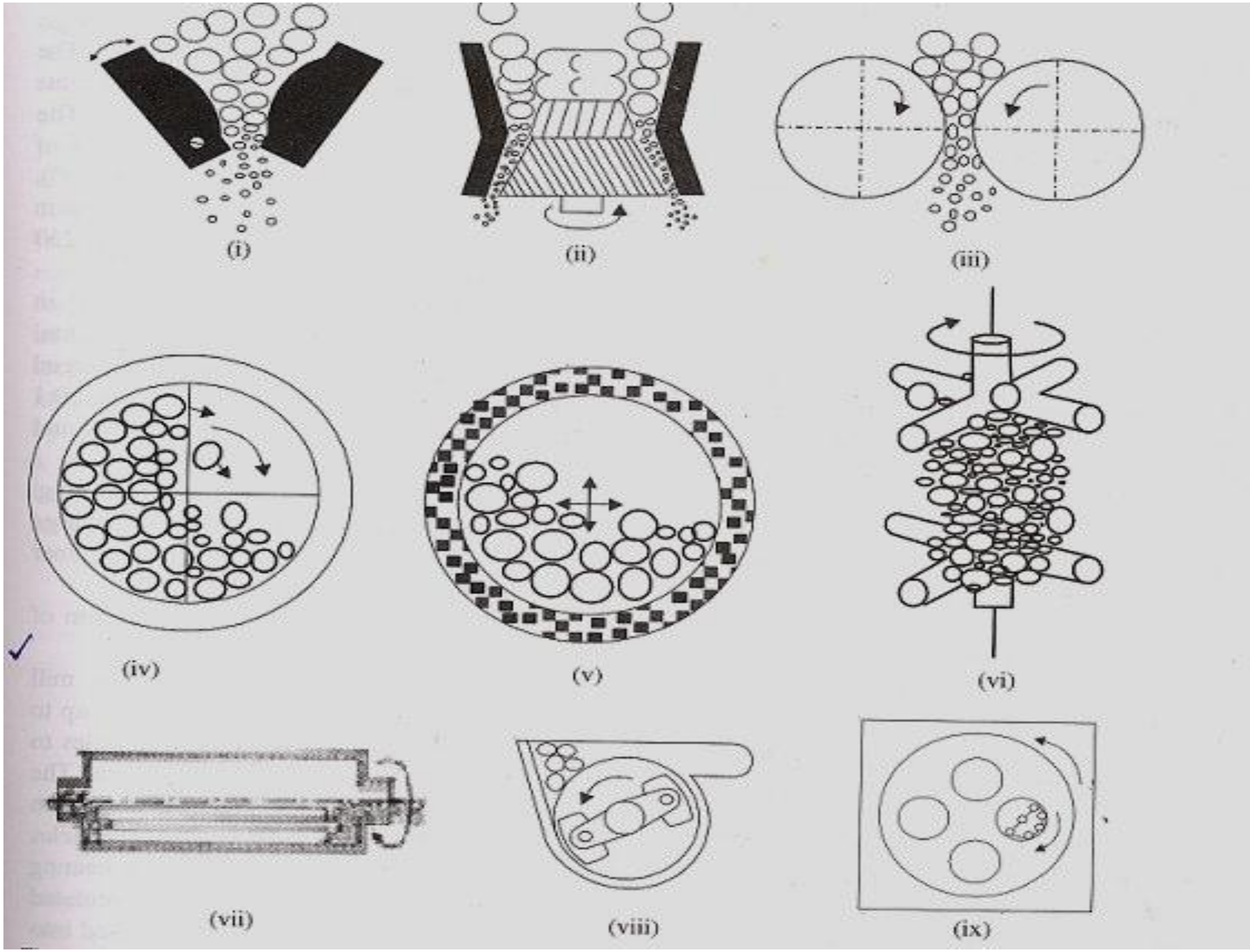


Fig. 3.1 (i) Jaw Crusher (ii) Gyratory Crusher (iii) Roll Crusher (iv) Ball Mill (v) Vibratory Mill (vi) Attritor (vii) Rod Mill (viii) Hammer Mill (ix) Planetary Mill

- Ball mills
- This contains cylindrical vessel rotating horizontally along the axis.
- Length of the cylinder is more or less equal to diameter.
- The vessel is charged with the grinding media.
- The grinding media may be made of hardened steel, or tungsten carbide, ceramics like agate, porcelain, alumina, zirconia.
- During rolling of vessel, the grinding media & powder particles roll from some height.
- This process grinds the powder materials by impact/collision & attrition.

- Milling can be dry milling or wet milling.
- In dry milling, about 25 vol% of powder is added along with about 1 wt% of a lubricant such as stearic or oleic acid.
- For wet milling, 30-40 vol% of powder with 1 wt% of dispersing agent such as water, alcohol or hexane is employed.
- Optimum diameter of the mill for grinding powders is about 250 mm.

- Vibratory ball mill
- Finer powder particles need longer periods for grinding.
- In this case, vibratory ball mill is better

  => here high amount of energy is imparted to the particles

  and

  milling is accelerated by vibrating the container.

- During operation, 80% of the container is filled with grinding bodies and the starting material.
- Here vibratory motion is obtained by an eccentric shaft that is mounted on a frame inside the mill.
- The rotation of eccentric shaft causes the drum of the vibrating mill to oscillate.

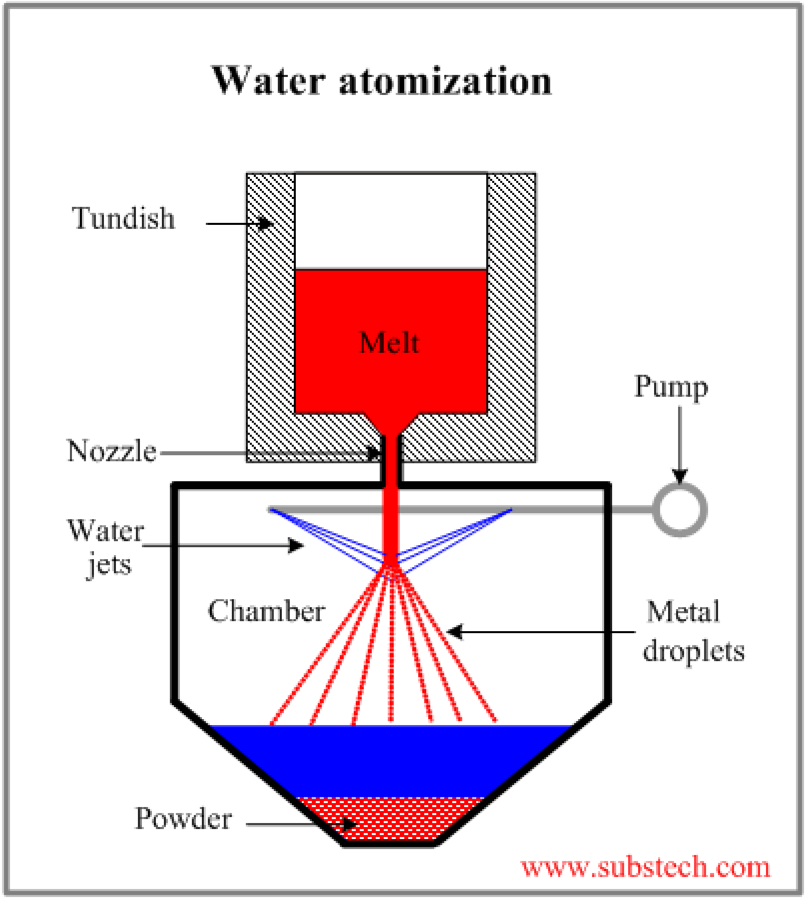
- In general, vibration frequency is equal to 1500 to 3000 oscillations/min.
- The amplitude of oscillations is 2 to 3 mm.
- The grinding bodies is made of steel or carbide balls, that are 10-20 mm in diameter.
- The mass of the balls is 8-10 times the charged particles.
- Final particle size is of the order of 5-100 microns.

- Attrition mill
- In this case, the charge is ground to fine size by the action of a vertical shaft with side arms attached to it.
- The ball to charge ratio may be 5:1, 10:1, 15:1.
- This method is more efficient in achieving fine particle size.
- Rod mills
- Horizontal rods are used instead of balls to grind.
- Granularity of the discharge material is 40-100 mm.
- The mill speed varies from 12 to 30 rpm.
- Planetary mill
- High energy mill widely used for producing metal, alloy, and composite powders.

Atomization

- This uses high pressure fluid jets to break up a molten metal stream into very fine droplets, which then solidify into fine particles.
- High quality powders of Al, brass, iron, stainless steel, tool steel, superalloys are produced commercially.

Atomization

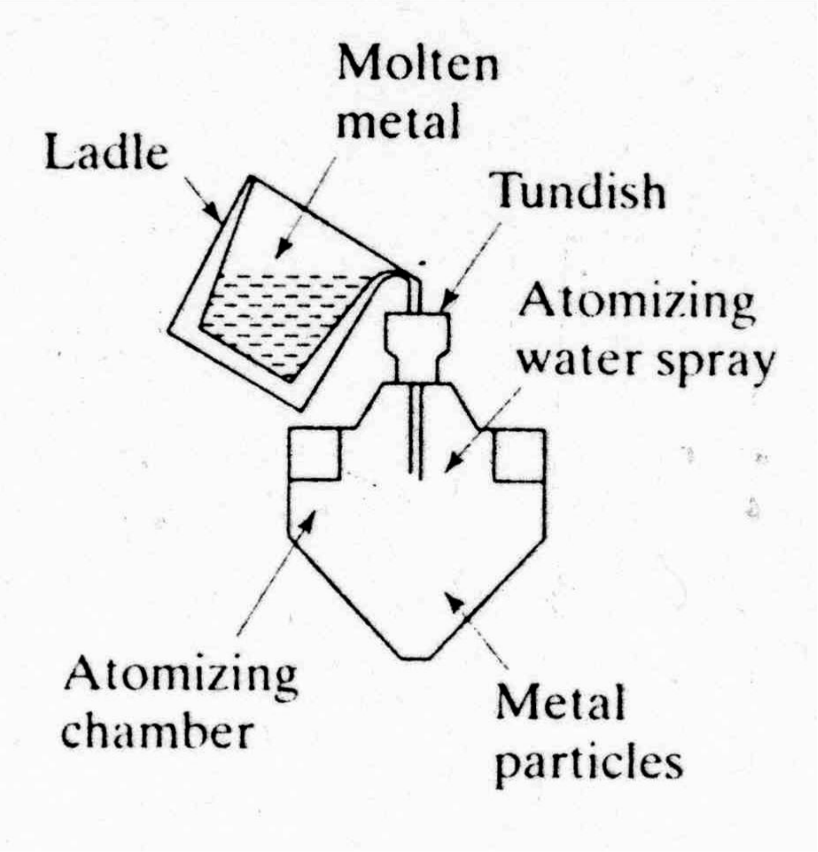


- Atomization is one of the most effective industrial powder preparation methods.
- This method involves disintegration (atomizing) of liquid metal by means of high speed medium (air, inert gas, water) striking the melt streaming through a nozzle.
- The molten alloy is prepared in a furnace and then it is transferred to the tundish.

- The melt is poured from the tundish through the nozzle into the chamber.
- The water (air, gas) jets break the melt stream into fine droplets.
- The droplets solidify when they fall in the chamber.
- The powder is collected at the bottom of the chamber.
- The powder is removed from the chamber and dried (if necessary).

ATOMIZATION

- Produce a liquid-metal stream by injecting molten metal through a small orifice.
- Stream is broken by jets of inert gas, air, or water.
- The size of the particle formed depends on the temperature of the metal, metal flow rate through the orifice, nozzle size and jet characteristics.



- Types**:**
- Water atomization
- Gas atomization
- Soluble gas or Vacuum atomization
- Centrifugal atomization
- Rotating disk atomization
- Ultrarapid solidification process
- Ultrasonic atomization.

- Mechanism of atomization:
- In conventional (gas or water) atomization,

  -a liquid metal is produced by pouring molten metal through a tundish with a nozzle at its base.
- The stream of liquid is then broken into droplets by the impingement of high pressure gas or water.
- This disintegration of liquid stream is shown in figure.

- This has five stages:

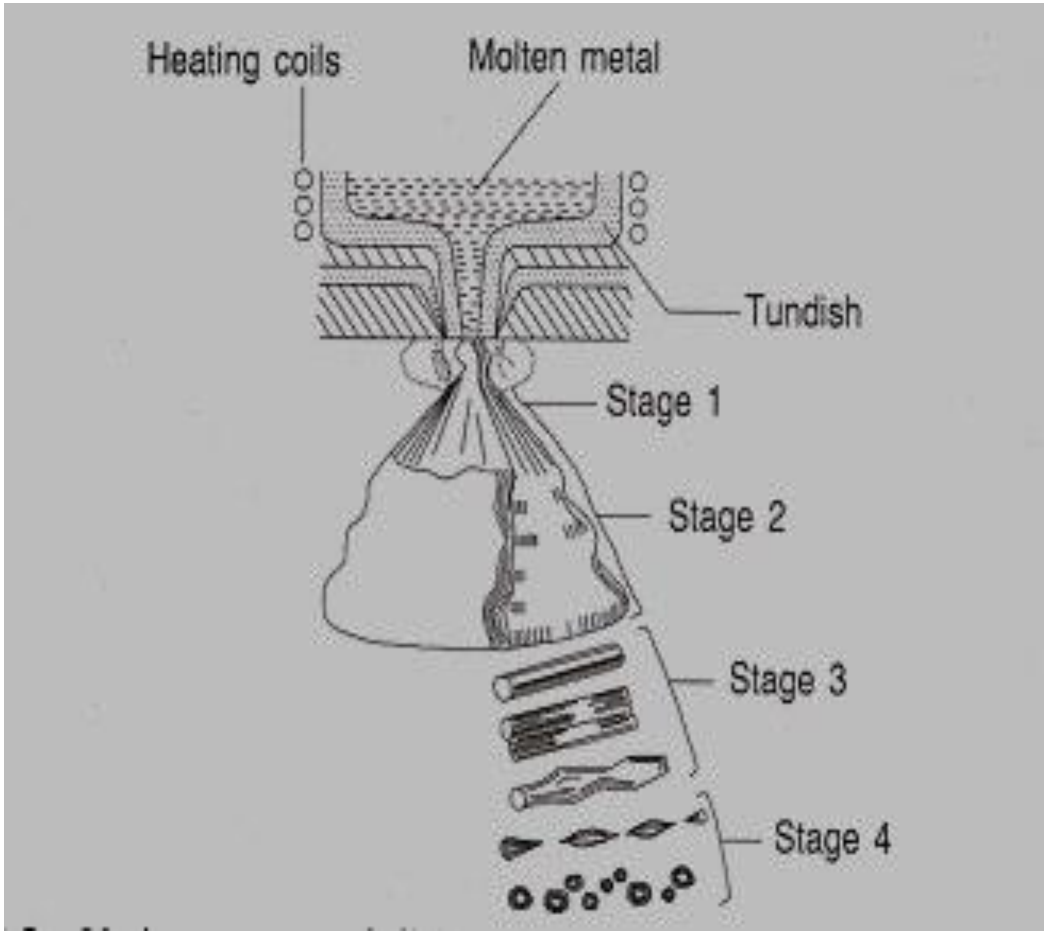
  i) Formation of wavy surface of the liquid due to small disturbances

  ii) Wave fragmentation and ligament formation

  iii) Disintegration of ligament into fine droplets

  iv) Further breakdown of fragments into fine particles

  v) Collision and coalescence of particles.


Heating coils
Molten metal
Tundish
Stage 1
Stage 2
Stage 3
Stage 4

- The interaction between jets and liquid metal stream

  -begins with the creation of small disturbances at liquid surfaces,

  -which grow into shearing forces that fragment the liquid into ligaments.
- The broken ligaments are further made to fine particles because of high energy in impacting jet.

- Lower surface tension of molten metal,

  -high cooling rate => formation of irregular surface => like in water atomization.

- High surface tension,

  -low cooling rates => spherical shape formation => like in inert gas atomization.

- The liquid metal stream velocity,

$$\boldsymbol{\upsilon = A\,[2g\,(Pi - Pg)\rho]^{0.5}}$$

where

Pi – injection pressure of the liquid,

- Pg – pressure of atomizing medium,
- ρ– density of the liquid

- Types of atomization
- Atomization of molten metal can be done in different ways depending upon the factors like economy and required powder characteristics.
- At present, water or gas atomizing medium can be used to disintegrate a molten metal stream.

- The various types of atomization techniques used are,

1. Water atomization: High pressure water jets are used to bring about the disintegration of molten metal stream.

- Water jets are used mainly because of their higher viscosity and quenching ability.
- This is an inexpensive process and can be used for small or large scale production.
- But water should not chemically react with metals or alloys used.

2. Gas atomization:

- Here instead of water, high velocity argon, nitrogen and helium gas jets are used.
- The molten metal is disintegrated and collected as atomized powder in a water bath.
- Fluidized bed cooling is used when certain powder characteristics are required.

3. Vacuum atomization:

- In this method,

  -when a molten metal supersaturated with a gas under pressure is suddenly exposed into vacuum,

  -the gas coming from metal solution expands, causing atomization of the metal stream.
- This process gives very high purity powder. Usually hydrogen is used as gas.
- Hydrogen and argon mixture can also be used.

4. Centrifugal atomization:

- In this method, one end of the metal bar is
  - -heated and melted by bringing it into contact with a non-consumable tungsten electrode, while
  - -rotating it longitudinally at very high speeds.
- The centrifugal force created causes the metal drops to be thrown off outwards.
- This will then be solidified as spherical shaped particles inside an evacuated chamber.
- Titanium powder can be made using this technique.

5. Rotating disk atomization:

- Impinging of a stream of molten metal on to the surface of rapidly spinning disk.
- This causes mechanical atomization of metal stream and causes the droplets to be thrown off the edges of the disk.
- The particles are spherical in shape and their size decreases with increasing disk speed.

6. Ultrarapid solidification processes:

- A solidification rate of 1000C/s is achieved in this process.
- This results in enhanced chemical homogeneity, formation of metastable crystalline phases, amorphous materials.

Atomization Unit

Melting and superheating facility:

- Standard melting furnaces can be used for producing the liquid metal.
- This is usually done by air melting, inert gas or vacuum induction melting.
- Complex alloys that are susceptible to contamination are melted in vacuum induction furnaces.
- The metal is transferred to a tundish, which serves as reservoir for molten metal.

Atomization chamber:

- An atomization nozzle system is necessary.
- The nozzle that controls the size and shape of the metal stream is fixed at the bottom of the atomizing chamber.
- In order to avoid oxidation of powders, the tank is purged with inert gas like nitrogen.

Powder collection tank:

- The powders are collected in tank. It could be dry collection or wet collection.
- In dry collection, the powder particles solidify before reaching the bottom of the tank.
- In wet collection, powder particles collected in the bottom of the water tank.
- The tank has to be cooled extremely if used for large scale production.
- During operation, the atomization unit is kept evacuated to 10-3 mm of Hg, tested for leak and filled with argon gas.

Atomizing nozzles

- Function is to control the flow and the pattern of atomizing medium to provide for efficient disintegration of powders
- For a given nozzle design, the average particle size is controlled by the pressure of the atomizing medium and also by the apex angle between the axes of the gas jets
- Higher apex angle lead to smaller particle size
- Apex angle for water atomization is smaller than for gas atomization

- Nozzle design:
  - i) annular type, ii) discrete jet type;
  - i) free falling, ii) confined design
- In free falling, molten metal comes in contact with atomizing medium after some distance.
- Here free falling of metal is seen.
- This is mainly used in water atomization

- In confined design used with annular nozzle, atomization occurs at the exit of the nozzle.
- Gas atomization is used generally for this.
- This has higher efficiency than free falling type.
- One has to be cautious that “freeze up” of metal in the nozzle has to be avoided.

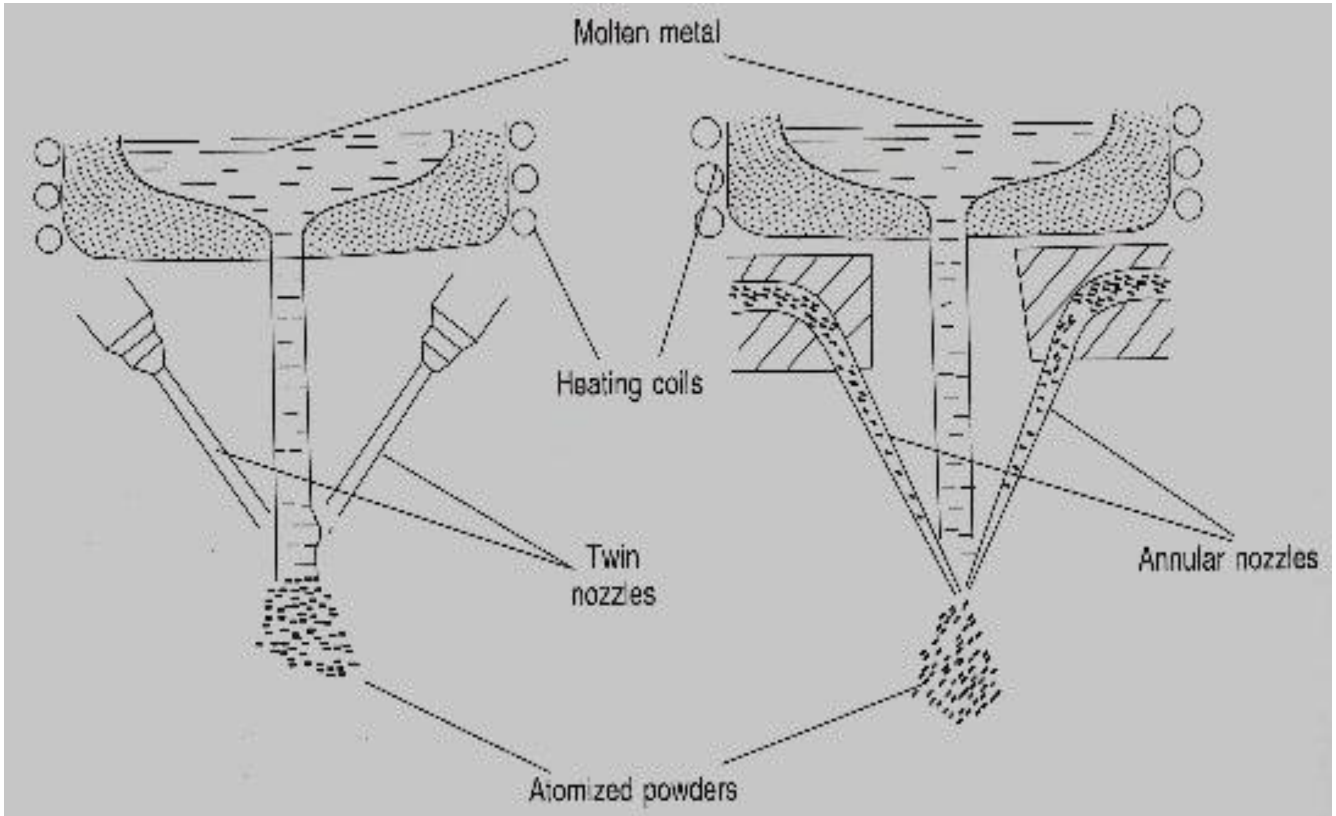


Figure 10.1 Atomic nozzle configurations: (a) twin jet nozzle, and (b) annular jet nozzle.

Atomic nozzle configuration:
a) twin jet nozzle, b) annular jet nozzle

Atomizing mediums

- The selection of the atomizing jet medium is based mainly on the reactivity of the metal and the cost of the medium
- Air and water are inexpensive, but are reactive in nature
- Inert gases like Ni, Ar, He can be used but are expensive and hence have to be recycled
- Pumping of cold gas along with the atomizing jet => this will increase the solidification rate

- Recently, synthetic oils are used instead of gas or water => this yields high cooling rate & lower oxygen content compared to water atomized powders
- Oil atomization is suitable for high carbon steel, high speed steels, bearing steals, steel containing high quantities of carbide forming elements like Cr, Molybdenum
- This method is not good for powders of low carbon steels

Important atomization processes

(1) Inert gas atomization

- Production of high grade metal powders with spherical shape, high bulk density, flowability along with low oxygen content and high purity
- - e.g., Ni based super alloys
- Controlling parameters**:**

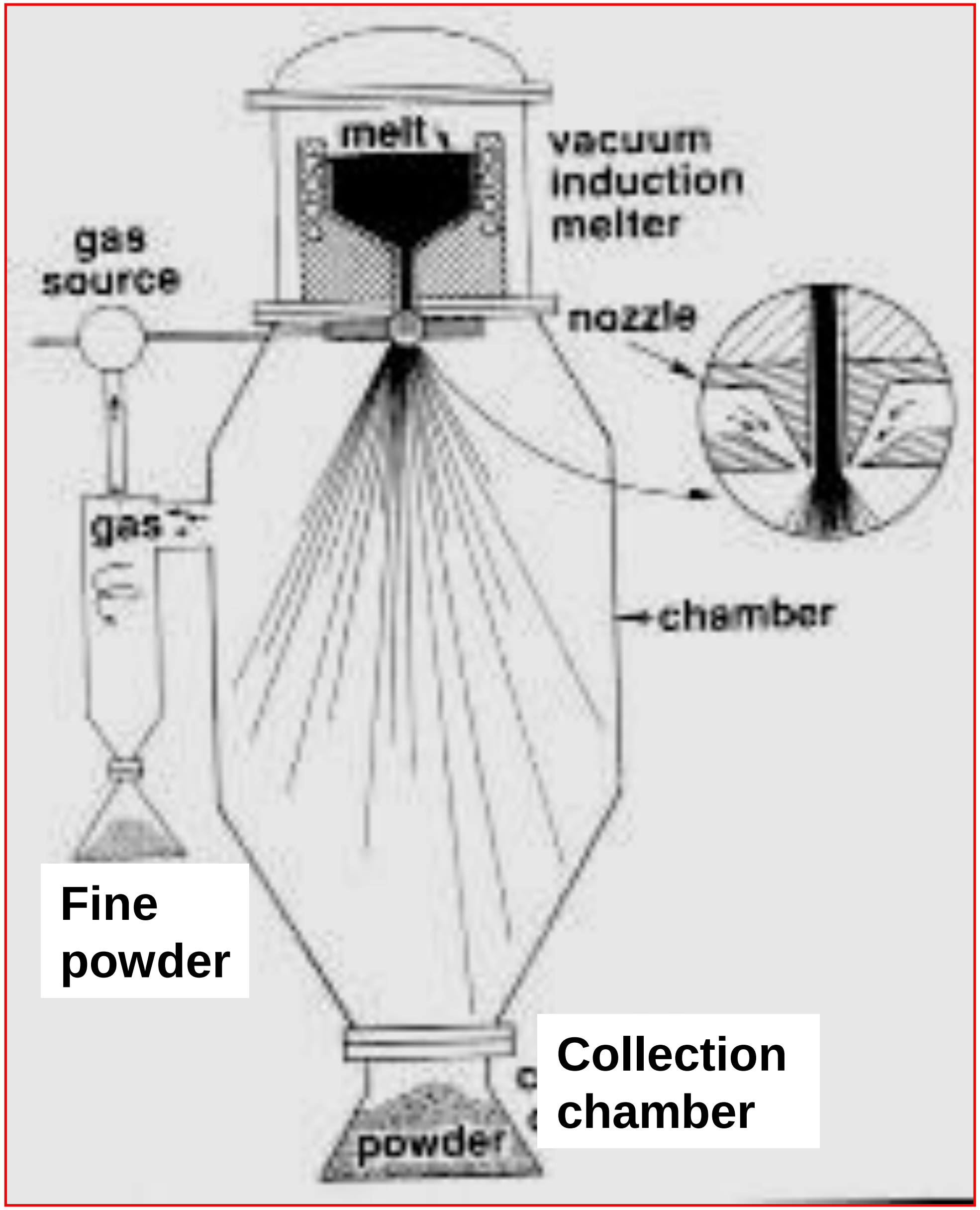
(1) viscosity, surface tension, temperature, flow rate of molten metal;

(2) flow rate, velocity, viscosity of atomizing medium;

(3) jet angle, jet distance of the atomizing system;

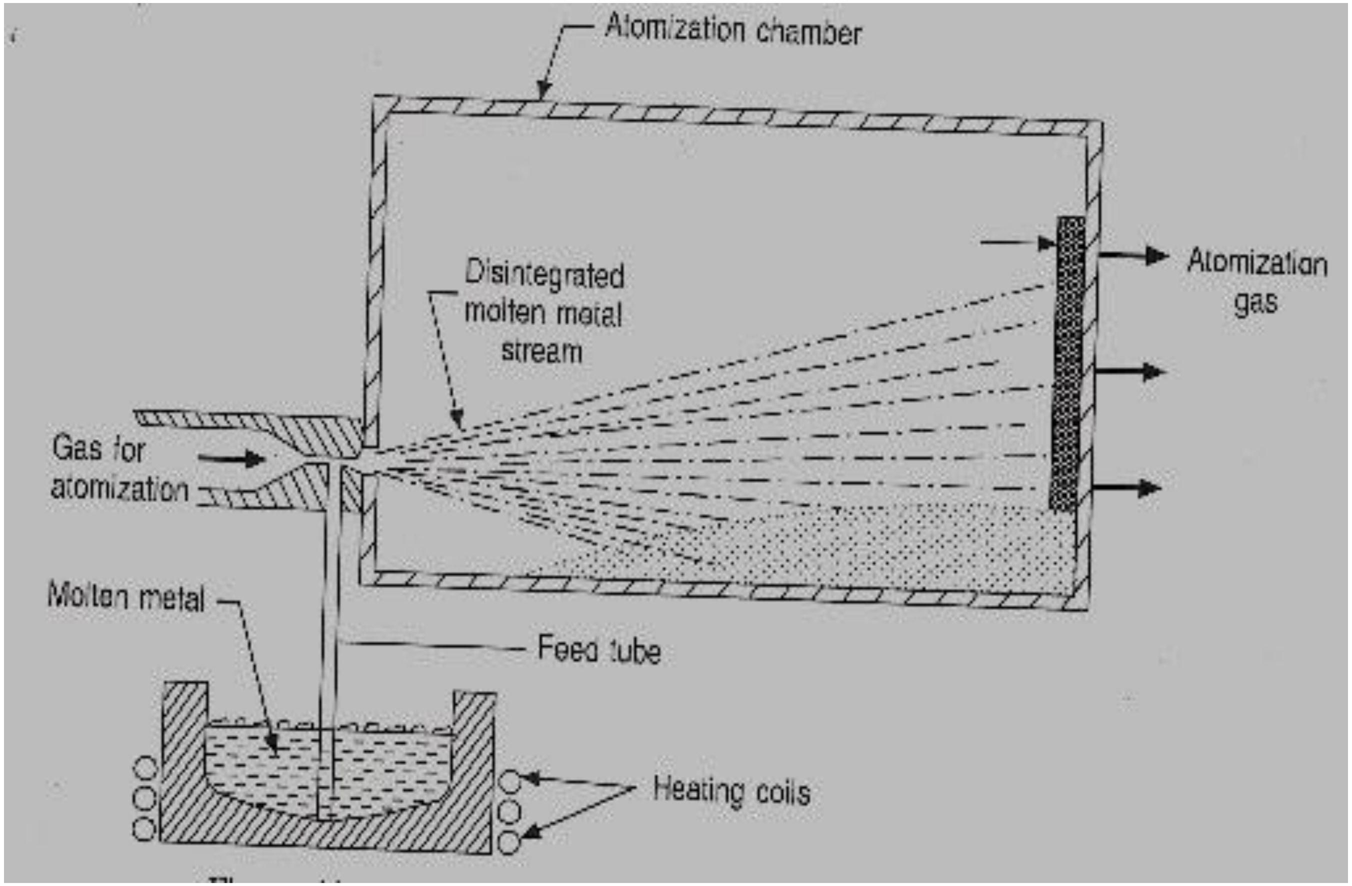
(4) nature of quenching media

Gas atomization



Fine powder

Collection chamber

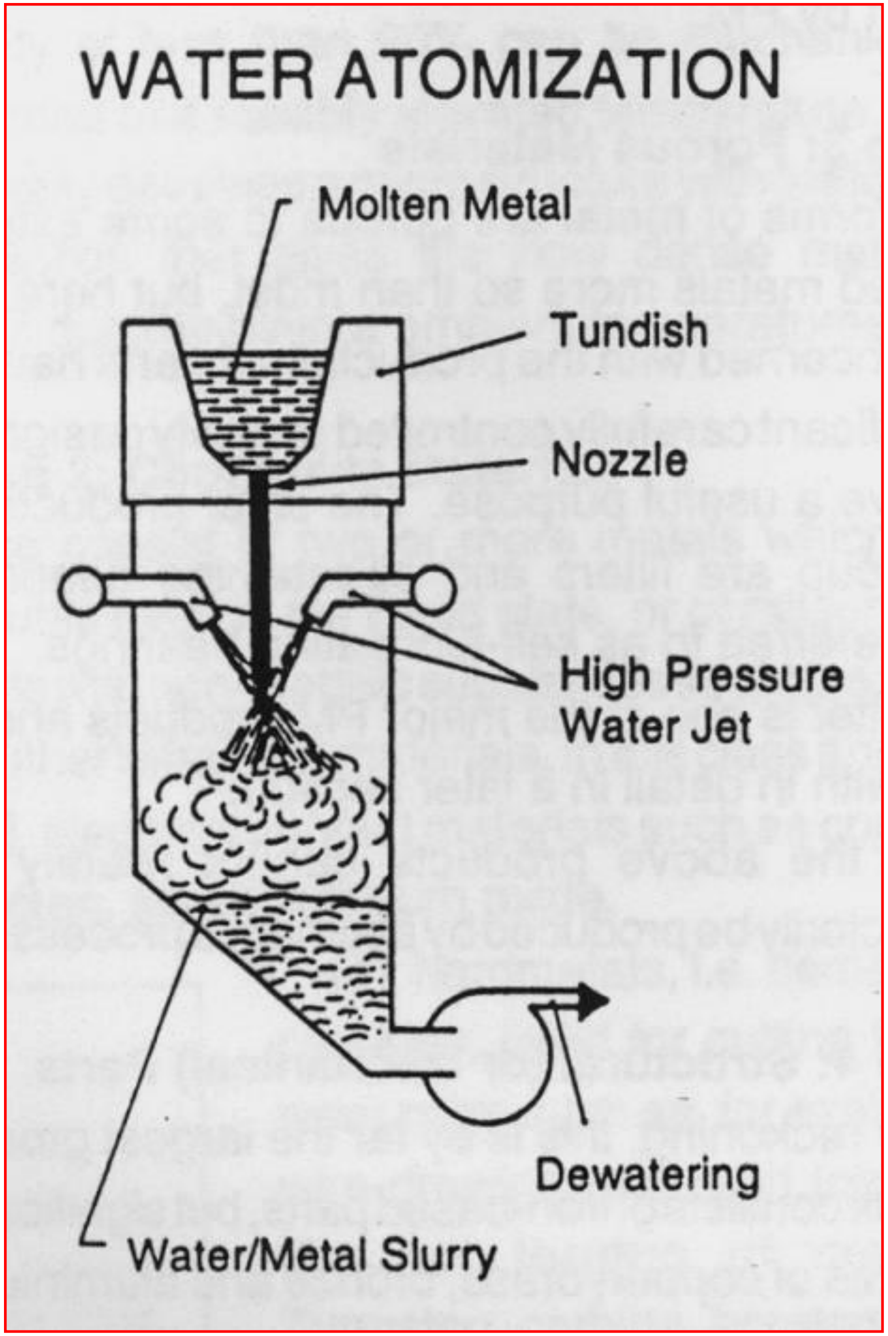


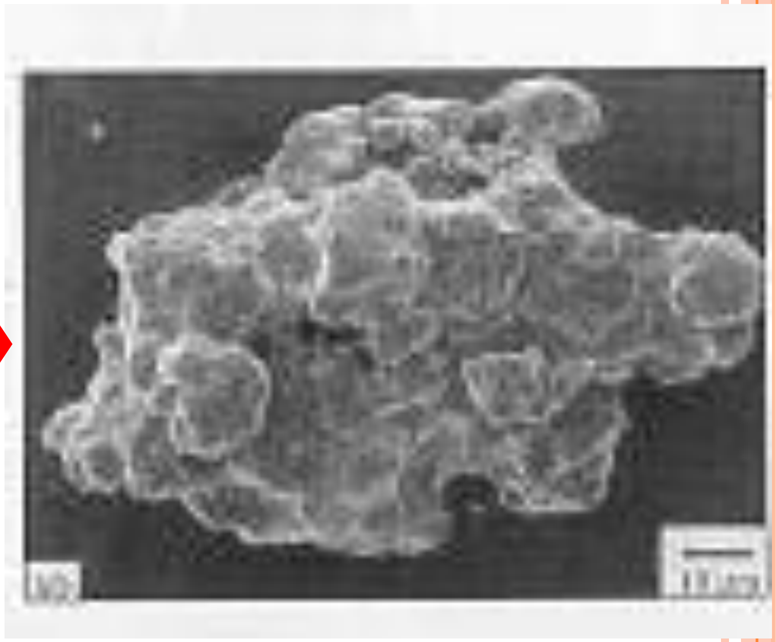
Schematic of horizontal gas atomization

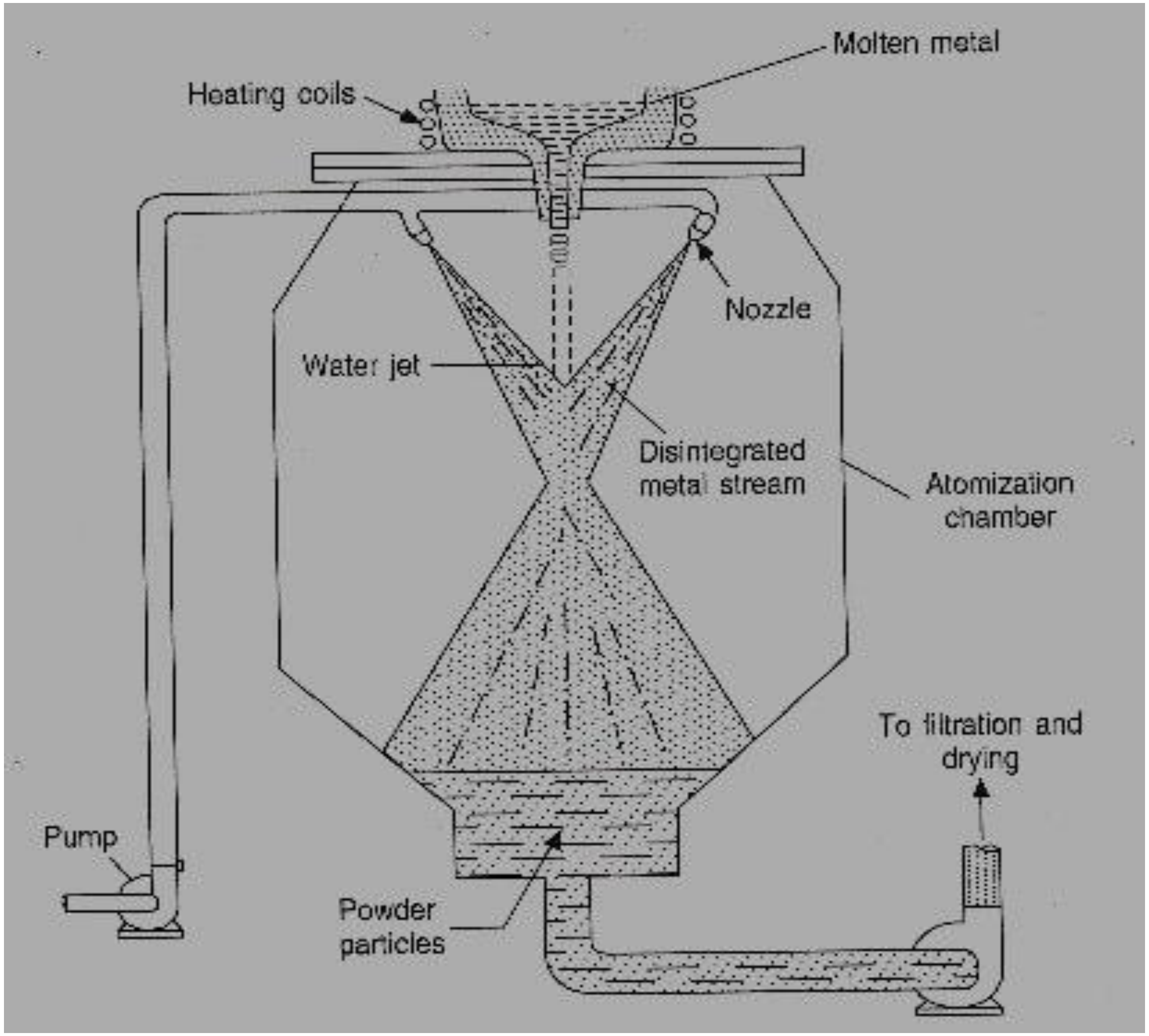
(2) Water atomization

- Water jet is used instead of inert gas
- Fit for high volume and low cost production
- Powders of average size from 150 micron to 400 micron; cooling rates from 103 to 105 K/s.
- Rapid extraction of heat results in irregular particle shape => less time to spheroidize in comparison to gas atomization
- Water pressure of 70 MPa for fine powders in 10 micron range

Water atomization

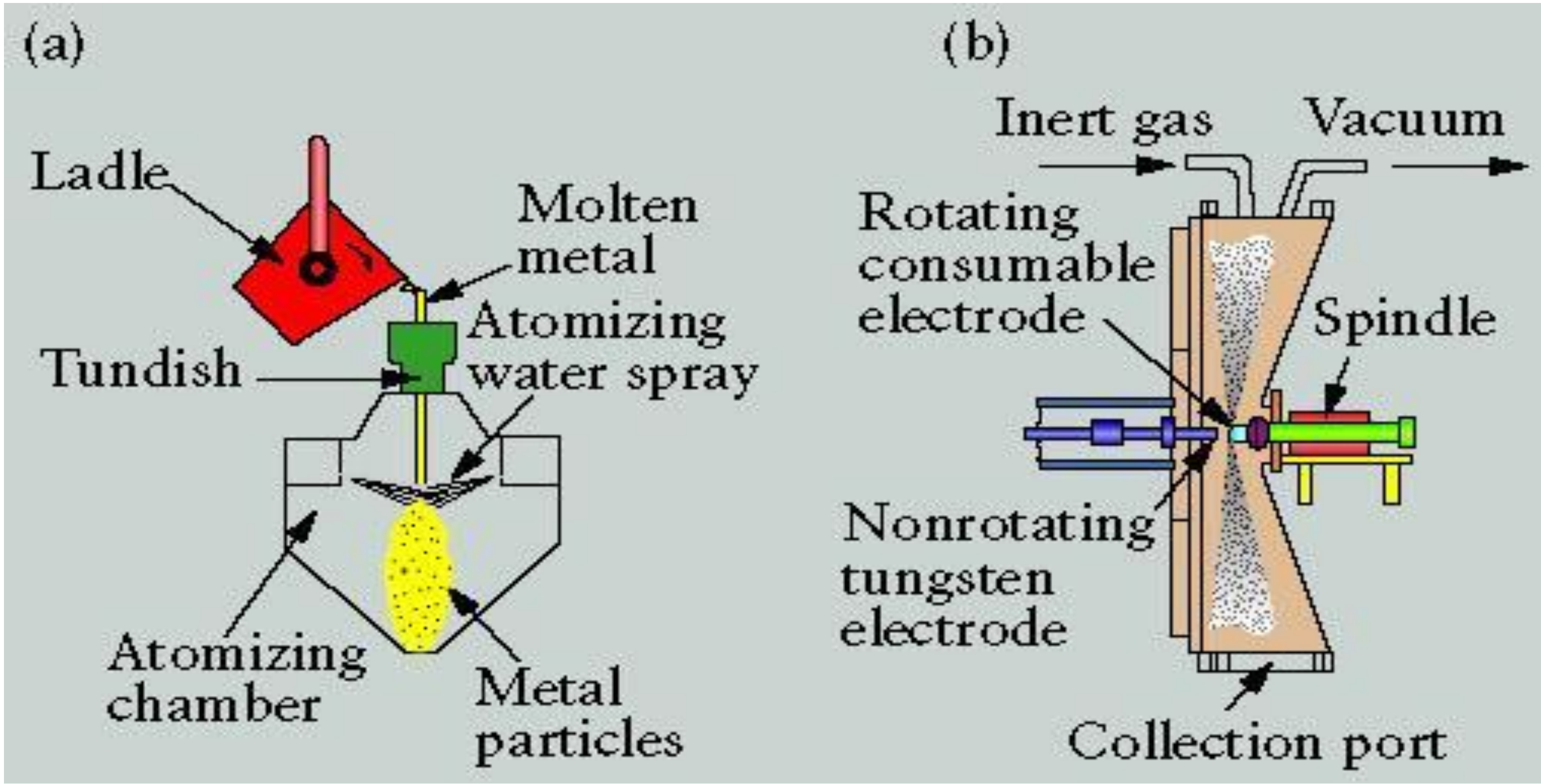






Schematic of water atomization

METHODS OF METAL-POWDER PRODUCTION BY ATOMIZATION



- (a) melt atomization
- (b) atomization with a rotating consumable electrode.

Important parameters:

1. Water pressure: Increase water pressure => size decrease => increased impact
2. water jet thickness: increase thickness => finer particles => volume of atomizing medium increases
3. Angle of water impingement with molten metal & distance of jet travel

Atomization process parameters

1. Effect of pressure of metal head:

   $r = a + bh$; *r – rate of atomization*

2. Effect of atomizing medium pressure:

   $r = ap + b$;

   -*Increase in air pressure* increases the fineness of powder up to a limit, after which no increase is seen

3. Molten metal temperature:

-As temperature increases,

-both surface tension and viscosity decrease; --so available energy can efficiently disintegrate the metal stream producing fine powders than at lower temperature;

- Temperature effect on particle shape is dependent on particle temperature at the instant of formation and time interval between formation of the particle and its solidification;

- Temperature increase will reduce surface tension and
  -hence formation of spherical particle is minimal;
  - however
  -spherical particles can still be formed
  -if the disintegrated particles remain as liquid for longer times.

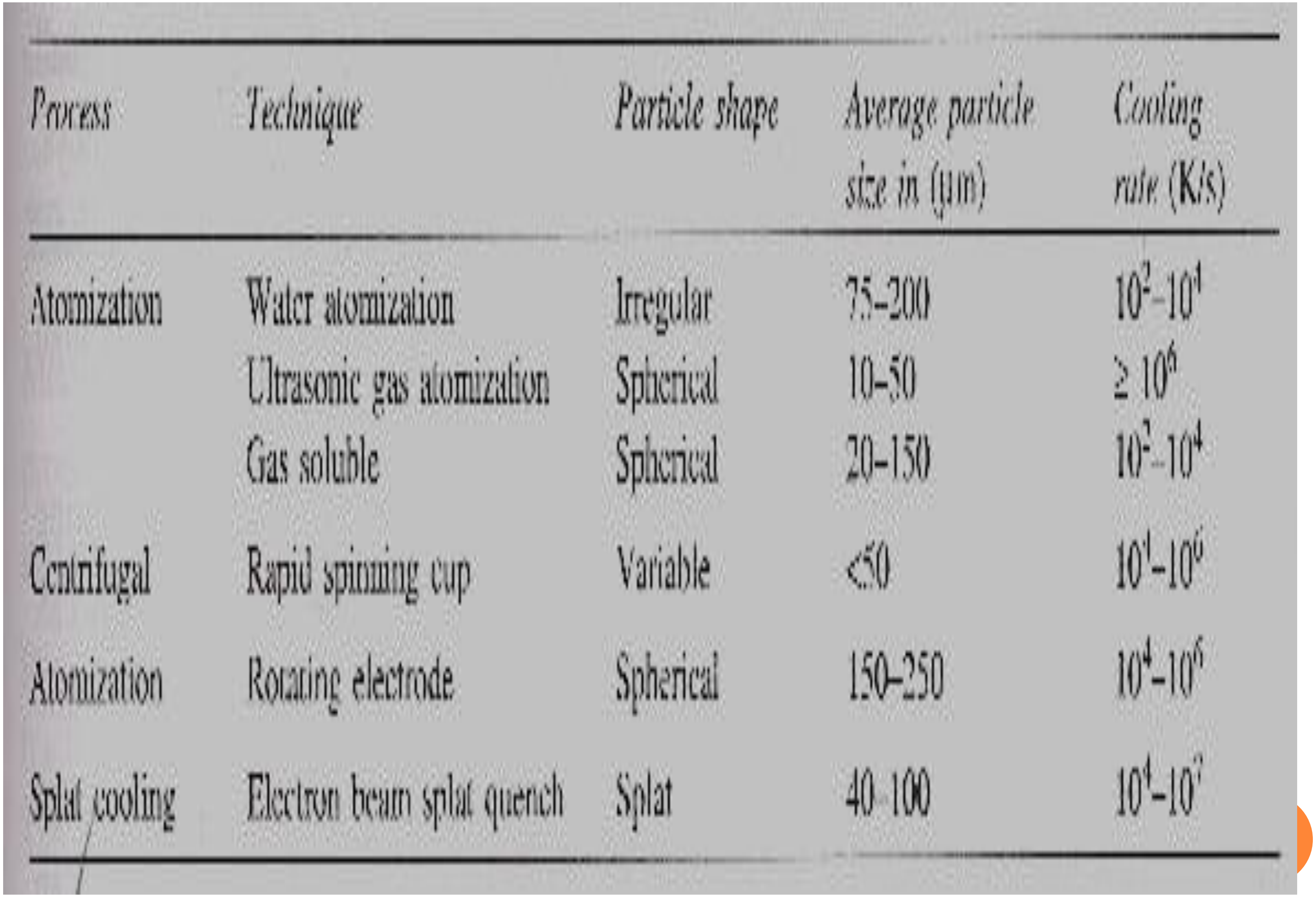
4. Orifice area: negligible effect

5. Molten metal properties:

   -Iron and Cu powder => fine spherical size; Pb, Sn => irregular shape powder;

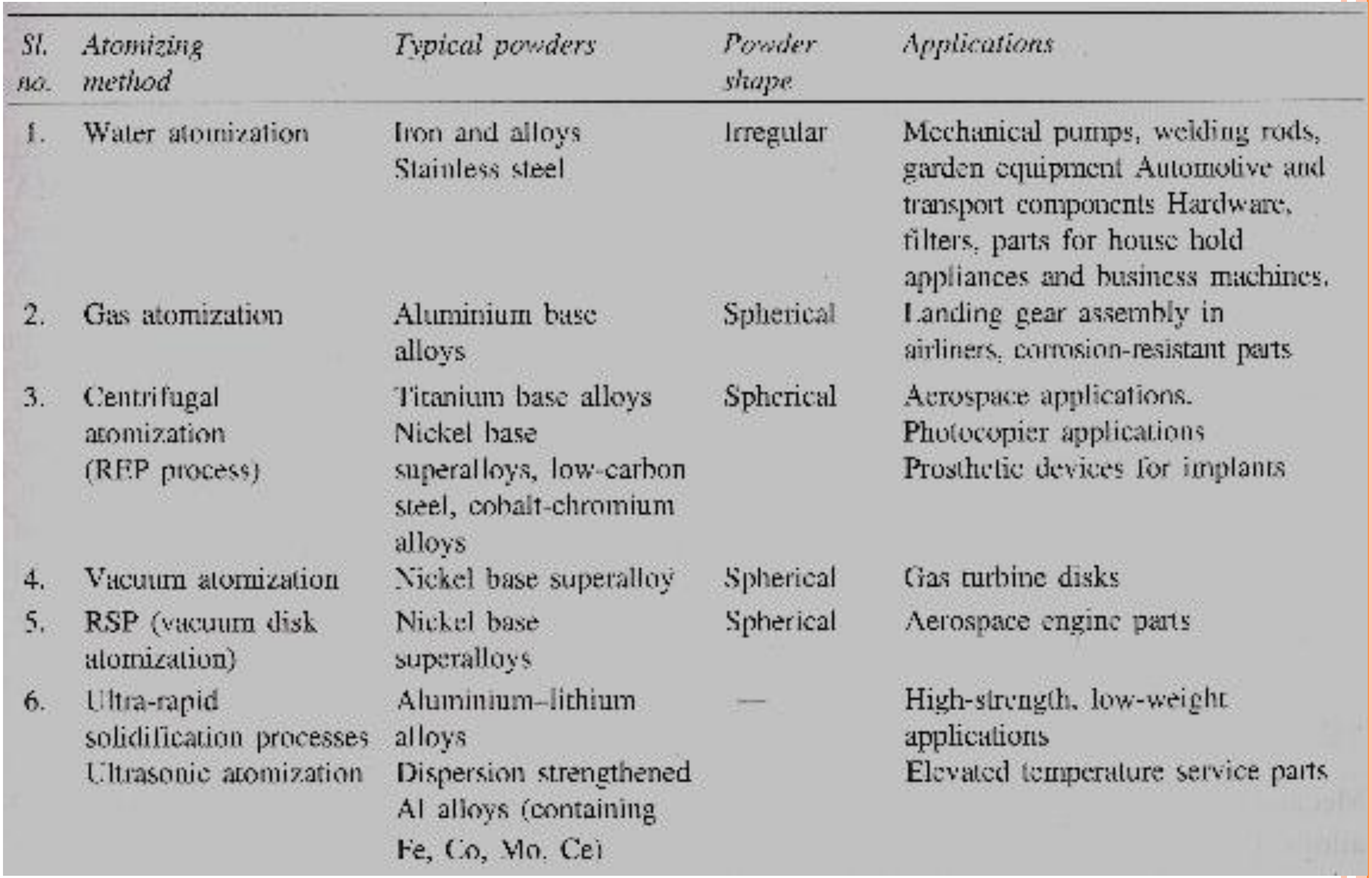
   -Al powders => irregular shape even at high surface tension (oxidation effect)

Characteristics of different atomization processes



Process	Technique	Particle shape	Average particle size in (μm)	Cooling rate (K/s)
Atomization	Water atomization	Irregular	75–200	10^2–10^4
	Ultrasonic gas atomization	Spherical	10–50	$\geq 10^6$
	Gas soluble	Spherical	20–150	10^2–10^4
Centrifugal	Rapid spinning cup	Variable	<50	10^1–10^6
Atomization	Rotating electrode	Spherical	150–250	10^4–10^6
Splat cooling	Electron beam splat quench	Splat	40–100	10^4–10^7

Powders produced by various atomization methods and applications



Sl. no.	Atomizing method	Typical powders	Powder shape	Applications
1.	Water atomization	Iron and alloys Stainless steel	Irregular	Mechanical pumps, welding rods, garden equipment Automotive and transport components Hardware, filters, parts for house hold appliances and business machines.
2.	Gas atomization	Aluminium base alloys	Spherical	Landing gear assembly in airliners, corrosion-resistant parts
3.	Centrifugal atomization (REP process)	Titanium base alloys Nickel base superalloys, low-carbon steel, cobalt-chromium alloys	Spherical	Aerospace applications. Photocopier applications Prosthetic devices for implants
4.	Vacuum atomization	Nickel base superalloy	Spherical	Gas turbine disks
5.	RSP (vacuum disk atomization)	Nickel base superalloys	Spherical	Aerospace engine parts
6.	Ultra-rapid solidification processes Ultrasonic atomization	Aluminium–lithium alloys Dispersion strengthened Al alloys (containing Fe, Co, Mo, Ce)	—	High-strength, low-weight applications Elevated temperature service parts

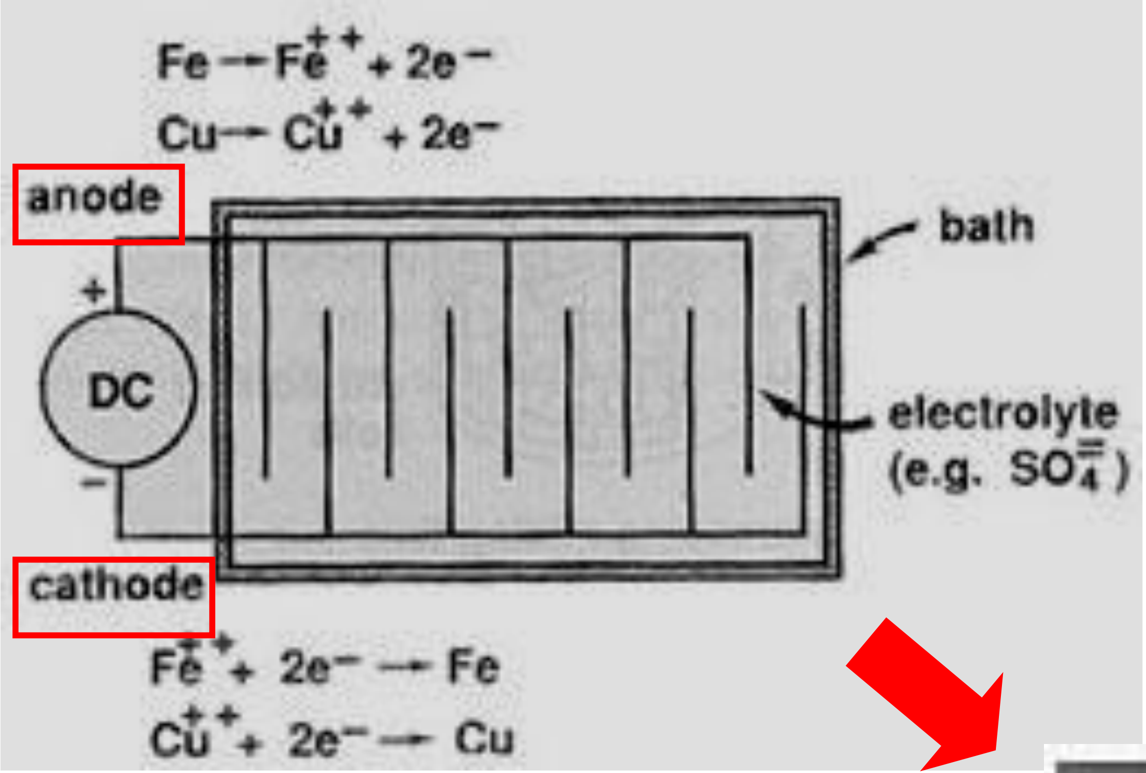
Electrodeposition

- In this method, the processing conditions are so chosen that metals of high purity are precipitated from aqueous solution on the cathode of an electrolytic cell.
- This method is mainly used for producing copper, iron powders.
- This method is also used for producing zinc, tin, nickel, cadmium, antimony, silver, lead, beryllium powders.

- Utilizes aqueous solutions or fused salts.
- Produces purest form of metal powder
- Metal powder deposits at the cathode from aqueous solution
- Powders are among the purest available

- By choosing suitable conditions, such as electrolyte composition and concentration, temperature, and current density, many metals can be deposited in a spongy or powdery state.
- Further processing–washing, drying, reducing, annealing, and crushing–is often required, ultimately yielding high-purity and high-density powders.

Electrolytic deposition



- Copper powder

  => Solution containing copper sulphate and sulphuric acid;

  crude copper as anode
- Reaction:

  at anode: $Cu \rightarrow Cu^+ + e^-$;

  at cathode: $Cu^+ + e^- \rightarrow Cu$
- Iron powder

  => anode is low carbon steel;

  cathode is stainless steel.

- The iron powder deposits are subsequently pulverized by milling in hammer mill.
- The milled powders are annealed in hydrogen atmosphere to make them soft.
- Mg powder => electrodeposition from a purified magnesium sulphate electrolyte using insoluble lead anodes and stainless steel cathodes.

- <u>Powders of thorium, tantalum, vanadium</u>

  => fused salt electrolysis is carried out at a temperature below melting point of the metal.

- Here deposition will occur in the form of small crystals with dendritic shape.

- In this method, final deposition occurs in three ways,

1. A hard brittle layer of pure metal which is subsequently milled to obtain powder (eg. iron powder)
2. A soft, spongy substance which is loosely adherent and easily removed by scrubbing
3. A direct powder deposit from the electrolyte that collects at the bottom of the cell.

- Factors promoting powder deposits are :
  -high current density,
  -low metal concentration,
  -pH of the bath,
  -low temperature,
  -high viscosity,
  -circulation of electrolyte to avoid of convection.

Advantages:

- Powders of high purity with excellent sinterability
- Wide range of powder quality can be produced by altering bath composition.

Disadvantages:

- Time consuming process;
- Pollution of work place because of toxic chemicals;
- Waste disposal is another issue;
- Cost involved in oxidation of powders and hence they should be washed thoroughly

Reduction From Oxides

- Manufacturing of metal powder
  - -by reduction of oxides
  - -is extensively employed,
  - -particularly for Fe, Cu, W and Mo.

- As a manufacturing technique,
  - -oxide reduction may exhibit
  - -certain advantages and disadvantages.
  - -These are listed below:

Advantages:

- A variety of reducing agents can be used and process can be economical when carbon is used.
- Close control over particle size

--- because oxides are generally friable, easily pulverized and easily graded by sieving.

- Porous powders can be produced which have good compressive properties.
- Adoptability either to very small or large manufacturing units and either batch or continuous processes.

Limitations:

- Process may be costly if reducing agents are gases.
- Large volumes of reducing gas may be required, and circumstances where this is economically available may be limited; in some cases, however, costs may be reduced by recirculation of the gas.
- The purity of the finished product usually depends entirely upon the purity of the raw material, and economic or technical considerations may set a limitation to that which can be attained.
- Alloy powders cannot be produced.

Mechanism of Reaction:

- Most metal powders manufactured by reduction of oxides are produced using

-solid carbon or hydrogen, cracked ammonia, carbon monoxide, or mixture of such gases.

- As a reducing agent for metal oxides, carbon holds an important and peculiar position

– because of its general cheapness and availability, and peculiar for the following reasons.

- According to circumstances and temperature, three carbon/oxygen reactions can occur:

(i) $C + O_2 = CO_2$

-In this reaction,

-the number of gaseous molecules remain constant and the entropy change is very small.

- The free energy change of the reaction is almost constant from room temperature to 2000 °C.

(ii) $2CO + O_2 = 2CO_2$

- The reaction is accompanied by a decrease in the number of gas molecules and in entropy with a considerable free energy change.

(iii) $2C + O_2 = 2CO$

- This reaction involves an increase in the number of gaseous molecules and a considerable increase in entropy and a considerable free energy change

- This implies that

  -within temperatures normally used metallurgically

  - carbon monoxide becomes increasingly stable the higher the temperature.
- Consequently,

  -the free energy change temperature curves for these reactions intersect at about 700 °C.

The important implication of these facts is that,

(a) All metal oxide are reducible by carbon from very low to very high temperatures

- although practically the temperatures necessary may be too high, but

(b) The reaction must be prevented from reversing on cooling, and

(c) The product of the reduction will be mainly CO_2 below 700 ^{o}C and mainly CO above this temperature. At high temperatures, any carbon dioxide is reduced by any excess carbon, forming more stable CO.

- When using a reducing gas, continued contact between the oxide and the reducing gas must take place by;

(a) Diffusion of gas through the metal to the oxide,
(b) Diffusion of oxygen, or oxide, through the metal to the gas,
(c) Both (a) and (b), or
(d) Movement of one kind or another through pores.

Production of Iron Powder by Reduction of Iron Oxide:

(Direct Reduction Process)

- Iron powders are commercially used for a large number of applications such as

  -fabrication of structural parts, welding rods, flame cutting, food enrichment and electronic and magnetic applications.

- The classical technique for production of iron powder is the reduction of iron

Theory of the process:

- It is the oldest process of production of iron powder by using carbon as the reducing agent.
- In this process pure magnetite (Fe_3O_4) is used.
- Coke breeze is the carbon source used to reduce iron oxide.
- Some limestone is also used to react with the sulphur present in the coke.
- The mixture of coke and limestone (85% + 15%) is dried in a rotary kiln and crushed to uniform size.

- The ore and coke-limestone mixture is charged into ceramic tubes (Silicon Carbide) with care

-so that ore and reduction mixture are in contact with each other but not intermixed.

- It can be achieved by using concentric charging tubes with in the ceramic tube.

-A pair of concentric steel charging tubes is lowered to the bottom of the ceramic tubes.

-The ore is fed between the steel tubes.

-The coke-limestone mixture is fed

-within the inner of the two concentric charging tubes and between the outer charging tube and the inner wall of the ceramic tube

-leaving the ore and the reduction mixture in contact with one another, but not intermixed.)

- Charged ceramic tubes are loaded on the Kiln cars (thirty six tubes on each) and

  cars are pushed into 170 meter long tunnel kiln where the reduction occurs.

- The total time a car is present in the kiln is 68 hrs.
- Gas burners heat the 150 meter tunnel at a temperature of 1200-1260 °C and remaining length is cooled by air circulation.
- Within the hot zone, several chemical reactions occur and metallic iron is formed in the form of sponge cake.

- The main reaction is;

$$MO + R \longrightarrow M + RO$$

- If magnetite ore is used, then the following reactions will take place:

$$Fe_3O_4 + 3CO \longrightarrow FeO + 3CO_2$$

$$FeO + CO \longrightarrow Fe + CO_2$$

$$C + \tfrac{1}{2} O_2 \longrightarrow CO$$

- Decomposition of the limestone generates carbon dioxide

  -which oxidizes the carbon in the coke to form carbon monoxide.

- The ferrous iron oxide is further reduced by the carbon monoxide to metallic iron.
- Desulphurization occurs in parallel with reduction by

  -reaction between gas and sulphides present in the ore

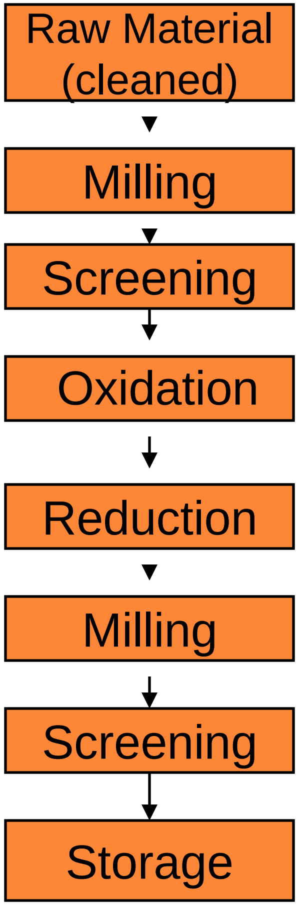
  -resulting in gaseous sulphide compounds

  which in turn react with lime to form calcium sulphide.

- The sponge cake is removed from ceramic tubes and dropped into a tooth crusher where this is broken into pieces.
- After these pieces are ground to desired particle size.
- During grinding the powder particles are considerably work hardened.
- The powder is annealed at 800 - 870 ^{o}C in the atmosphere of dissociated ammonia.
- The powder is loosely sintered, but requires only light grinding and screening to produce a finished product.

PYRON PROCESS

- Mill scale
- Reducing agent ---- Hydrogen gas



Raw Material (cleaned)

Milling

Screening

Oxidation

Reduction

Milling

Screening

Storage

- Mill scale is basically obtained from steel mills which produce sheets, rods, wires, plates and pipes.
- The mill scale mainly consists of $Fe_3 O_4$, and also contains oxides of tramp elements normally associated with steel,

  -especially Si, Mn and Cr in the form of very finely dispersed oxides difficult to reduce.
- The mill scale is dried and ground up to the desired particle size in a continuous ball mill. (- 100 mesh)
- Oxidation of the mill scale at 870 to 980 ^{o}C converts Fe O and $Fe_3 O_4$ to ferric oxide ($Fe_2 O_3$).
- This process is essential to ensure uniform properties of Pyron-iron Powder.

- Reduction of ferric oxide by hydrogen is done in an electric furnace (30 – 40 meter long) at 980 ^{O}C . (continuous belt furnace).
- Hydrogen is supplied by NH_3 cracking plant and reduction is done at 980 ^{O}C.

$$Fe_2O_3 + 3H_2 \longrightarrow 2Fe+3H_2O$$

- The reduction product is ground and mechanically densified to make it suitable for production of structural parts.
- Fine particle size -----small pores -----------faster sintering.

Powder Characteristics:

- The Pyron Powder is a porous and finer.
- It has sponge like microstructure.
- It sinters faster as compared to powder formed by other commercials processes.

Advantages:

- There is no relative movement of particles of the charge to each other or to the belt, therefore sticking and welding is avoided.
- Low carbon contents in the final product because of use of hydrogen.
- Low labor cost.
- Thin beds and continuous flow of reducing gases lead to a comparatively short time of reduction.

* The purity of the iron powder product is entirely a function of the raw mill scale.

CARBONYL PROCESS

- React high purity Fe or Ni with CO to form gaseous carbonyls
- The reaction products are then decomposed to iron and nickel.
- Small, dense, uniformly spherical powders of high purity

- A process in powder metallurgy for the production of iron, nickel, and iron-nickel alloy powders for magnetic applications.
- A process used in putting a metallic coating on molybdenum tungsten and other metals.
- Thermal decomposition of a chemical compound is used in some cases, a notable one being nickel carbonyl.

- This Carbonyl Process was originally developed as a means of refining nickel

  -crude metal being caused selectively to react with carbon monoxide

  -under pressure to form the carbonyl

  -which is gaseous at the reaction temperature and

  -which decomposes on raising the temperature and lowering the pressure.

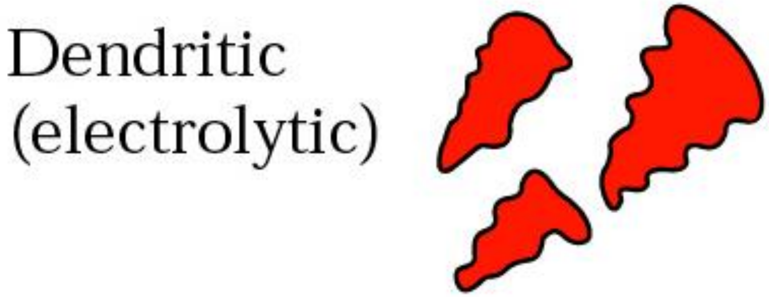
- The same process is used for iron,

  -and carbonyl iron powder finds small-scale application where its very high purity is useful.
- Recently, demand for very fine powders for the injection moulding process has given a considerable impetus to the carbonyl process.
- Typically the particle size of carbonyl iron powder is 1 - 5 µm, but,

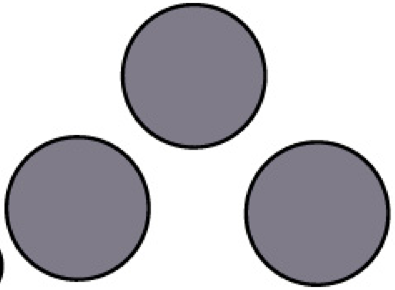
  -as in the case of nickel, it can be tailored to suit particular requirements.

ELECTROLYTIC DEPOSITION AND CARBONYLS

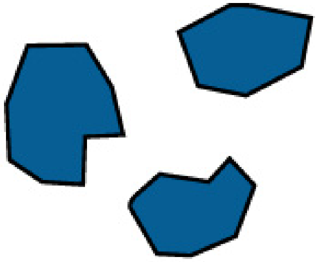
- Electrolytic Deposition utilizes either aqueous solutions or fused salts
- Makes the purest powders that are available



- Metal carbonyls are formed by letting iron or nickel react with carbon monoxide
- Reaction product is decomposed to iron and nickel
- Forms small, dense, uniform spherical particles



Spherical
(atomization,
carbonyl (Fe),
precipitation
from a liquid)



Angular
(mechanical disintegration,
carbonyl (Ni))

PRODUCTION OF ALLOY POWDERS

- Premixes are easy to compact and effect less tool wear, but

  -need longer sintering times than prealloyed powders.
- Production of prealloyed steel powders

  -addition of alloying elements being made to permit the production of a strong material.

- Stainless steel powders are widely available
- High speed steel powders for the production of high quality parts has become a reality.
- Other ferrous alloy powders include

  -iron-nickel

  -iron-manganese

  -iron-molybdenum

  -iron-nickel-molybdenum

- More common non-ferrous alloy powders include
  -bronzes containing 90% Cu-10% Sn
  -brasses containing 90% Cu-10% Zn, or
  80% Cu-20% Zn
  (with small additions of Pb)
  -aluminum bronze
  -a range of copper-nickel and nickel-silver.

- In recent years, following methods have been employed to produce complex powders:

  (i) atomization process

  (ii) combined precipitation in the thermal decomposition of carbonyls

  (iii) combined precipitation of metals in electrolysis, and

  (iv) spray drying.

- Atomization process already discussed.
- Simultaneous thermal decomposition of several carbonylic metals or unstable organic compounds

  -following combined recrystallisation of powder particles

  -result in the production of alloy powders such as

  -iron-nickel powders with a nickel content in the range of 10 to 80% , and

  -iron-nickel-molybdenum powders with a molybdenum content upto 1.5% and with various nickel contents.

- Complex alloy powders such as

  -iron-nickel, iron-manganese, iron-molybdenum,

  iron-nickel-molybdenum,

  -brass, bronze, etc.

  are produced by electrolytic deposition method by using

  (i) a mixture of electrolytes containing two or more metal salts

  (ii) cast alloy of required composition as the anodes, or

  (iii) composite anodes of the appropriate metal and alloy component.

- Spray drying consists of

  -contacting a spray

    -(of an aqueous mixture of salts such as cobalt oxalate, nickel oxalate, chromium acetate, molybdenum trioxide and thorium nitrate containing low solid content)

  -with a blast of hot air

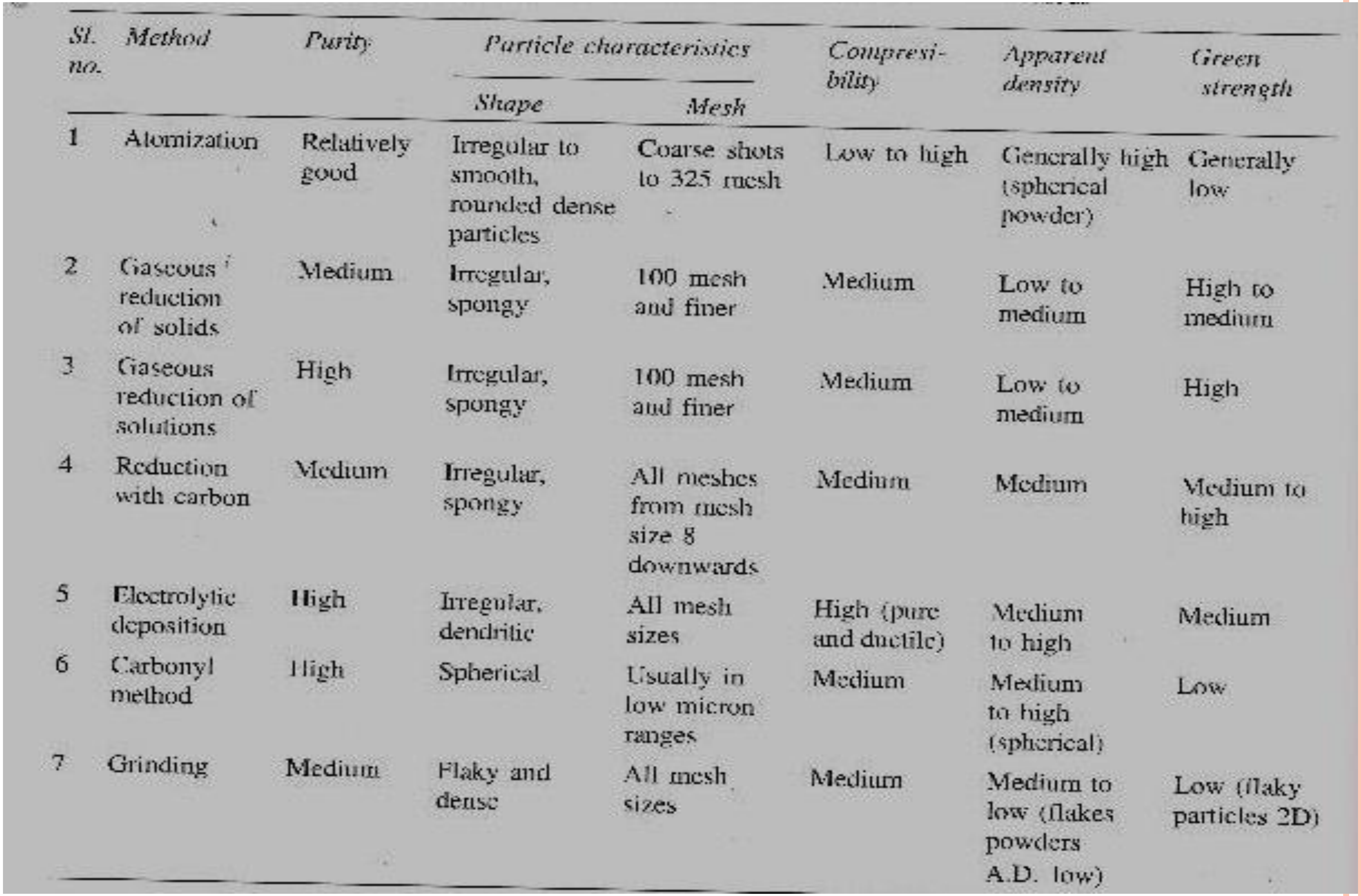
  -calcining dried mass

    -to convert all the metal compounds to the oxides at 800 ^{0} C in air and

  -reduction in hydrogen

  -in order to produce a superalloy powder with dispersed thoria.

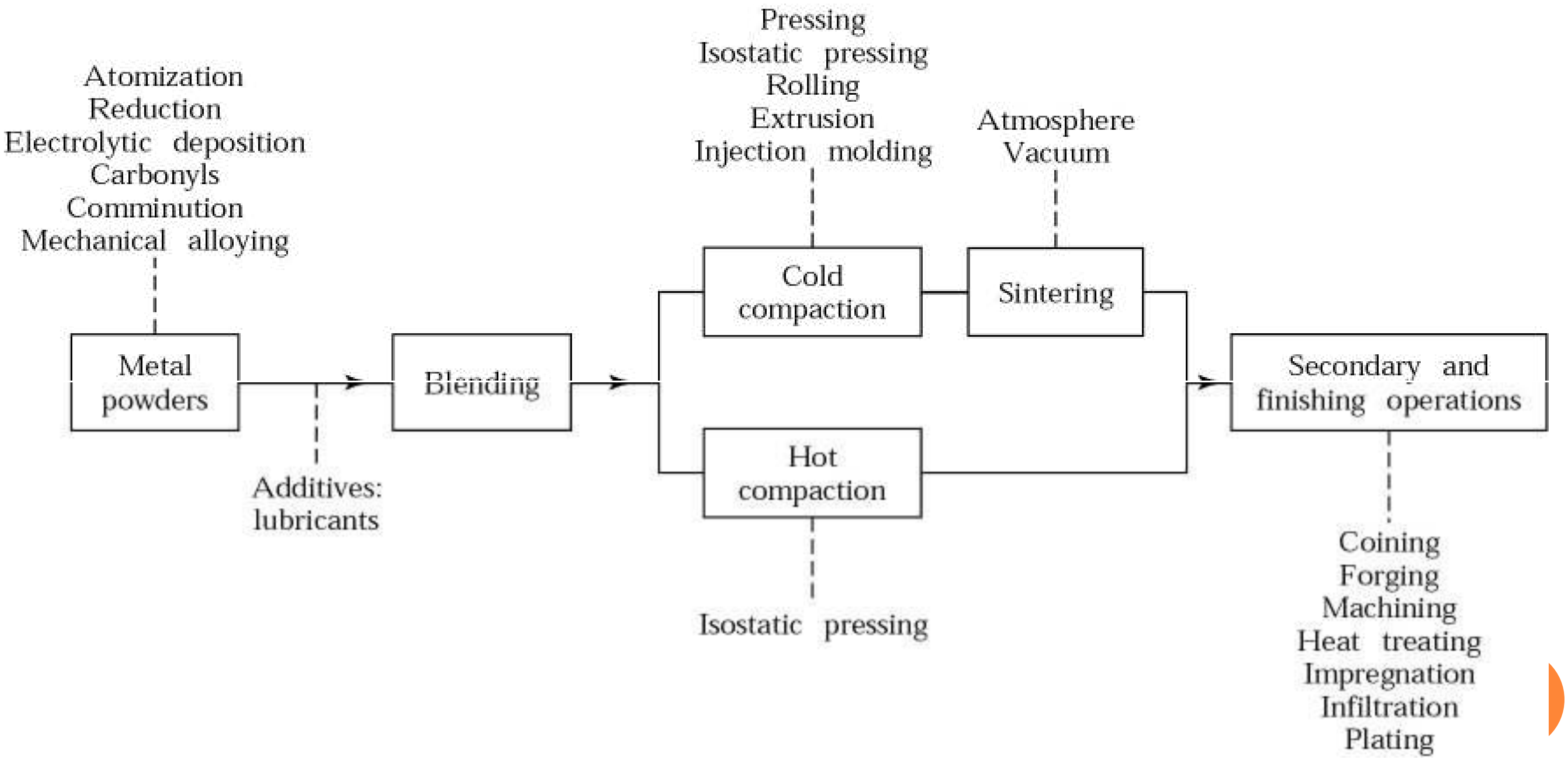
Summary of various powder production methods



Sl. no.	*Method*	*Purity*	*Particle characteristics*		*Compresibility*	*Apparent density*	*Green strength*
			Shape	*Mesh*			
1	Atomization	Relatively good	Irregular to smooth, rounded dense particles	Coarse shots to 325 mesh	Low to high	Generally high (spherical powder)	Generally low
2	Gaseous reduction of solids	Medium	Irregular, spongy	100 mesh and finer	Medium	Low to medium	High to medium
3	Gaseous reduction of solutions	High	Irregular, spongy	100 mesh and finer	Medium	Low to medium	High
4	Reduction with carbon	Medium	Irregular, spongy	All meshes from mesh size 8 downwards	Medium	Medium	Medium to high
5	Electrolytic deposition	High	Irregular, dendritic	All mesh sizes	High (pure and ductile)	Medium to high	Medium
6	Carbonyl method	High	Spherical	Usually in low micron ranges	Medium	Medium to high (spherical)	Low
7	Grinding	Medium	Flaky and dense	All mesh sizes	Medium	Medium to low (flakes powders A.D. low)	Low (flaky particles 2D)

POWDER CONDITIONING

- Making powder & subsequent processing



Atomization
Reduction
Electrolytic deposition
Carbonyls
Comminution
Mechanical alloying

Metal powders

Additives: lubricants

Blending

Pressing
Isostatic pressing
Rolling
Extrusion
Injection molding

Cold compaction

Hot compaction

Isostatic pressing

Atmosphere
Vacuum

Sintering

Secondary and finishing operations

Coining
Forging
Machining
Heat treating
Impregnation
Infiltration
Plating

- Powders manufactured for P/M applications can be classified into –
- Elemental powders, and pre-alloyed powders
  - Elemental powders => powders of single metallic element; eg.: iron for magnetic applications
  - Pre-alloyed powders => more than one element; made by alloying elemental powders during manufacturing process itself; IN this case, all the particles have same nominal composition and each particle is equivalent to small ingot

MAJORITY OF POWDERS UNDERGO HEAT TREATMENTS PRIOR TO COMPACTION LIKE,

1. Drying to remove moisture,
2. grinding/crushing to obtain fine sizes,
3. particle size classification to obtain the desired particle size distribution,
4. annealing,
5. mixing and blending of powders,
6. lubricant addition for powder compaction,
7. powder coating

CLEANING OF POWDERS:

- Refers to the removal of contaminants, solid or gaseous, from the powder particles
- Solid contaminants => come from several sources like nozzles or crucible linings. They interfere during compaction and sintering preventing proper mechanical bonding
- Most of these contaminants are non-reactive, but they act as sites for crack nucleation and reduce the dynamic properties of the sintered part; Non-metallic solid impurities can be removed from superalloy powders by particle separators, electrostatic separation techniques

- Gaseous impurities like hydrogen and oxygen get into powders during processing, storage or handling if proper care is not taken. Finer the powders, contamination will be more because of large powder surface area.
- These gaseous impurities can form undesirable oxides during processing at relatively high temperature or gets trapped inside the material as pores, reducing the in situ performance of the P/M part; Degassing techniques like cold, hot static or dynamic degassing methods are used to remove adsorbed gases from the powders
- Lubricants added to the powders for better compaction has to be removed for desirable final P/M part

GRINDING

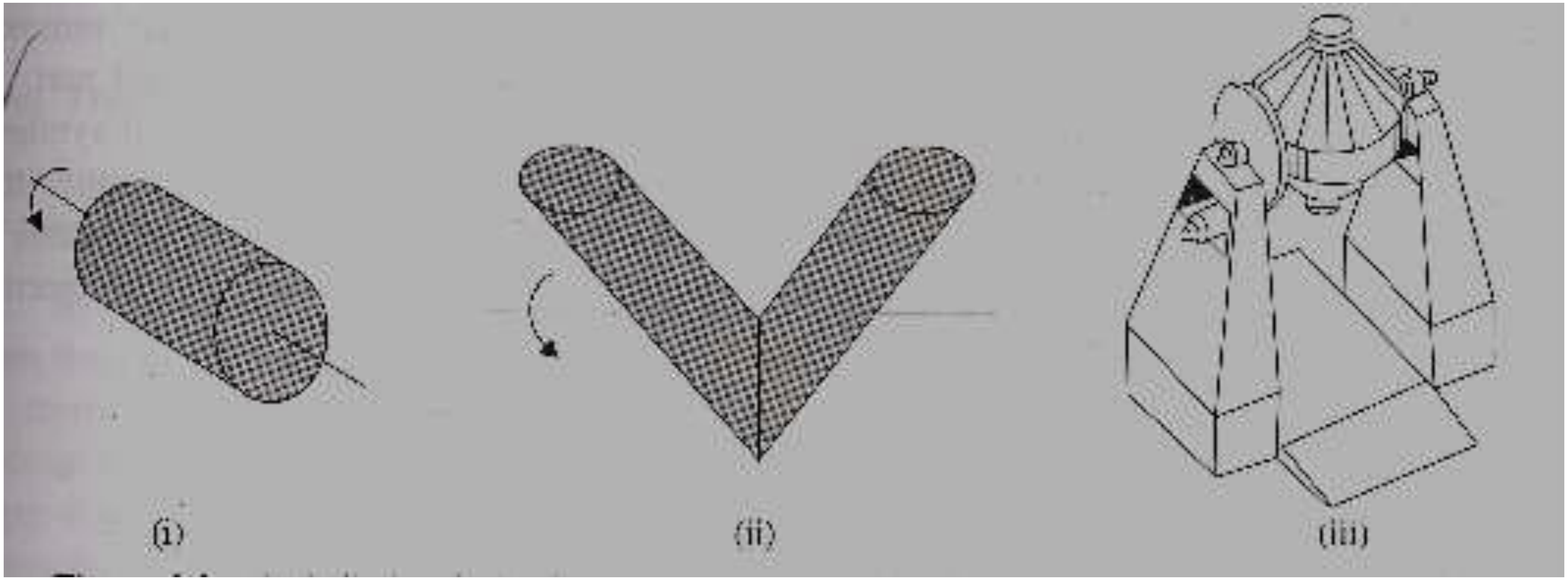
- similar to the mechanical methods seen earlier; Milling is widely used for reducing the aggregates of powder; Milling time, speed, type can be selected for getting required degree of grinding

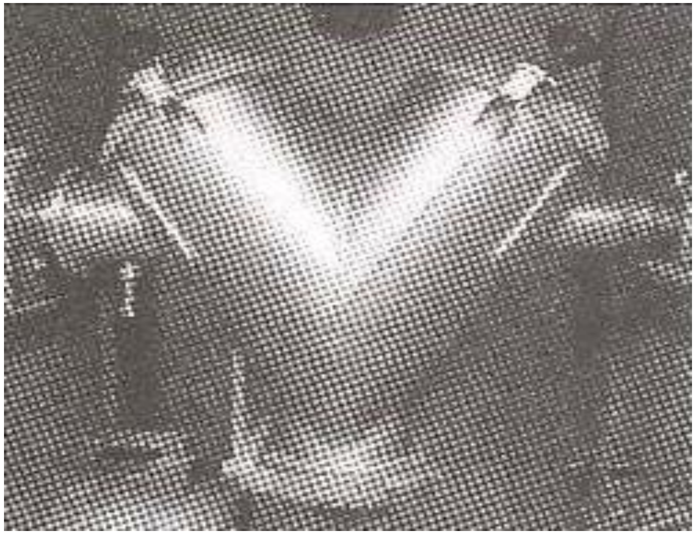
POWDER CLASSIFICATION & SCREENING

- Powder size and shape, size distribution varied within specified range is required for better behavior of P/M parts; In this method, the desired particle size distributions with particle sizes within specific limits can be obtained; These variation depends on lot also

BLENDING & MIXING

- Blending:
- Process in which powders of the same nominal composition but having different particle sizes are intermingled.
- This is done to
  1. obtain a uniform distribution of particle sizes, i.e. powders consisting of different particle sizes are often blended to reduce porosity,
  2. for intermingling of lubricant with powders to modify metal to powder interaction during compaction


(i)
(ii)
(iii)



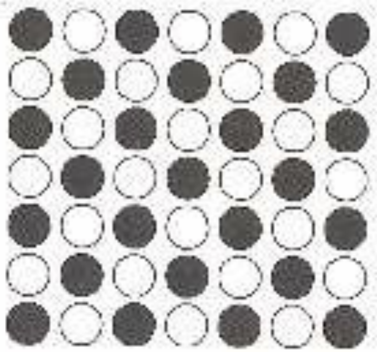
MIXING

- process of combining powders of different chemistries such as elemental powder mixes (Cu-Sn) or metal-nonmetal powders.
- This may be done in dry or wet condition.
- Liquid medium like alcohol, acetone, benzene or distilled water are used as milling medium in wet milling.
- Ball mills or rod mills are employed for mixing hard metals such as carbides.

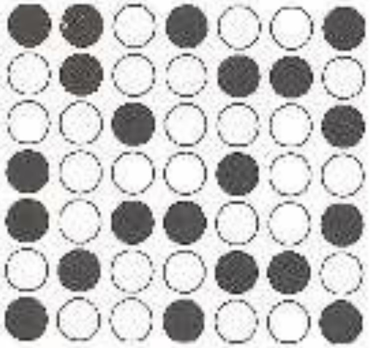
MIXING METHODS

- The various types of mixing methods are,
  1. convective mixing: transfer of one group of particles from one location to another,
  2. diffusive mixing: movement of particles on to newly formed surface,
  3. shear mixing: deformation & formation of planes within the powders

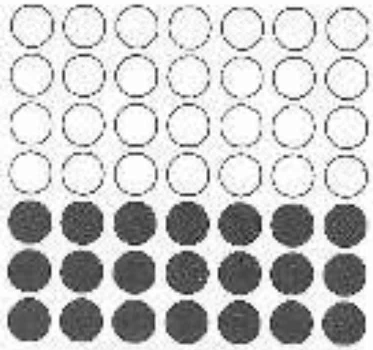
- Depending on the extent of mixing, mixing can be classified as
  1. perfectly mixed or uniform mixing,
  2. random mixed, &
  3. totally un-mixed.
- The mixing should be stopped when random mixture is achieved. Overmixing leads to reduced flow characteristics of the mix.



(i)



(ii)



(iii)

- Where,

  i. Uniform Mixing.
  ii. Random Mixing.
  iii. Unmixed.

HEAT TREATMENT OF POWDERS

- Heat treatment is generally carried out before mixing or blending the metal powders.
- Some of the important objectives are:

- ***Improving the purity of powder:***
- Reduction of surface oxides from powders by annealing in hydrogen or other reducing atmosphere.
- Dissolved gases like hydrogen and oxygen, other impurities are removed by annealing of powders.

- Lowering impurities like carbon results in lower hardness of the powder and hence lower compaction pressures & lower die wear during compaction.
- For eg., atomized powders having a combined carbon and oxygen content as high as 1% can be reduced after annealing to about 0.01% carbon and 0.2% oxygen.
- Heat treatment is done at protective atmosphere like hydrogen, vacuum.

IMPROVING THE POWDER SOFTNESS

- Aim is to reduce the work hardening effect of powders that has be crushed to obtain fine powders; while many powders are made by milling, crushing or grinding of bulk materials.
- Powder particles are annealed under reducing atmosphere like hydrogen.
- The annealing temperature is kept low to avoid fusion of the particles.

MODIFICATION OF POWDER CHARACTERISTICS

- The apparent density of the powders can be modified to a higher or lower value by changing the temperature of treatment

TOXICITY OF POWDERS

- Toxicity leads to undesirable health effects like eye, skin irritation, vomiting, respiratory problems, blood poisoning etc.
- powder like lead, nickel are highly toxic & Al, iron are less toxic
- Precautions: Use of protective gloves, respiratory masks, protective clothing etc.; use of well ventilated storage, workplace; careful handling, disposal of wastes

- flammability & reactivity data is required
- Health effects: Inhalation – disturbs the respiratory track; remedial measures include moving the person to fresh air.
- Artificial breathing is required if patient not breathing properly.

COMPACTION OF METAL POWDERS

- Compaction is an important step in powder processing as it enables the forming of loose metal powders into required shapes with sufficient strength to withstand till sintering is completed.
- In general, compaction is done without the application of heat.
- Loose powders are converted into required shape with sufficient strength to withstand ejection from the tools and subsequent sintering process.

- IN cases like cemented carbide, hot compaction is done followed by sintering.
- One can not call this as compaction strictly, as sintering is also involved in this.

POWDER COMPACTION METHODS

- Methods without application of pressure –
  1. loose powder sintering in mould,
  2. vibratory compaction,
  3. slip casting,
  4. slurry casting,
  5. injection moulding

- Methods with applied pressure –
  1. cold die compaction (single action pressing, double action pressing, floating die pressing),
  2. isostatic pressing,
  3. powder rolling,
  4. powder extrusion,
  5. explosive compaction

PRESSURE LESS COMPACTION TECHNIQUES

- Used for the production of simple and low density parts such as filters, other parts that are porous in nature; these techniques involve no external force and depend upon gravity for powder packing.
- Loose powder sintering: - Also known as loose powder shaping, gravity sintering, pressureless sintering. In this method, the metal powder is vibrated mechanically into the mould, which is the negative impression of the product and heated to sintering temperature.

- This is the simplest method and involve low cost equipment. The main reasons for not using this method for part production are, difficulty of part removal from the mould after sintering, & considerable shrinkage during sintering.
- Applications:
  - Amount of porosity ranges from 40 vol% to as high as 90 vol%;
  - Highly porous filter materials made of bronze, stainless steel, and monel,
  - porous nickel membrane for use as electrodes in alkaline storage batteries and fuel cells are typical examples.

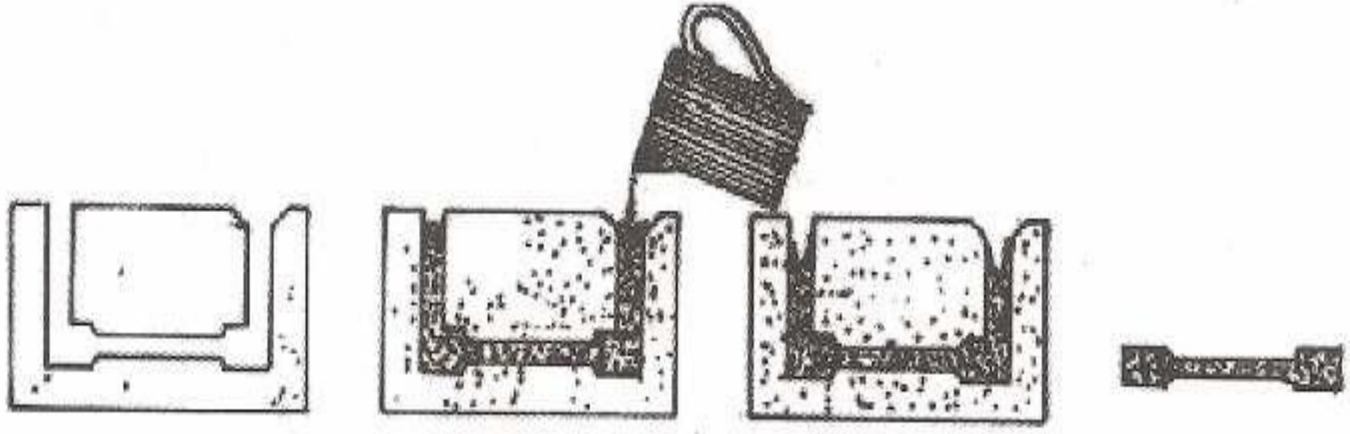
- II) Slip casting: - Used for compacting metal and ceramic powders to make large & complex shapes for limited production runs
- A slip is a suspension of metal or ceramic powder (finer than 5 µm) in water or other soluble liquid which is pored into a mould, dried and further sintered.

- Slip is usually made of,
  1) a dispersion agent to stabilize the powder against colloidal forces,
  2) a solvent to control the slip viscosity and facilitate casting,
  3) a binder for giving green strength to the cast shape,
  4) plasticizer to modify the properties of the binder

- For successful slip casting, formation of appropriate and a consistent slip is important.
- This is achieved by proper control of particle size, size distribution, order of component addition, their mixing time, addition of proper *deflocculant*
- *deflocculant* - to prevent the settling and aggregation of powders and maintains the desirable viscosity of the slip.

- Mostly water is used as suspending medium, but absolute alcohol or other organic liquids may also be employed.
- Additives like alginates – ammonium and sodium salts of alginic acids, serve three fold functions of deflocculant, suspension agent & binding agent to improve green strength of the compact
- The slip to be cast is obtained in a form of suspension of powder in a suspending medium. The slip should have low viscosity & low rate of setting so that it can be readily poured. The slip cast should be readily removable from the mould. Low shrinkage and high strength after drying is expected.

- To obtain these properties, 5 µm powder particles should be used. In the case of fine molybdenum powders, a slip can be prepared by suspending the powder in 5% aqueous polyvinyl alcohol with a minimum viscosity, at a pH value of 7.
- For coarser, spherical stainless steel powder, a mixer of 80.7% metal powder, 19% water, 0.3% of sodium alginate as deflocculant having a pH value of 10 can be used.



- Steps in slip casting:

  i) Preparing assembled plaster mould,

  ii) filling the mould,

  iii) absorption of water from the slip into the porous mould,

  iv) removal of part from the mould,
  v) trimming of finished parts from the mould

- Sometimes mould release agents like oil, graphite can be used.
- Hollow and multiple parts can be produced
- <u>Advantages of slip casting: </u>Products that can not be produced by pressing operation can be made, no expensive equipment is required, works best with finest powder particles
- <u>Disadvantage: </u>slow process, limited commercial applications
- <u>Applications</u>: tubes, boats, crucibles, cones, turbine blades, rocket guidance fins; Also products with excellent surface finish like basins, water closets

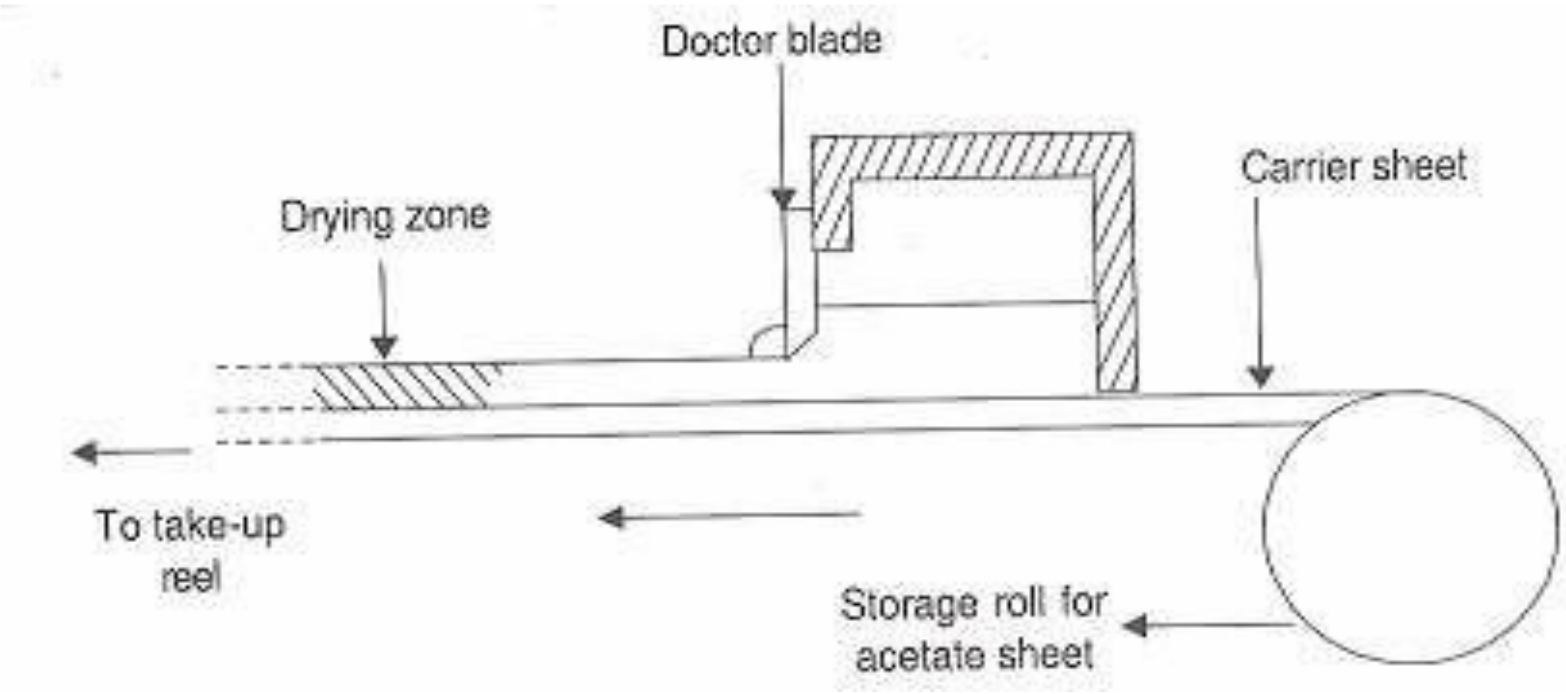
SLURRY CASTING

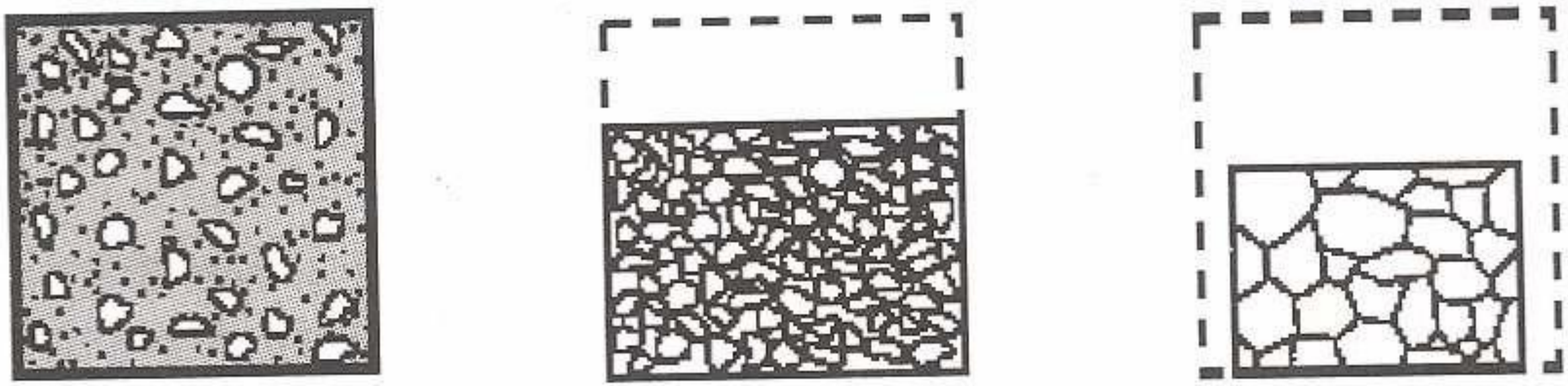
- This process is similar to slip casting except that a slurry of metal powders with suitable liquids, various additives, and binders is poured into a mould and dried.
- The solvent is removed either by absorption into the POP or by evaporation.
- Very high porous sheet for use as electrodes in fuel cells and nickel- cadmium rechargeable batteries are produced by this method

TAPE CASTING (DOCTOR BLADE CASTING):

- This is a variation of slurry casting process and is used to produce thin flat sheets.
- This process involves preparing a dispersion of metal or ceramic powder in a suitable solvent with the addition of dispersion agent (to improve the dispersion of the particles).
- Then a binder is added and fed to a reservoir. Whole mixture is fed on to a moving carrier film from the bottom of the reservoir.
- This slurry layer is deposited on the film by the shearing action of a blade

- The slurry should be free of air bubbles, otherwise result in porosity. During sintering, the binder is burnt off first and densification of material occurs.
- In present days, endless stainless steel belt is used instead of carrier tape.
- This process can be used for making very thin tapes between 50 to 1000 µm thickness. This method is used for making electronic substrates, dielectrics for capacitors and piezoelectric actuators





Slip

Green tape

Sintered tape

Stages in tape casting

VIBRATORY COMPACTION

- Vibratory compaction uses vibration energy to compact the powder mass.
- During this process, smaller voids can be filled with particles of still smaller size and this sequence is carried out till a high packing density of powder is achieved even before consolidation.
- Mechanical vibration facilitates the formation of nearly closed packed powder by settling particles in the voids present in the powder agglomerate.
- During vibration, small pneumatic pressure is usually superimposed on the powder mass.

- Brittle powders can be compacted by this method as they develop crack if done by pressure compaction
- This method is generally used when,

1) powders have irregular shape,

2) use of plasticizers for forming is not desirable,

3) sintered density is required to be very close theoretical density

IMPORTANT VARIABLES IN VIBRATORY COMPACTION

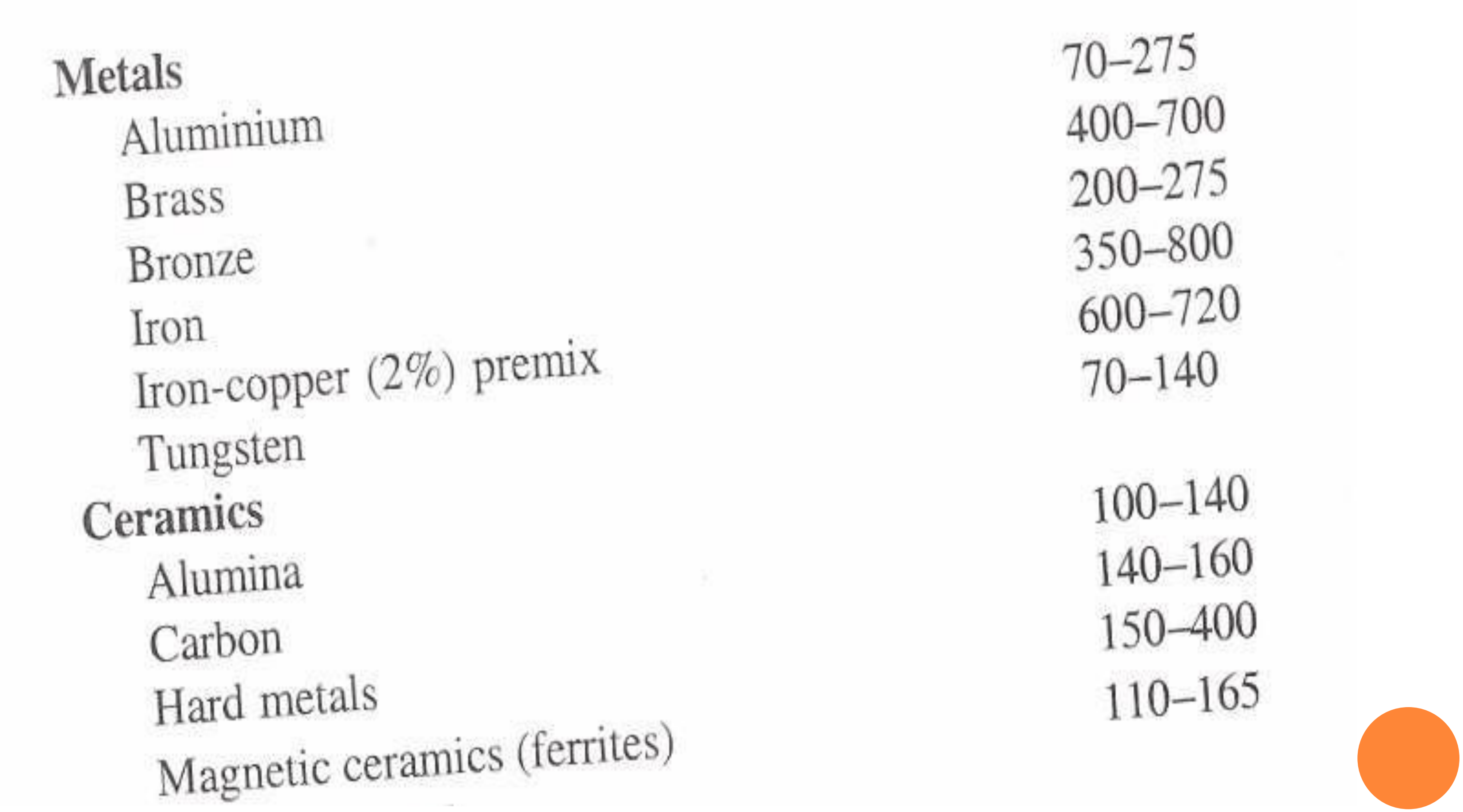
1. inertia of system: larger the system, more the energy required for packing
2. friction force between particles: more friction results in need of more KE for compaction
3. particle size distribution: more frequency required if more large particles are present.

PRESSURE COMPACTION TECHNIQUES

- These techniques involve application of external pressure to compact the loose powder particles; Pressure applied can be unidirectional, bidirectional or hydrostatic in nature.
- Die compaction: In this process, loose powder is shaped in a die using a mechanical or hydraulic press giving rise to densification. The mechanisms of densification depend on the material and structural characteristics of powder particles.

- Unidirectional and bidirectional compaction involves same number of stages and are described in this figure. They are,
- i) charging the powder mix,
- ii) applying load using a punch (uni-) or double punch (bi-) to compact powders,
- iii) removal of load by retracting the punch,
- iv) ejection of green compact.

THE TABLE GIVES COMPACTION PRESSURE RANGES FOR METALS AND CERAMICS.



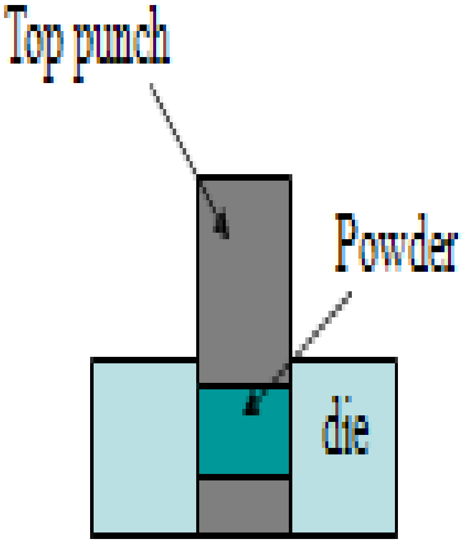
Material type	Compaction pressure range (MPa)
Metals	70–275
Aluminium	400–700
Brass	200–275
Bronze	350–800
Iron	600–720
Iron-copper (2%) premix	70–140
Tungsten	
Ceramics	100–140
Alumina	140–160
Carbon	150–400
Hard metals	110–165
Magnetic ceramics (ferrites)	

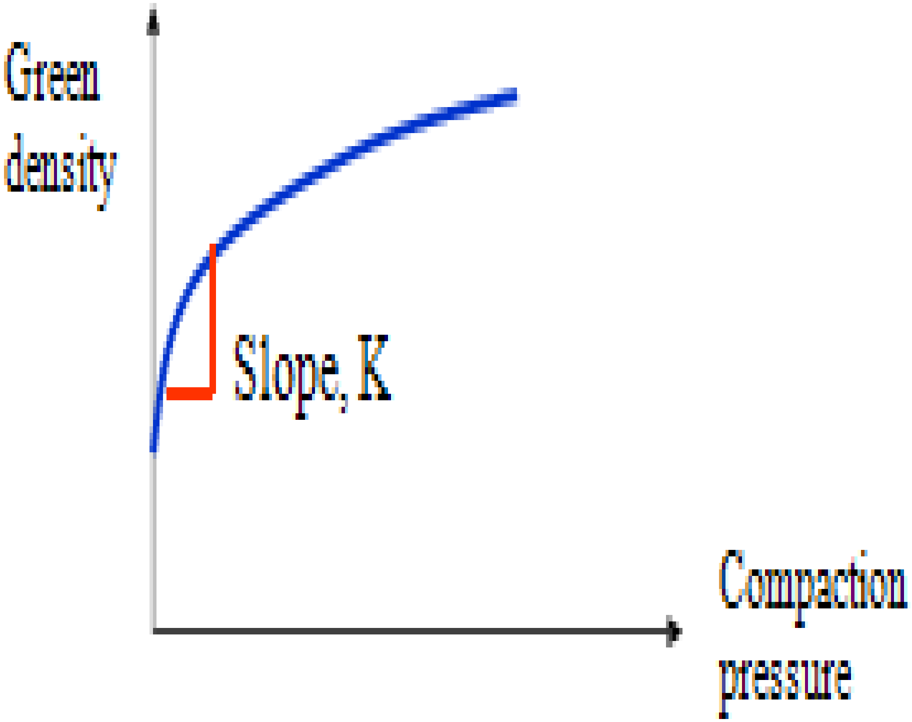
EFFECT OF POWDER CHARACTERISTICS

- 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.

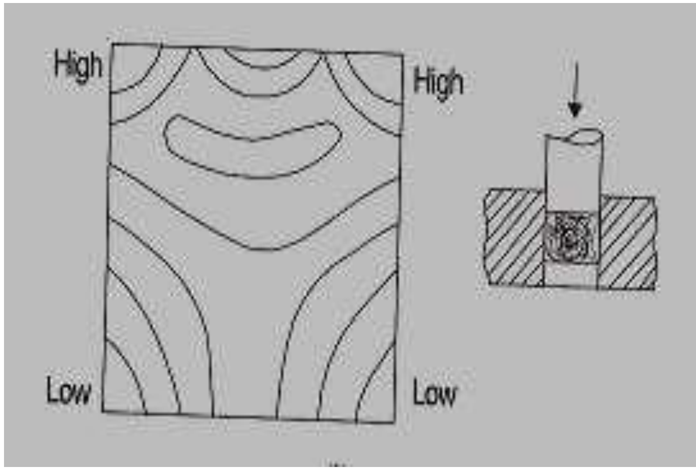
POWDER BEHAVIOR DURING COMPACTION

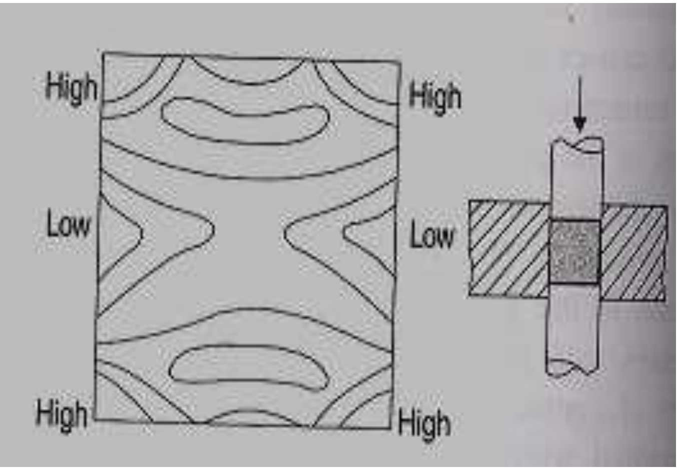
- Compaction involves,
  1) flow of powder particles past one another interacting with each other and with die-punch,
  2) deformation of particles. In the case of homogeneous compaction, two stages are observed.
     - First stage => rapid densification occurs when pressure is applied due to particle movement and rearrangement resulting in improved packing;
     - Second stage => increase in applied pressure leads to elastic and plastic deformation resulting in locking and cold welding of particles. In the second stage, large increments in pressures are seen to effect a small increase in density.


Top punch
Powder
die


Green density
Slope, K
Compaction pressure

- The green compact produced can be considered as a two-phase aggregate consisting of powder particles and porosity each having own shape and size.
- Compaction can be done at low and high temperatures. Room temperature compaction employs pressures in the range of 100-700 MPa and produce density in the range of 60- 90% of the theoretical density. At higher temperatures, pressures are kept low within the limits for preventing die damage.



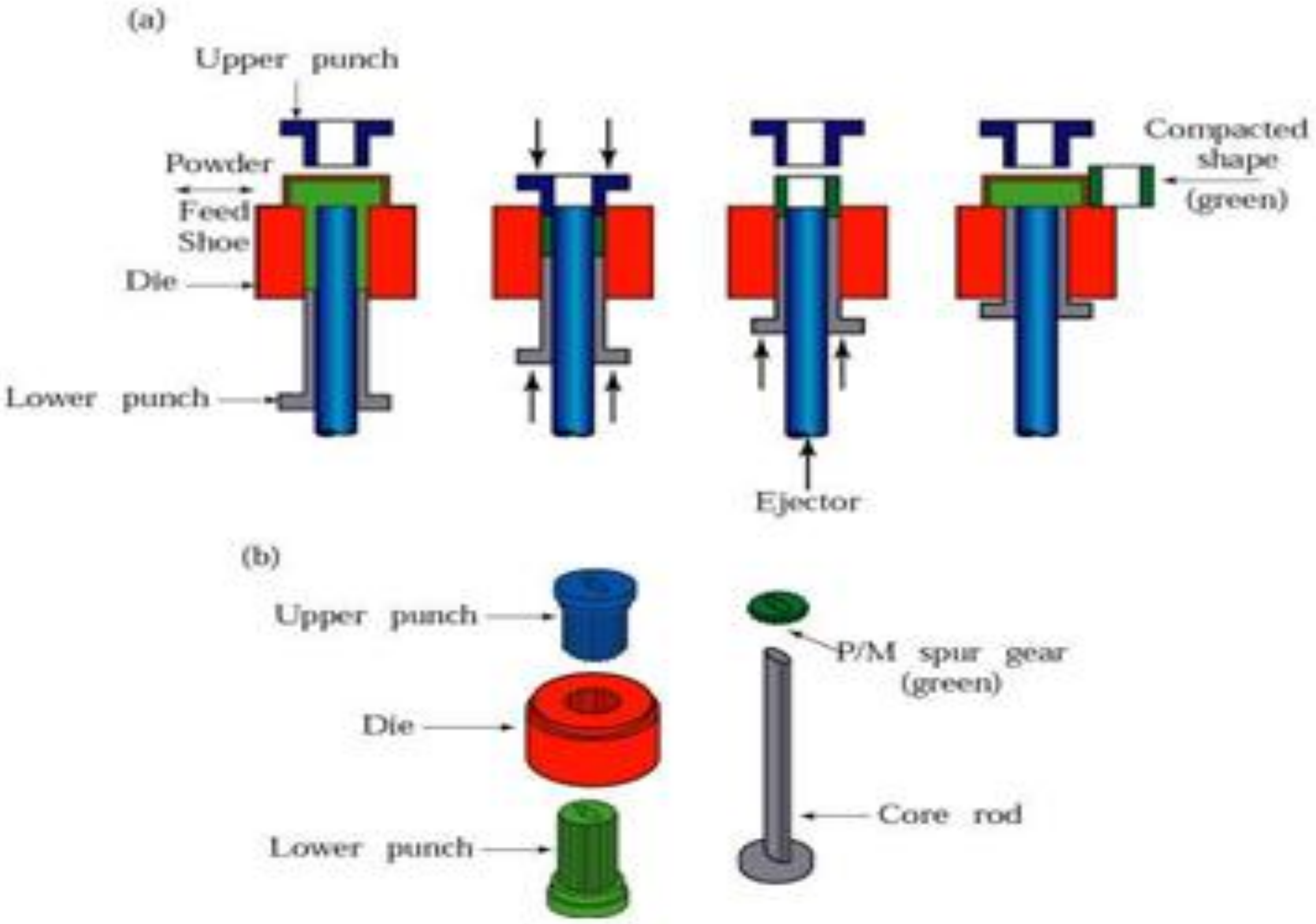


Single ended
compaction

Double ended
compaction

- In single die compaction, powders close to the punch and die walls experience much better force than in center. This results in green density variation across the sample length. Longer the sample more the density difference. This non-uniformity can result in non-uniformity in properties of sintered part.
- This density variation and hence final property variation can be greatly reduced by having double ended die compaction. In this case, powder experiences more uniform pressure from both top and bottom, resulting in minimization of density variation. But this variation will still be considerable if the components have high aspect ratio (length to diameter ratio). This means that long rods and tubes cannot be produced by die compaction. In this case, isostatic pressing can be used.

SCHEMATIC OF POWDER COMPACTION



DIE COMPACTION LUBRICANTS

- It is known that presence of frictional forces limits the degree of densification.
- Usage of lubricants either mixed or applied to contact surfaces can be done to minimize friction

- Lubricants => organic compounds such as waxes or metallic stearates or salts and they generally have low boiling points; Amount of lubricant added can be 0.5 to 2 % by weight of charge

- Mixed lubrication => Reduce the interparticle friction and aid better packing. But they may affect the densification property depending on their volume and density. The mixed lubricants should be removed before sintering to avoid distortion of compact.

- Even 1 wt% of lubricant can occupy large volume of app. 5% and maximum attainable density will be 95% (assuming zero porosity) only.

- Die wall lubrication => Graphite & MoS_2 can be applied physically on the die, punch surfaces; They can be easily removed, but takes longer production times.

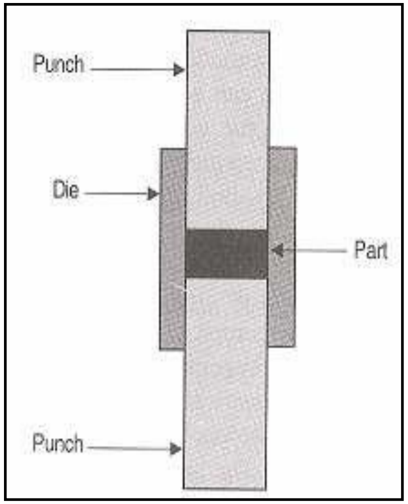
- Commonly used lubricants in P/M => Paraffin wax, Aluminium stearate, Lithium stearate, Zinc stearate, Magnesium stearate, stearic acid, Oleic acid, Talc, Graphite, boron nitride, Mos_2

TOOLING FOR DIE COMPACTION

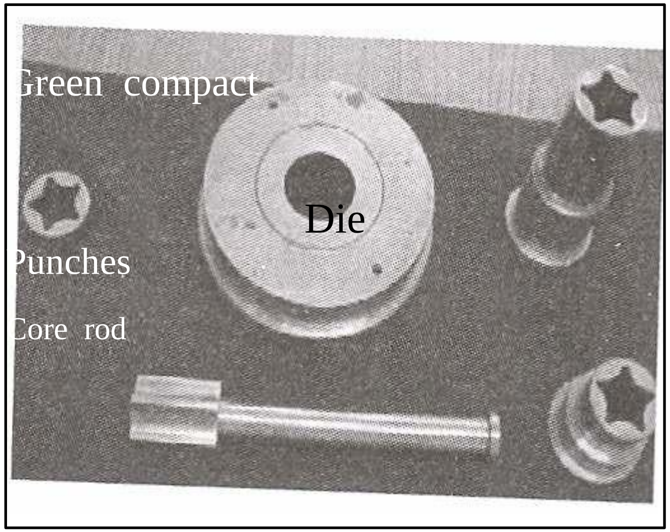
- P/M part classification
- Class I P/M part => simple, thin sections, uni-directionally pressed with single level compaction; class II P/M Part => Simple, but thick sections requiring pressing from two direction; class III => Two different thickness levels requiring two direction pressing; class IV => Multiple levels of thickness, requiring pressing from both the directions
- Tooling: Single action tooling: pressure is applied by lower punch, while the die cavity and upper punch remain stationary. After compaction, the upper punch moves away and compact is ejected by movement of lower punch. Class I parts can be made by this tooling.

- Tooling: Single action tooling: pressure is applied by lower punch, while the die cavity and upper punch remain stationary. After compaction, the upper punch moves away and compact is ejected by movement of lower punch. Class I parts can be made by this tooling.
- Double action tooling: IN this, Simultaneous movement of top and bottom punches are seen, while die and core rod remain stationary. Class II, III, IV type parts are made by this tooling.

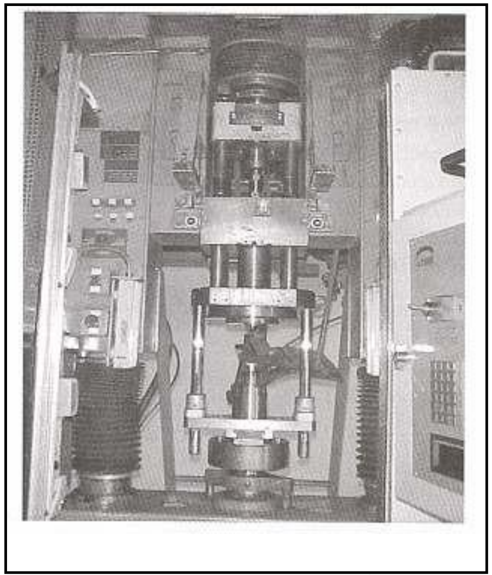
- Powder characteristics that affect the tooling design include, 1) Flow of powders – powder particles should flow freely to fill the die. By using lubricants, flow can be made smooth and improved; 2) die fill – this is the amount of powder in the cavity before compaction. This depends on shape and geometry of part, free flow of powders, complexity of part like thin sections and protrusions.



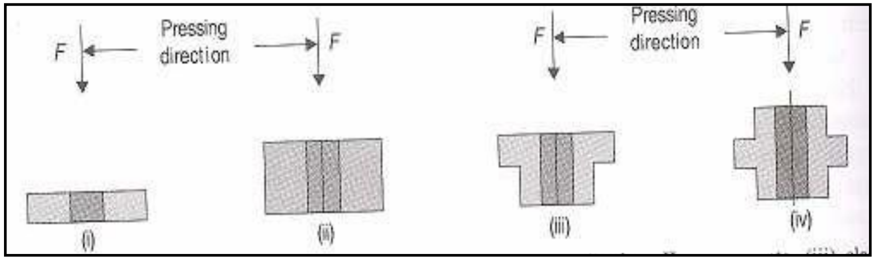
Double action tooling



Tooling for double action die compaction



Hydraulic press used for die compaction

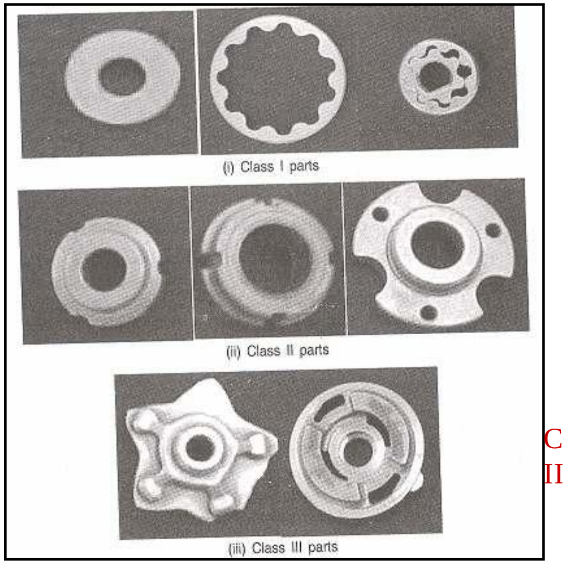


Class I part

Class II part

Class III part

Class IV part


(i) Class I parts

(ii) Class II parts

(iii) Class III parts

Class I

Class II

Class III

DIE MATERIALS

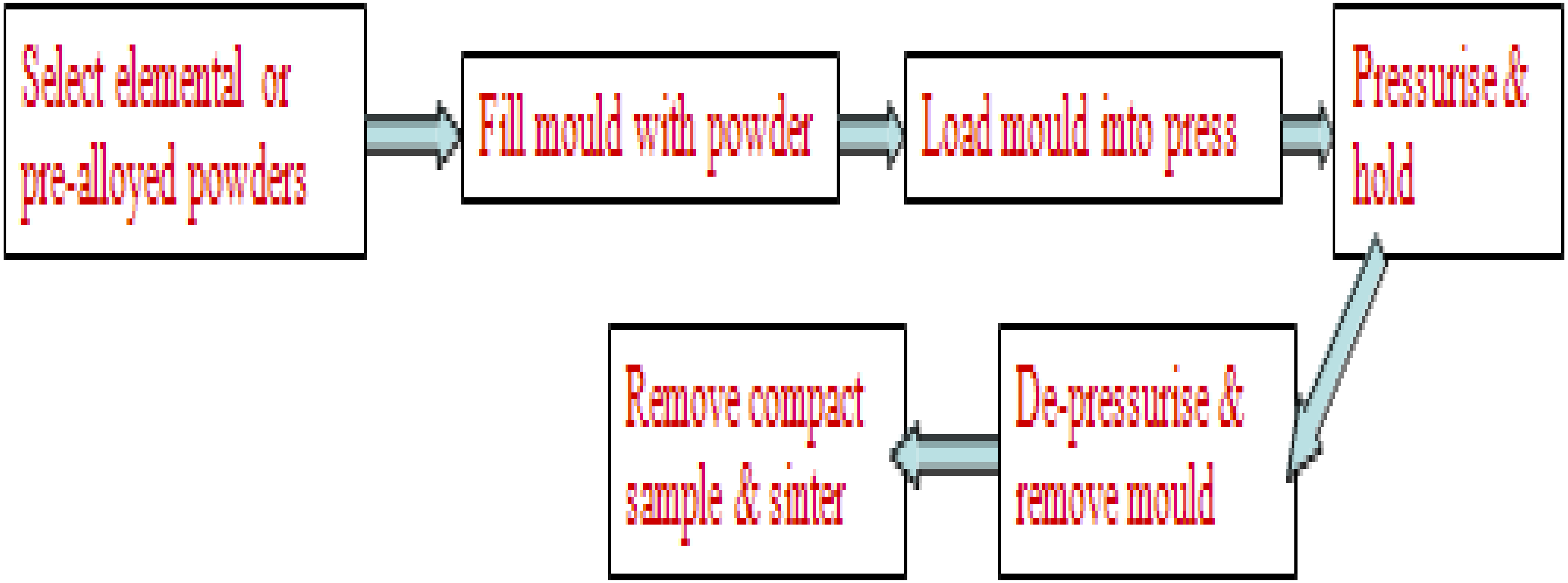
- Soft powders like aluminium, copper, lead => abrasion resistant steel such as air- hardened steels, die steels are used for making die
- Relatively hard powders => dies made of tool steel are used More hard & abrasive powders like steel => tungsten carbide dies are used. But carbide
- dies are costly & high hardness (difficult to machine)
- Coated dies with hard & wear resistant coating material like titanium nitride or titanium carbide can be used

DEFECTS OCCURRING IN DIE PRESSING OF POWDERS:

1) lamination cracking – this is caused by trapped air in compact sample. This cracking occurs perpendicular to load direction. This trapped air prevents the interlocking of particles.
2) Blowout – occurs when all the entrapped air tries to escape at the interface between the die and punch

COLD ISOSTATIC COMPACTION (CIP)

- CIP is a compaction process in which isostatic fluid pressure is applied to a powder mass at room temperature to compact it into desired shape. The powder parts can be compacted up to 80-90 % of their theoretical densities. Water or oil can be used as pressuring medium.
- Process details: High density near-net shape green parts, long thin walled cylinders, parts with undercuts can be readily fabricated. In this process, pressure is applied simultaneously and equally in all directions using a fluid to an elastomeric fluid with powder at room temperature. Sintered CIP component can reach up to 97 % of theoretical density. Steps in this process is shown in flowchart.



Select elemental or pre-alloyed powders

Fill mould with powder

Load mould into press

Pressurise & hold

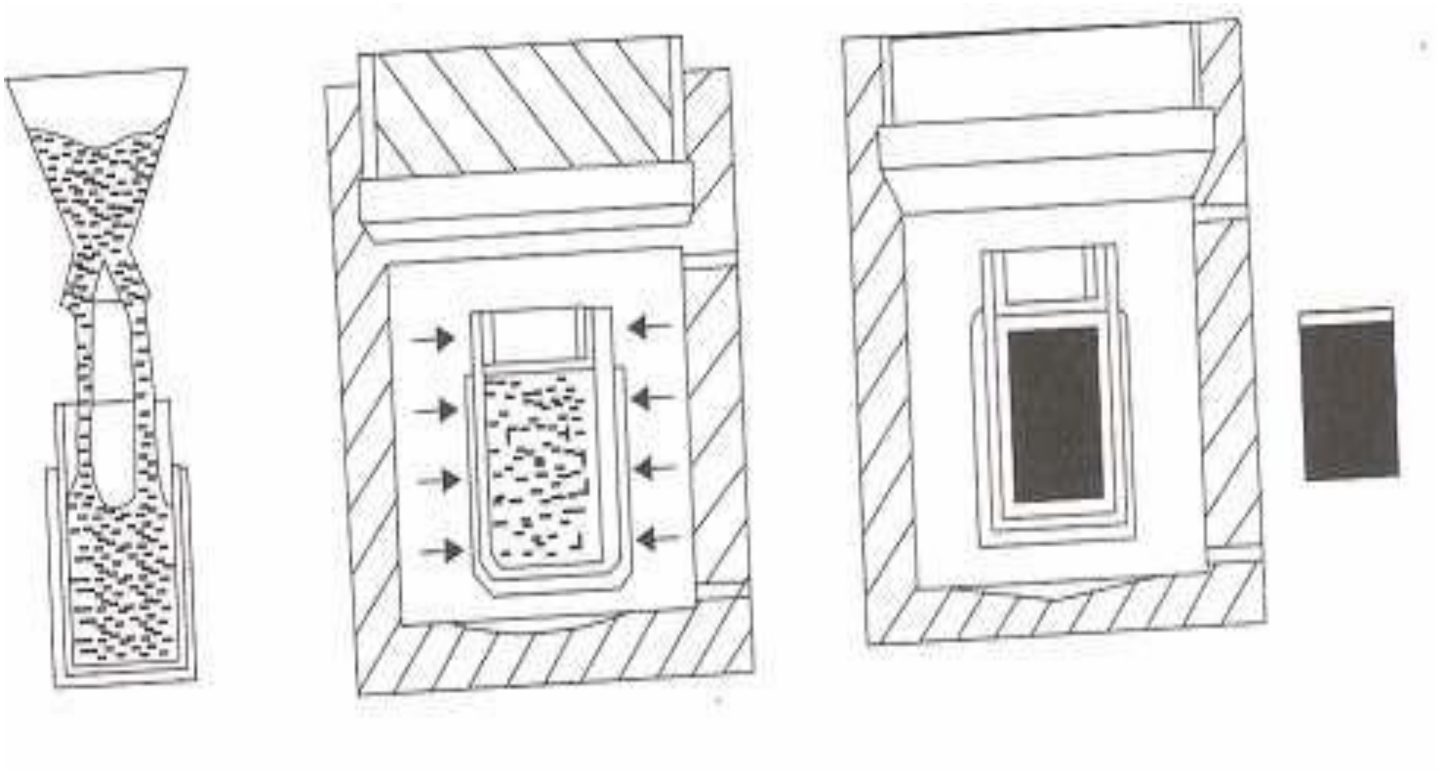
De-pressurise & remove mould

Remove compact sample & sinter

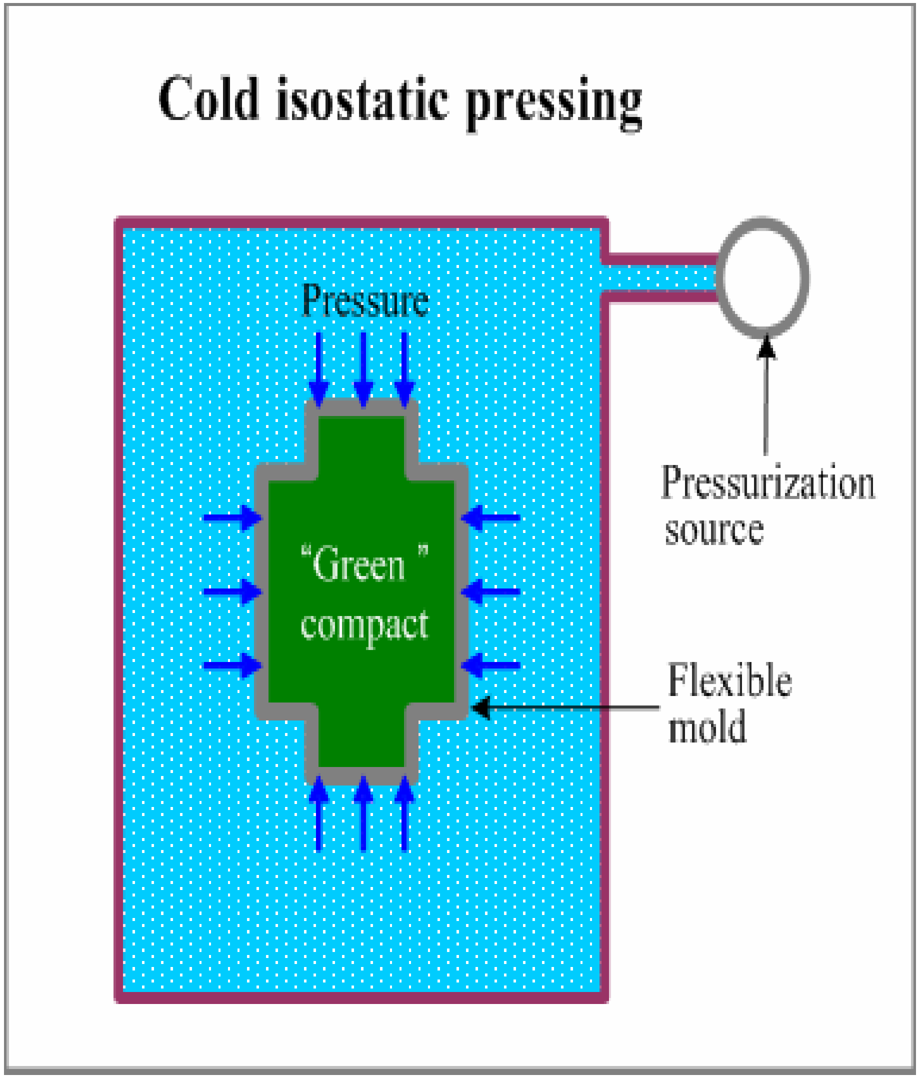
- Good mould filling is required in CIP because the initial powder distribution and density affect the preform shape. Powder size, shape, density and mechanical properties affect the flowability of powder into the mould and the packing density.
- Optimum pressing is obtained by using a free-flowing powder along with controlled vibration or mould tapping.
- Materials used for flexible mould are natural synthetic rubbers like neoprene, urethane, silicones, nitrile.

- During pressing, high density is achieved at a low pressure, while the green strength of the compact rises linearly with pressure.
- The pressure applied can range from 100- 400 MPa.
- Initially the applied stress (exactly shear stress) serves to improve the density of the compact by particle sliding and rotation. In the next stage, deformation of powder particles occur and particle characteristics like shape play vital role in deciding this stage.

- Irregular particles which interlock with one another and also deform during both the stages, tend to densify much easily than spherical powders.
- In the case of spherical powders, in spite of their higher initial packing densities, particles do not mechanically interlock with one another and hence do not easily deform.
- Hence high pressures are required for their compaction.



1. Mould Filling.
2. Mould Pressurization.
3. Depressurization.
4. Green Compact


Cold isostatic pressing
Pressure
"Green" compact
Pressurization source
Flexible mold

TYPES OF COLD ISOSTATIC PRESSING:

- Wet bag process: IN this, the mould is directly in contact with the fluid. This reduces the productivity, since the bag has to be removed every time before refilling. Tooling costs are reduced in this.
- Fixed mould process: the mould is fixed in the pressure vessel and powders are filled in situ. The tooling has internal channel into which fluid is pumped. This is an automated process in which the powder filling, compaction, depressurization and removal of green parts are done continuously. This involves higher tooling cost, but has higher production rate.

- Advantages of CIP:
- Uniform, controlled, reproducible densification of powder; long, slender parts can be pressed; neat net shape forming; short production times; economy of operation for complex and large parts.
- Applications:
- Metallic filters made from bronze, brass, stainless steel, Inconel, Monel, Titanium, high speed tools, carbide tools. Also ceramic parts such as sparks plugs and insulators are made by this method.