

## **Module 4-Surface coating technologies and Powder Metallurgy**

***Subject: Material Science and Engineering***

***Subject Code: 21ME33***

### ***Syllabus***

***Surface coating technologies:*** Introduction, coating materials, coating technologies, types of coating, advantages and disadvantages of surface coating.

***Powder metallurgy:*** Introduction, Powder Production Techniques: Different Mechanical and Chemical methods, Characterization of powders (Particle Size & Shape Distribution), Powder Shaping: Particle Packing Modifications, Lubricants & Binders, Powder Compaction & Process, Sintering and Application of Powder Metallurgy

### **Surface coating Technologies**

#### **Introduction**

Surface coating can be defined as a process in which a substance is applied to other materials to change the surface properties, without changing the bulk properties. Production of surface coating by any method depends primarily on two factors: the cohesion between the film forming substances and the adhesion between the film and the substrate. Coating layers can reduce the cost and neglect scarcity of materials as the thickness of coating layers rarely pass micrometers. Coatings can offer different properties such as corrosion/wear resistance, enhanced surface hardness, modified surface texture, thermal/electrical insulation, enhanced wettability, hydrophobicity, etc.

#### **Coating materials**

Coating methods are available in a wide variety due to the enormous diversity of applications and needs in different fields. Variations in the processes parameters will lead to different outcomes in the form of material microstructure, effectiveness, suitability, and durability. However, coating methods are useful in specific applications according to the desired functionality among which corrosion and wear protection are the most important. Mechanical properties of the materials decrease by corrosion process whereas the corrosion products are released in different forms that may cause a more extreme corrosive environment or harmful side effects in different applications. Coating materials have different deposition mechanisms that needs to be investigated for the revelation of their pros and cons for the desired application. Many different materials, including metals, ceramics, and polymers, can be used to form a protective layer. Al, Ti, Hf, Zr, Ni, Co, Pt, MgO, ZrO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Y<sub>2</sub>O<sub>3</sub>, BeO, PEEK, and PTFE etc. are commonly used protective coating materials against wear or corrosion

#### **Coating technologies**

There are many processes available, but only a few are among the most effective and applicable, including physical vapor deposition (PVD), chemical vapor deposition (CVD), micro-arc oxidation (MAO), electrodeposition, sol-gel, thermal spray, and polymer coatings. Each of these methods is suitable for different applications as they offer different deposition methods, different materials, second phases, different thicknesses, and densities. As a result,

mechanical stability, corrosion properties, biocompatibility (for biomedical applications), and enhancement of material behavior for a specific type of coating have to be considered carefully

### **Common types of coating**

**Anodizing:** This technique involves the electrolytic oxidation of aluminium. The metal surface is converted into an oxide layer, which provides impermeable protection. Depending on the type of alloy, anodized coatings offer a wear-resistant, hard surface with reliable corrosion protection. In addition, they are electrically non-conductive and therefore have a high insulating effect. In terms of optical design, different colours and a smooth or matt surface finish can be achieved, which is why anodized metal parts can also be used for decorative purposes.

**Electroplating:** Here, components are provided with a metallic coating - such as aluminium, chrome or zinc - which makes the surface electrically conductive. This is achieved by treatment in an immersion bath. Alternatively, the electrolyte can be applied with a sponge during tampon electroplating. In addition, there are several other techniques that are used depending on the size and material of the components. Basically, all common metallic base materials can be coated. The functional added value of the galvanic coating is in the protection against wear and corrosion, especially in the case of mechanical damage. Furthermore, frictional forces are improved by electrical conductivity, abrasion resistance and sliding properties. Depending on the layer, the electroplating also serves as an optical enhancement. For example, chrome elements are popular in the design of cars because of their shiny surface.

**Powder coating:** In addition to everyday objects, electrically conductive components for machines and vehicles are protected with powder coating. The electrostatically charged paint powder is applied in an application plant and then cured at up to 250 °C. In this process, the structures of the paint powder mesh with the surface of the workpiece. In this process, the structures of the paint powder crosslink with the surface of the workpiece. At the same time, the treated components obtain a high-quality appearance. With a few exceptions, all metals can be powder-coated with different colours and gloss effects.

**E-Coating:** In electrophoretic deposition, components are immersed in a bath of electrified liquid varnish. The main advantages of this technique are that the layer thickness can be

determined by the amount of electricity. Even complex structures with hard-to-reach areas can be easily coated.

**Wet spray:** By means of chemical and physical processes, the liquid coating material forms a solid film on the workpiece. Painting with liquid paints offers numerous colour variants and a fast colour change. With this technology, special effects can also be achieved.

### **Advantages and Disadvantages of surface coating**

#### **Advantages**

Coatings can offer different properties such as corrosion/wear resistance, enhanced surface hardness, modified surface texture, thermal/electrical insulation, enhanced wettability, hydrophobicity, etc.

#### **Disadvantages**

Negative thermal effects (e.g., distortion, crack, delamination, etc.) destructive effects of loose atmospheric protection (e.g., penetration of inclusions and contaminations into the substrate) and coating materials properties (e.g., melting point, availability in different forms of oils/powders/rods, biocompatibility, etc.) are the most crucial ones to be considered.

### ***Powder metallurgy:***

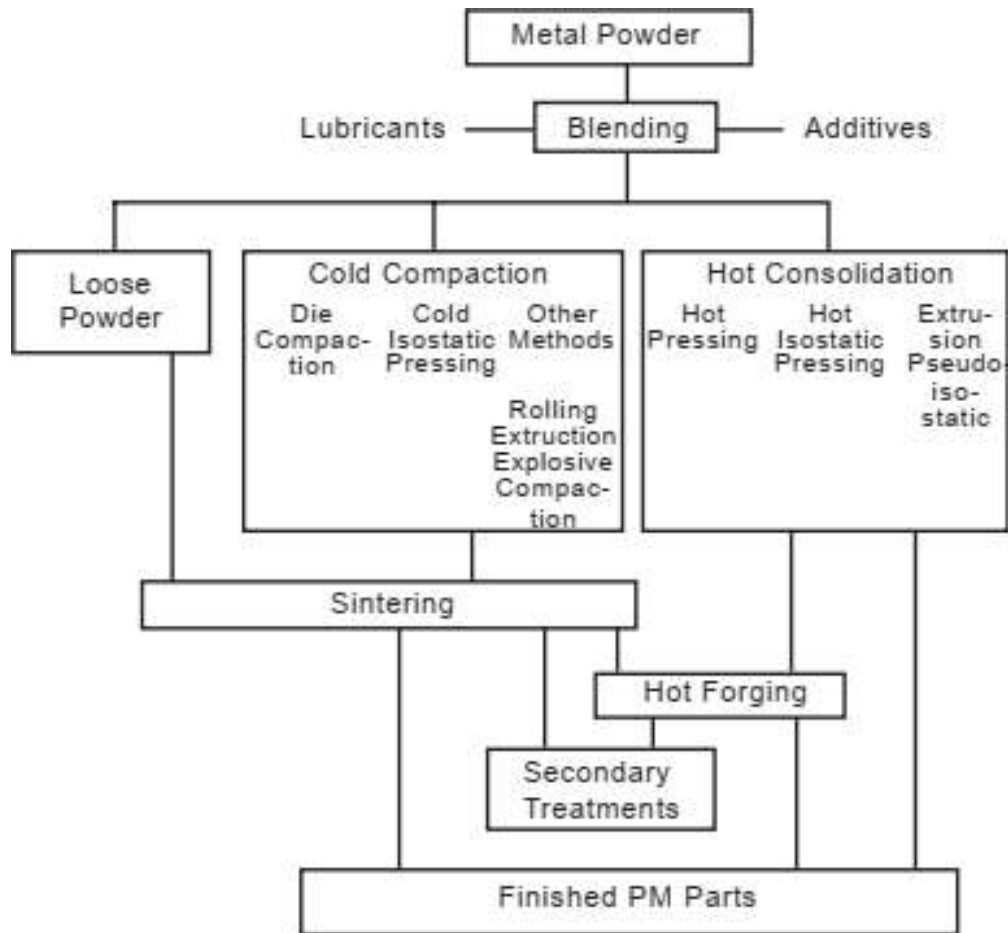
#### **Introduction**

Modern powder metallurgy (P/M) technology commenced in the 1920s with the production of tungsten carbides and the mass production of porous bronze bushes for bearings. During the Second World War, further development took place in the manufacture of a great variety of ferrous and nonferrous materials, including many composites and a steady growth period developed during the postwar years until the early 1960s.

Advantages of P/M:

- economical processing
- unique properties and
- captive processes

It is a rapid, economical and high-volume production method for making precision components from powders. The basic steps involved are shown in Figure below.



Automobile industries, Hardware, tools, cameras, farm and garden equipment industries, business machines, sporting goods and military products are just a few more areas where usage is on the upswing. P/M offers greater precision, eliminating most or all of the finish machining operations required for castings. It avoids casting defects such as blow holes, shrinkage and inclusions.

### **Powder Production Techniques:**

The significant manufacturing methods may be classed as follows:

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

### **Mechanical Methods**

Not used as a primary method of producing powders. It consists of the application of impact, attrition, shear and compression mechanism wither individually or in combination to obtain powders. These mechanisms are used in the following cases:

- materials which are relatively easy to fracture such as pure antimony and bismuth, relatively hard and brittle metal alloys and ceramics.

– reactive materials such as beryllium and metal hydrides.

– common metals such as aluminium and iron which are required sometimes in the form of flake powder.

**(i) Crushing:** The major equipment's are mortar and pestle, heavy drop hammer, and jaw crushers. In jaw crushing the crushing chamber is formed by one fixed jaw and one movable jaw between stationary support walls. The movable jaw is mounted eccentrically at the top and is driven by a motor via a flywheel. During the crushing process, the material is drawn down into the tapered crushing chamber as a result of the eccentric jaw motion and is reduced in size by compression and frictional forces. In addition, the angle between the jaws can be altered to give optimum adjustment to the crushing of the material. The final crushed product particle size can be adjusted to values between 15 and 1 mm by adjusting the gap at the base of the jaws. The standard jaws and side walls are manufactured from hardened steel. If the feed material is very abrasive or particular impurities are to be avoided, these components are also available in stainless steel or hard tungsten carbide. If the fixed jaw is removed, access is given to the crushing chamber and the equipment can be cleared easily. In addition, the connection of an exhaust device allows work to be carried out in dust free conditions.

**(ii) Ball milling**

Ball milling is the most common method used. It consists of a rotating drum with wear resistant hard balls that tumble during operation. The impact of these balls on the raw material placed within the drum after certain duration of time at a required speed of rotation produced powdered particles. The most important parameter during the process is the speed of rotation of the drum. A very high speed will cause the material and the ball to be pressed against the walls of the drum, because of the centrifugal forces and prevent relative motion between the material and the balls. Too low a speed will result in an insignificant amount of movement in the lower part of the drum. The optimum speed corresponds to a situation in which some amount of ball and material is lifted up to the top of the drum and falls down on the remaining material.

**(iii) Disc Grinder:** The disc grinders are suited for processing hard brittle materials. A wet grinding in a closed grinding vessel which is driven horizontally and eccentrically and which contains grinding elements (disc or ring) is used to reduce the material to give a final particle size of a few micrometers. Impact and friction between the grinding elements and the grinding vessel cause such grinding energy that the process is generally concluded within a few minutes.

**(iv) Attritor Milling:** Attritor milling or mechanical alloying is achieved by high energy ball milling under conditions such that powders are not only fragmented but also rewelded together. In this case,

the ball charge is stirred vigorously with rotating paddles. The first commercial production used attritors able to process up to 34 kg of powder per charge but nowadays, up to 1 t of powder is milled in a 2 m diameter mill containing more than a million balls which weigh a total of 10 t. The charge is a blend of elemental and prealloyed powders at least one of which is a ductile material. To provide a dispersed phase in superalloys, fine inert oxides can be included in the charge, usually  $Y_2O_3$ .

### (v) Vortex mill

In this particle of materials to be ground are fractured by mutual contact or collision. Such mills consist of two or more very rapidly rotating propellers within the mill casing and gas flow systems which remove a desired size fraction of particles.

Disadvantage of mechanical powder formation: potential contamination from the balls and mill walls

Flake metal powders are produced by flattening equiaxed particles produced by another method. These may employ ball, hammer or roll mills. When milling the original particles lubricants are added to prevent them from welding or sticking to each other. Aluminium, copper, bronze, silver, gold, iron and stainless steel flake powders are produced commercially by the milling method.

**Table: Some grinding element materials**

Material	Abrasion behaviour	Specific weight g/cm <sup>3</sup>	Mohs hardness	No chemical resistance in
Agate (SiO <sub>2</sub> )	Very abrasion-proof approx. 200 times more resistant than hard porcelain	2.65	7	Hydrofluoric acid (HF)
Zirconium oxide (ZrO <sub>2</sub> )	Very abrasion-proof approx. 10 times more resistant than sintered corundum	5.7	8.5	Sulphuric acid (H <sub>2</sub> SO <sub>4</sub> ) Hydrofluoric acid (HF)
Alumina (Al <sub>2</sub> O <sub>3</sub> )	Good abrasion resistance	4.0	9	conc. Acids
Hard porcelain	Sufficiently abrasion proof	3.1	8	conc. Acids
Hardened chromium steel 2080	Good abrasion resistance better than CrNi-steel	7.9		Acids
Hardened steel CK45	Good abrasion resistance	7.9		Acid
Stainless steel 4301	Average abrasion resistance	7.9		Acids
Hard metal tungsten carbide	Extremely abrasion proof approx. 200 times more resistant than agate	14.75	8.5	Nitric acid (HNO <sub>3</sub> ) Hydrochloric acid (HCl)

## Chemical Method

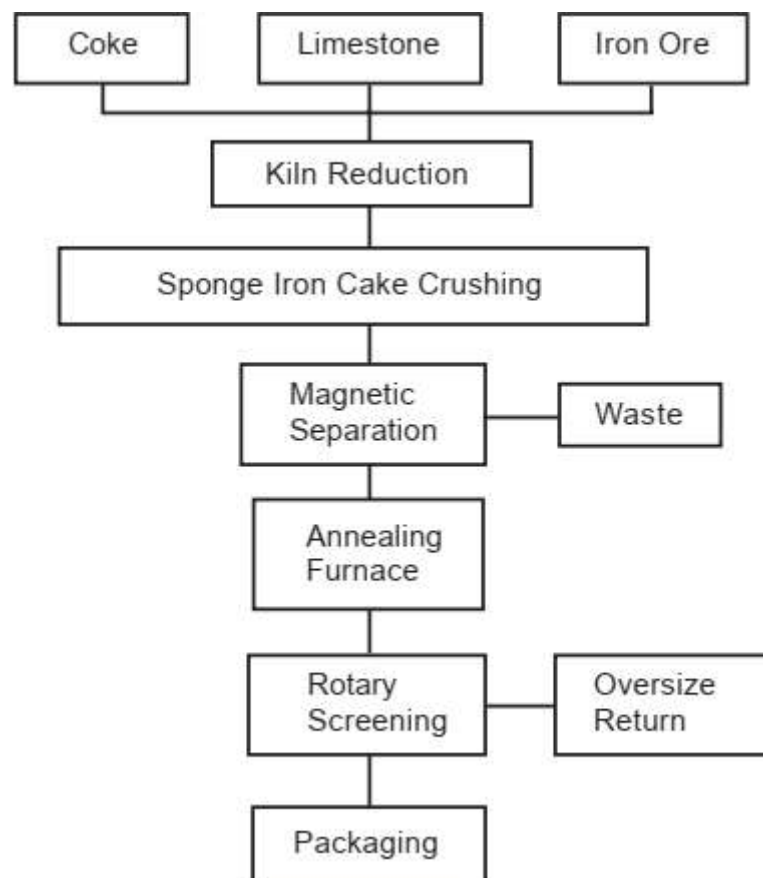
These methods can be further classified as:

- Chemical reduction- from the solid, gaseous and liquid state
- Decomposition- of metal hydrides and of metal carbonyls

### Chemical reduction methods

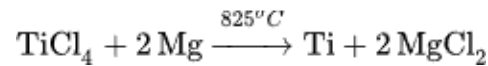
(a) from the solid- involves reduction of oxides by substances. Ex: iron oxide by carbon, tungsten oxide by hydrogen.

This is a batch process in which the ore to be reduced is in static condition. Hoganas process is a typical example which makes use of pure magnetite ( $\text{Fe}_3\text{O}_4$ ) and is reduced using carbonaceous material. In this process the ore is placed in the centre of a cylindrical ceramic container called saggars surrounded on the outside by a concentric layer of a mixture of coke and limestone. The saggars are placed in layers upon cars which are pushed through a fuel fired tunnel kiln. The carbon monoxide produced from the coke reduces the ore to iron. Total reduction time is of the order of 24 hours at a reduction temperature of  $1200\text{ }^\circ\text{C}$ . The limestone serves to bind any sulphur in the coke and prevents its contaminating the iron. The sponge iron is mechanically removed from the saggars, ground and the resulting powder magnetically separated from impurities. In a final reduction step the powder is carried through a continuous furnace in hydrogen atmosphere on a belt made of stainless steel. The process flow is shown in the figure below.



**Figure: Flowsheet for sponge iron powder production from iron ore**

- (b) **from the gaseous state-** in the Kroll process, the  $\text{TiCl}_4$  is reduced by liquid magnesium to give titanium metal:



The reduction is conducted at 800–850 °C in a stainless steel retort. Complications result from partial reduction of the  $\text{TiCl}_4$ , giving to the lower chlorides  $\text{TiCl}_2$  and  $\text{TiCl}_3$ . The  $\text{MgCl}_2$  can be further refined back to magnesium. The resulting porous metallic titanium sponge is purified by leaching or vacuum distillation. The sponge is crushed, and pressed before it is melted in a consumable carbon electrode vacuum arc furnace. The melted ingot is allowed to solidify under vacuum. It is often remelted to remove inclusions and ensure uniformity. These melting steps add to the cost of the product. Titanium is about six times as expensive as stainless steel.

- (c) **from the aqueous solution-** involves precipitation from solutions such as cement copper from copper sulphate solution or reduction of an ammoniacal nickel salt solution with hydrogen under pressure (hydrometallurgical method). leaching of copper ores or copper scrap, and the subsequent precipitation of copper powder from an acidified solution of copper sulphate with iron is achieved. Large quantities of cement copper are produced at low cost however, they cannot be directly converted to powder for further use because of following limitations:

- (i) the cement copper produced as a by-product is rather impure unless special precautions are taken and
- (ii) the powder is quite fluffy, i.e. it has a low apparent density, which is not satisfactory for many copper powder applications.

Nickel powder produced by the Sherrit Gordon process is the typical hydrometallurgy method for production in which reduction of an ammoniacal solution of nickel sulphate with hydrogen under a pressure of 1.38 MPa (200 psi) and a temperature of 190–200°C in an autoclave is carried out.

### **Chemical decomposition methods:**

#### **Decomposition of metal hydrides**

This involves first hydriding the refractory metals like Ti, Zr, Hf, V, Th or U by heating the metal in the form of sponge, chip or turnings or even compact metal in hydrogen.  $\text{TiH}_2$  is formed from titanium in the temperature range between 300–500 °C. These hydrides are quite brittle and can be readily ball-milled into powder of the desired fineness. These may be dehydrided by heating them in a good vacuum at the same temperature at which the hydride was formed. Care must be taken to avoid contamination of  $\text{O}_2$ ,  $\text{N}_2$  and C during hydriding or dehydriding.

#### **Decomposition of metal carbonyls:**

Used in the production of iron and nickel powder. The carbonyls are liquids at normal temperature with a low boiling point. These are formed by reaction of the metal and carbon-monoxide gas under pressure. For example, iron carbonyl ( $\text{Fe}(\text{CO})_5$ ) is formed at 70–200 atmosphere pressure and a temperature of 200–220 °C. The carbonyls can now be decomposed by heating the vapour at atmospheric pressure. Care must be taken to have the decomposition take place in the gas phase and not on the surface of the reaction vessel, in order to obtain metal in the powdery form. The usual carbonyl iron powder particles are spherical with an onion skin

structure, because the iron powder ‘nuclei’ first formed catalyze the decomposition of CO into C and CO<sub>2</sub>. Carbon deposits on the iron powder nucleus; another layer of iron is deposited on top and so on. This type of iron powder is quite pure with respect to metallic impurities, but contains considerable amount of carbon and oxygen (fraction of a percent). Powder devoid of such impurities can be produced by adding ammonia during the decomposition of the carbonyl and by a subsequent annealing treatment. But these would naturally enhance the cost. Carbonyl iron powder is usually spherical in shape and very fine (<10 μm), while the nickel powder is usually quite irregular, porous and fine.

**Characterization of powders**

**Introduction**

The success of any powder metallurgical process depends to a great extent on the complete characterization and control of the metal powders. The method of powder production influences particle chemistry and structure, apart from the precise nature of particle size distribution. These properties also influence the behaviour of the powder during compaction and sintering, and the composition, structure and properties of the sintered material.

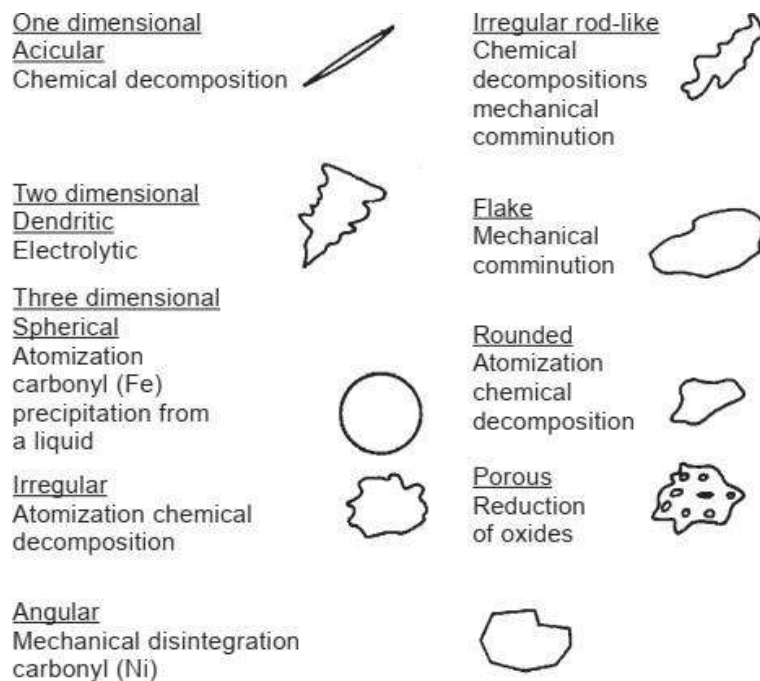
**Particle & Shape Distribution**

Powder properties and methods of measuring them

Particle size and size distribution	Sieve analysis; Permeability; Sedimentation electrical resistance; Light obscuration; Light scattering; Microscopy; Surface area.
Particle shape [external]	SEM; Shape parameters; Morphological analysis; Fractals.
Particle shape [external and internal]	Stereology; Mercury Porosimetry; Gas absorption.

**Particle shape**

The shape of the powder is characterised by the dimensionality of the particle and its contour surface.



**System of particles shape characterization.**

Most powder particles are three-dimensional in nature and they may be considered as being somewhat equiaxed. Spherical particles represent the simplest and ideal example of this shape. Porous particles differ from irregular ones because of the presence of the porosity, which itself may be very irregular in both size and shape. A large amount of porosity makes any shape characterisation very difficult

### Particle size

In a real mass of powder, all prepared in the same manner, all the particles will not have the same exact size, even though the shape may be essentially the same. Particle size distribution curves relate the particle size to the corresponding fraction of the powder with that size. Figure 1 illustrates various size distributions. In unimodal distribution, there is one high point or maximum amount of a certain critical size. The polymodal distribution consists of two or more narrow bands of particle sizes, each with a maximum, with virtually no particles between such band. The broad band distribution simply corresponds to a uniform concentration of particle sizes over a rather broad size interval with virtually no particles having sizes outside this range. The irregular distribution represents a continuous and finite variation of particle sizes within a relatively broad range.

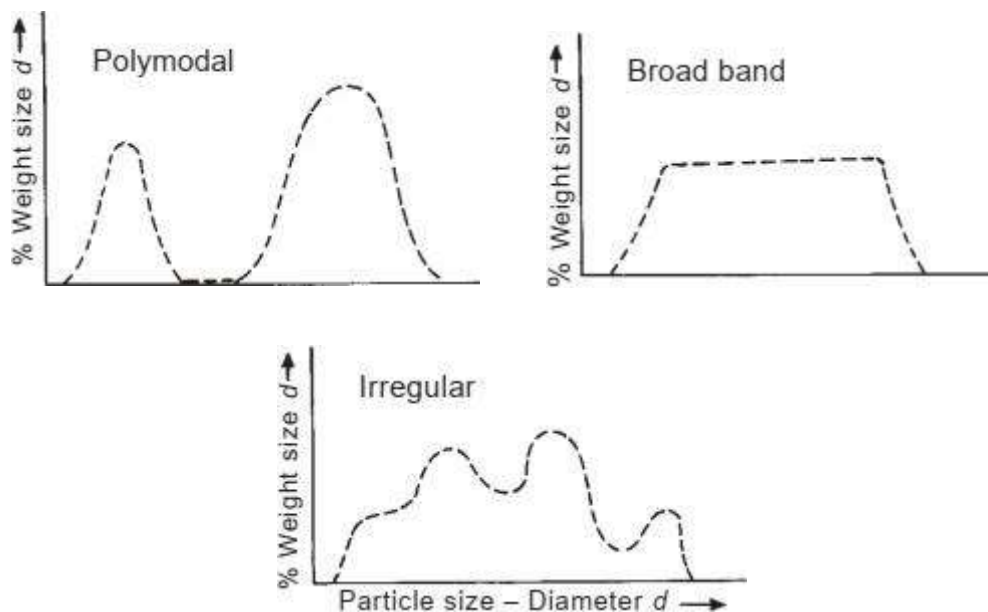


Figure 1: Schematic illustrations of some realistic particle size distributions.

classifies some of the common methods of particle size determination and their limits are provided in the table below.

Out of all the methods, sieving is technologically most satisfactory for reporting and plotting particle size distribution, in which the successive sizes form a geometrical series. The reference point for their scale has become 75 micrometer which is the opening of the 200-mesh woven wire screen standardized by the National Bureau of Standards. Because of the widespread use of this method, one distinguishes between particles which are larger than 44 micrometers and fines or subsieve powder that is smaller than 44 micrometers. Conventional sieving requires a sample of 50 g for accurate analysis and this becomes difficult in analysis of expensive metal powders. This is now overcome with the development of small sieves. A Ro-tap type machine

is a common sieve shaker used in size analysis. Sieve shakers with different shaking mechanisms are used which depend on the shape of powder. A swirling motion is effective for round particles but is extremely slow for elongated particles. A jumping motion is very effective for elongated particles because it throws them into the air and allows them to rotate and perhaps land point first in a hole and pass through it. This means that a very consistent shaking motion is needed. The Fisher Subsieve Sizer is very much common in refractory metal powder and cemented carbide industries. the measured surface area is converted into an equivalent spherical surface diameter, which is only an approximate measurement tool. The technique does not measure the surface-connected porosity. A preweighed amount of powder is exposed to a known flow rate and the pressure drop is measured to determine permeability. From the knowledge of powder porosity and theoretical density, the surface area is calculated. The advantage of this method is that it is a direct reading one, which is very convenient for quick industrial quality control of fine powders. It must be clearly recognised that the value of specific surface obtained from a permeability experiment is representative of the 'friction' surface presented by powder mass to the flowing fluid.

**Table: Common particle size determination methods and their limits of applicability**

Class	Method	Approximate useful size range (microns)
Sieving	Sieving using mechanical agitation or ultrasonic induced agitation and screens	44–800
Microscopy	Micromesh screens	5–50
	Visible light	0.2–100
	Electron microscopy	0.001–5
Sedimentation	Gravitational	1–250
	Centrifugal	0.05–60
Turbidimetry	Turbidimetry (light intensity attenuation measurements)	0.05–500
Elutriation	Elutriation	5–50
Electrolytic resistivity	Coulter counter	0.5–800
Permeability	Fisher sub-sieve sizer	0.2–50
Surface area	Adsorption from gas phase	0.01–20
	Adsorption from liquid phase	0.01–50

### Lubricants:

Solid lubricants are generally used in a range of 0.5 to 1.5%, depending on the part density and size, to allow part ejection and maintain good surface finish. Many metal powders for P/M use are prelubricated by the powder manufacturer. Typical lubricant additions range from 0.5 to 1.0 wt%. While the presence of lubricants or other chemical additives or particle surfaces may

inhibit wetting and cause agglomeration, lubricants have another significant effect. Lubricants or other chemical additives are much less dense than metal particles. Consequently, a small amount of lubricant by weight may contribute greatly to the particle count (population) distribution. In the case of iron and steel powders, constituents such as graphite, copper, nickel, or ferroalloys are used to increase strength through diffusion during the sintering process. Powdered EBS (Ethylene Bis Stearamide) and polyethylene waxes in iron powder mixes reduce compressibility and improve green strength. Stearate lubricants have good lubricating properties and maintain good mix compressibility, but lower the green strength. For applications requiring high green strength, Acrawax or stearic acid used as lubricant. Dry organic lubricants, such as lithium and zinc stearate, stearic acid for use in the manufacture of P/M structural components. Amide wax is another lubricant that is used. Other lubricants used are Iron-carbon-lubricant, copper-tin-lubricant, iron-copper-carbon lubricant, and copper-tin-carbon-lubricant. With die wall lubrication, the solid lubricant (for example, zinc stearate, 100 g) is mixed with a volatile organic liquid (for example, methylchloroform, 1 L) and is either painted or sprayed on the tooling. The organic liquid evaporates, leaving a thin film of dry lubricant on the working surfaces of the die cavity and punches.

## **Binders**

The binders are formulated specially to provide the proper rheological properties during injection molding as well as ease of binder removal after the molding step. Once the part is ejected from the mold, the binder material is removed using either solvent extraction or thermal processes (or both).

Suitable binder materials must be homogeneously dispersable (preferably soluble) in the liquid used to form the slurry. When dry, binders must form a coating and/or adhere to the material being agglomerated. They must impart the required strength and crush resistance to the particle for subsequent handling.

The most important feature is its suitability for the manufacturing process. For example, when mixing, milling and spray drying in aqueous media must be used the water-soluble binder and paraffins are excluded. In the dry blending and mixing in kerosene are inversely they paraffins (waxes) better. Second most important requirement for the binder in powder metallurgy is the following: Binder must be possible perfectly evaporate in vacuum (the less carbon remains after the evaporation of binder, the better). As a water-soluble binder are often taken a following aqueous solutions: polyvinyl alcohol (PVA) and polyvinyl acetate (PVAc). As a non-water soluble many different hydrocarbons (paraffins) come into question.

Polymeric binders are mostly used. The binder system could contain several components and are normally classified as major binders, minor binders and processing aids. High-molecular weight polymers as polypropylene, low-density polyethylene, ethylene vinyl acetate and low-molecular weight waxes have been used as major binders. Minor additives are mainly used to control the viscosity of the powder-polymer blend. Processing aids are minor additives that act as surfactants to the powder and improve the wetting characteristics between powder and binder during compounding control. The exact compositions are still proprietary in nature. These binders are generally thermoplastic ones, but a thermosetting system (epoxy resin + paraffin wax + butyl stearate) has also been used. Although thermosetting binders offer an advantage in shape retention but generally prove difficult to control in practice.

Table shows the main binder systems used for powder injection moulding

<b>Binder systems</b>		
Thermoplastic binders	main ingredient: polymer backbone: additives (surfactants):	Paraffin/microcrystalline/carnauba/bees-wax, vegetable/peanut oil, acetanilide, antipyrine, naphthalene PE, PP, PS, PA, PE-VA, PE-A, PP-A, PBMA-E-VA stearic/oleic acid and esters thereof, phthalic acid esters
Duroplastic binders	main ingredient: additives	epoxy resin, furan resin waxes, surfactants
Gellation binders	main ingredient: polymer backbone: additives:	water methyl cellulose, agar glycerin, boric acid
Freeze-drying binders	main ingredient: additives:	water, aniline paraffin wax
Polymer binder	main ingredient: additives:	polyoxymethylene proprietary

## **Metal powder compaction**

The compaction of metal powders has the following major functions:

- (a) to consolidate the powder into desired shape
- (b) to impart, to as high a degree as possible, the desired final dimensions with due consideration to any dimensional changes resulting from sintering.
- (c) to impart the desired level and type of porosity.
- (d) to impart adequate strength for subsequent handling.

Several approaches exist for achieving these goals. In general the techniques can be categorised as

- (a) continuous vs discontinuous process
- (b) pressures – high vs low
- (c) compaction velocity – high vs lo
- (d) temperature – room to elevated temperature
- (e) uniaxial vs hydrostatic pressures

### **(i) Die Compaction**

Most widely used method and is considered as the conventional technique. This involves rigid dies and special mechanical or hydraulic presses. Densities of up to 90 % of full density

can be achieved following the compaction cycle, the duration of which may be of the order of just a few seconds for very small parts.

A high uniformity in green parts can be achieved depending on:

- the kind of compacting technique
- the type of tools
- the materials to be pressed and the lubricant.

The compacting techniques used may be characterised by references to the movement of the individual tool elements – upper punch, lower punch and die relative to one another.

Pressing within fixed dies can be divided into:

- Single action pressing
- Double action pressing

Operation sequence: Pressing Operation

The pressing operations can be sequenced as follows:

1. Filling of the die cavities with the required quantity of powder.
2. Pressing in order to achieve required green density and part thickness.
3. Withdrawal of the upper punch from the compact
4. Ejection

Compaction Presses- three types – mechanical, hydraulic and Rotary Presses

**Hydraulic presses** produce working force through the application of fluid pressure on a piston by means of pumps, valves, intensifiers and accumulators.

In **mechanical presses**, a flywheel stores energy, which is then released and transferred by one of a variety of mechanisms (eccentric, crank, knuckle joint, toggle etc.) to the main slide.

A rotary press is a mechanically operated machine, which uses a number of identical sets of tools to produce parts at high production rates

## (ii) Cold Isostatic Compaction

In cold isostatic compaction a flexible mould is filled with the powder and pressurised isostatically using a fluid such as oil or water. Compaction pressures up to 1400 MPa have been achieved in this manner, however, cold isostatic compaction is usually performed at pressures below 350 MPa. The use of rubber mould provides a means of creating complex shapes.

Cold

isostatic compaction has following advantages:

1. Uniform density of compacted bodies.
2. High green density, about 5–15 per cent higher than that achieved with die compaction at the same pressure.
3. High green strength and good handling properties of the powder body.
4. Reduction in internal stresses.
5. Possibility to compact powder without binding or lubricant additives.
6. Possibility to compact bodies having complex shapes or with a large length to cross-section ratio and achieve a high, uniform density.
7. Composite structures can easily be obtained.
8. Low tool costs through the use of rubber or plastic moulds.
9. Low material and finish machining costs.

On the other hand, isostatic compaction has some disadvantages too. They are:

1. Dimensional control of the green compacts is less precise than in rigid

die pressing.

2. The surfaces of isostatically pressed compacts are less smooth.
3. In general the rate of production in isostatic pressing is considerably lower.
4. The flexible moulds used in isostatic pressing have shorter lives than rigid steel or carbide dies

### **(iii) Dynamic Powder Compaction**

Dynamic powder compaction is a single compaction/ sintering operation brought about by the impact of a high-speed punch on powder. This produces a discrete shock wave in the powder, which under optimized conditions, results in metallurgical bonding and sometimes fusion of the particles surface. The work of compaction produced by inter particle shear is transferred on the surface of the powders in such a short time (microseconds or less) that there is no possibility for heat to be conducted away from the surface and thus localized melting or welding occurs.

### **(iv) Powder Roll Compaction**

Powder rolling, also called roll compacting, is the important process to produce metal strips. In powder rolling metal powder is fed from a hopper into gap of a rolling mill and emerges from the gap as a continuous compacted green strip. The rolls of the mill may be arranged vertically or horizontally. The latter type of arrangement is more common, with either saturated feed or starved feed

## **Sintering**

Sintering may be considered the process by which an assembly of particles, compacted under pressure or simply confined in a container, chemically bond themselves into a coherent body under the influence of an elevated temperature. The temperature is usually below the melting point of the major constituent. The driving force for solid state sintering is the excess surface free energy.

Various stages of sintering can be grouped in the following sequence:

- (1) Initial bonding among particles
- (2) Neck growth
- (3) Pore channel closure
- (4) Pore rounding
- (5) Densification or pore shrinkage
- (6) Pore coarsening

### **(i) Liquid Phase Sintering**

In this the presence of liquid phase during all or part of the sintering cycle of material is used for enhanced densification. There are two variations of the process:

- (a) normal liquid phase sintering for which the formation of the liquid phase is associated with one or more components contained in the original green compact.
- (b) infiltration of the original green compact with a liquid formed outside the compact during the very early period of sintering.

### **(ii) Activated Sintering**

Refers to process in which the activation energy for sintering is lowered. This is mostly achieved by chemical addition to the powder. For certain metals, particularly refractory metals, the addition of dopant causes the densification kinetics to increase as much as 100 times compared with undoped compacts. The best activators are palladium and nickel. Nickel is often added as a solution of its salt which is reduced to the metal and forms a layer several monatomic layers thick on the surface of the tungsten powder particles.

### **(iii) Loose Sintering**

This method is quite widely used for manufacture of highly porous parts like filters. Basically, metal powder is poured or vibrated into a mould which is then heated to the sintering temperature in an appropriate atmosphere. Shrinkage usually takes place during sintering, only shapes where this can occur without mould constraint causing cracking can be used. The characteristics required of the mould material for loose sintering are:

- (i) It should be easily machined or formed into the required shape
- (ii) it should withstand the sintering temperature without appreciable deformation and
- (iii) it should not weld to the powder during sintering.

For most applications machined or welded metal moulds are used, although graphite may also be employed where no reaction with the powder is likely, and even here a refractory mould wash may suffice to prevent reaction. Since no pressure is applied to the powder any unreducible oxide skin on the particle will prevent metal-to-metal contact and inhibit sintering. For this reason, it is virtually impossible to lose sinter aluminium powder

### **Powder Metallurgy Application:**

- To produce a porous product and
- Babbitt bearing for automobiles.
- To produce oil pump gears for automobiles.
- Used for production of cutting tools, wire drawing dies and deep drawing dies.
- To produce refractory metal composites, eg: tungsten, molybdenum, tantalum For manufacturing the tungsten wires for filaments in the lamp industry.
- Diamond impregnated tools are produced by a mixture of iron powder and diamond dust.
- To produced electrical contract material, eg: circuit breakers, relays and resistance welding electrodes.
- Parts of cars, aircraft, gas turbine, electric clocks, etc.
- Parts of vacuum cleaners, refrigerators parts of guns, sewing machines.