Powder Metallurgy- Unit 4

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Syllabus

- Mechanism of sintering, liquid-phase sintering, infiltration process.
- Study of sintered bearings, cutting tools, and metallic filters.
- Study of friction and antifriction parts and electrical contact materials.

Mechanism during liquid phase sintering

- In the sintering of multi-component systems, the material transport mechanisms involve self diffusion and interdiffusion of components to one another through vacancy movement.
- Sintering of such systems may also involve liquid phase formation, if the powder aggregate consists of a low melting component whose melting point is below the sintering temperature

LIQUID PHASE SINTERING:

- In this, the liquid phase formed during sintering aids in densification of the compacts. Liquid phase sintering employs a small amount of a second constituent having relatively low melting point. This liquid phase helps to bind the solid particles together and also aids in densification of the compact. This process is widely used for ceramics – porcelain, refractories..
- Three main considerations are necessary for this process to occurs,
  1. presence of appreciable amount of liquid phase,
  2. appreciable solubility of solid in liquid,
  3. complete wetting of the solid by liquid.

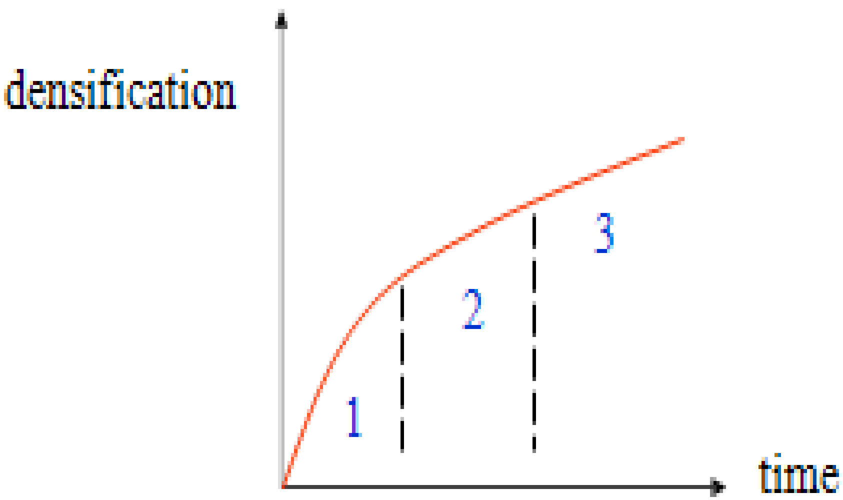
Three main stages are observed in liquid phase sintering

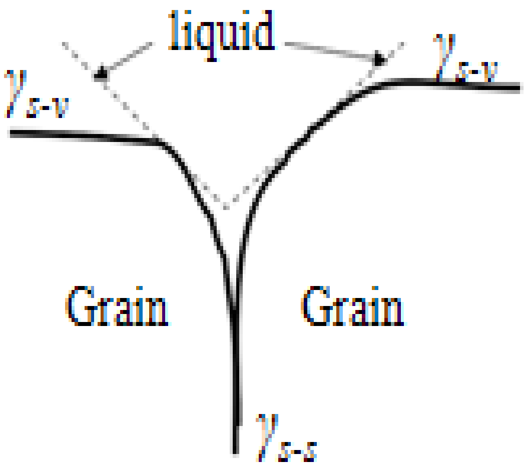
1. initial particle rearrangement occurs once the liquid phase is formed. The solid particles flow under the influence of surface tension forces,

2. solution & reprecipitation process: in this stage, smaller particles dissolve from areas where they are in contact. This causes the particle centers to come closer causing densification. The dissolved material is carried away from the contact area and reprecipitate on larger particles,

3. solid state sintering

- This form of liquid phase sintering has been used for W-Ni-Fe, W-Mo-Ni-Fe, W-Cu systems. The three stage densification is schematically shown in figure.





- IN solid phase sintering, the solid particles are coated by the liquid in the initial stage.
- In liquid phase sintering, the grains are separated by a liquid film. The dihedral angle (θ) is important.
- For the figure shown here, the surface energy for the solid-liquid- vapour system is, $\theta = \gamma_{s\text{-}s}/2\gamma_{l\text{-}s}$ where $\gamma_{s\text{-}s}$ & $\gamma_{l\text{-}s}$ are the interfacial energies between two solid particles and liquid-solid interfaces respectively.

- For complete wetting θ should be zero. This means that two liquid-solid interface can be maintained at low energy than a single solid-solid interface. This pressure gradient will make the particles to come closer.
- If θ is positive, grain boundaries may appear between the particles and an aggregate of two or more grains will be established. This creates formation of rigid skeleton and will hinder with densification

Sintering Atmospheres

- Functions of sintering atmosphere:

  1. preventing undesirable reactions during sintering,
  2. facilitate reduction of surface oxides,
  3. facilitating the addition of other sintering and alloying elements which enhance the sintering rate and promote densification,
  4. aiding the removal of lubricants,
  5. composition control and adjusting the impurity levels.

For sintering atmosphere:

- pure hydrogen,
- ammonia,
- reformed hydrocarbon gases,
- inert gases,
- vacuum,
- nitrogen based mixtures without carburizing addition,
- nitrogen based mixtures with carburizing addition

Infiltration process

- It is an important powder metallurgy process in which

  -the pores of a sintered solid are filled with a liquid metal or alloy.
- Solid must have melting point

  -considerably higher than that of the

  -infiltrating metal or alloy.
- Infiltration is used to improve the strength of ferrous structural parts.

- Infiltration consists of

  -fabricating a porous skeleton of a refractory based material, followed by

  -infiltration with a molten metal to produce

  -a sound, strong, nonporous body.
- Only a few metals are suitable as infiltrant

  -copper and copper alloys,

  -silver, and

  -nickel.

- An infiltrant must

  -wet the skeleton completely,

  -have low surface tension so as to fill small interstices, and

  -must not alloy or react with the base material.
- A continuous network of a ductile infiltrant metal gives the composite

  -much greater resistance to thermal and mechanical stresses.

- The infiltrant can be injected by a variety of techniques such as

  -capillary dip

  -contact infiltration

  -gravity feed, and

  -pressure or vacuum infiltration.

- Major advantages of infiltration are:

1. Enhanced mechanical properties

   -higher tensile strengths, hardness, greater impact energy and fatigue strength.
2. Uniform density as infiltration tends to even out variations in density.
3. Higher density by increasing the weight of the sintered part without altering its size.

4. Removal of porosity which permits
   -secondary operations such as
   -pickling, plating to be carried out.
5. Selective-property variations can be achieved
   -by infiltrating only selected areas of a part.
6. Assembly of multiple parts by
   -sintering the different parts assembled together and
   -bonding the parts into a single part through common infiltration.

Applications

1. Electrical contacts

   -W skeleton infiltrated with Cu.

   -Other examples are W and Ag, Mo and Ag.

2. W-Cu compound materials

   -used as resistance welding electrodes.

3. Rocket nozzles made of W and Ag.

4. Experimental cermet turbine blades made of titanium carbide-superalloy.

5. Tools made of titanium-carbide steel.

6. Mechanical parts made of iron/steel- copper alloy.

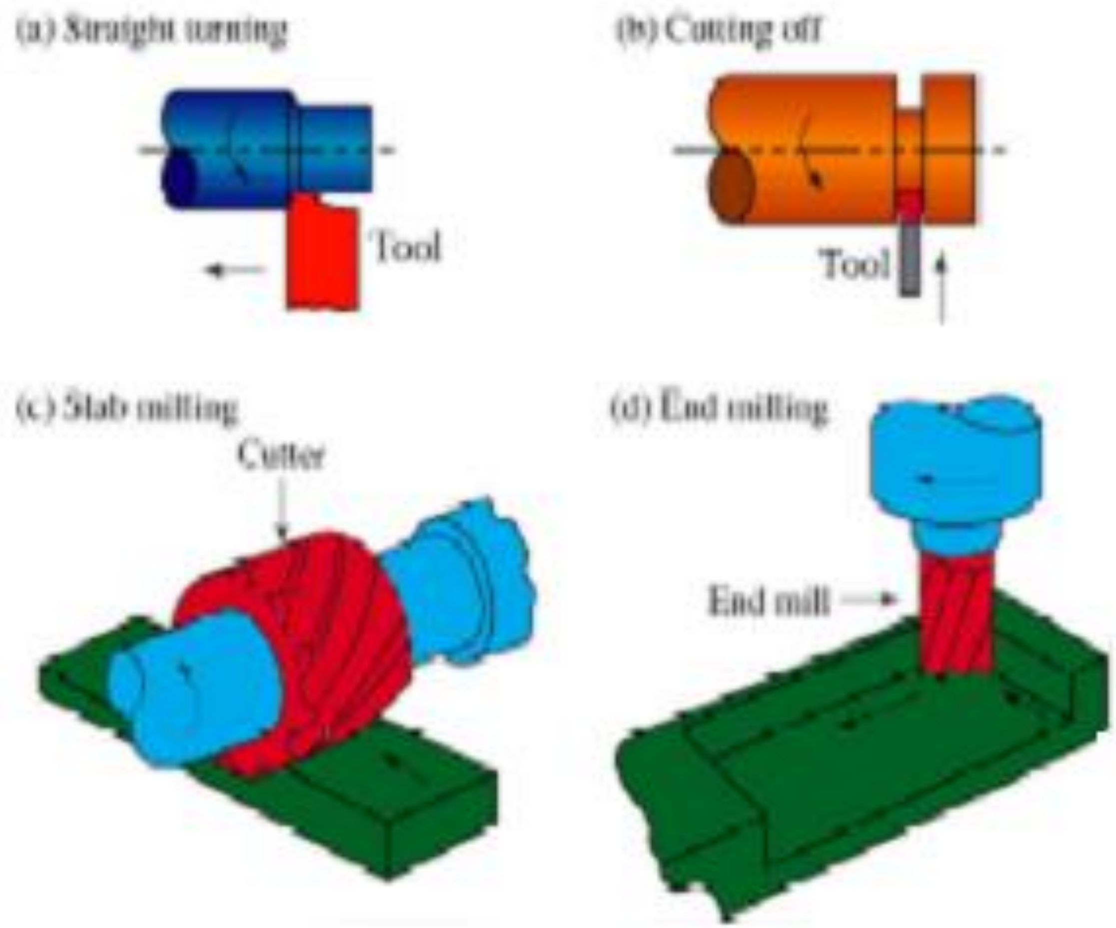
7. Bearings steel-babbit alloy.

8. Superconducting Nb_3Sn tapes and wires.

Cutting tools

- Cutting process : Remove material from the surface of the work piece by producing chips
- Turning operation : the work piece is rotated and a cutting tool removes a layer of material as it moves to the left
- Cutting off: Cutting tool moves radially inwards and separated the right piece from the back of the blank.
- Slab-milling rotating cutting tool removes a layer of material from the surface of the work piece
- End-milling rotating cutter travels along a certain depth in the work piece and produces a cavity

Fundamentals of cutting



Examples of cutting process

FACTOR INFLUENCING CUTTING PROCESS

Parameter	Influence and interrelationship
Cutting speed depth of cut,feed,cutting fluids.	Forces power , temperature rise , tool life, type of chips , surface finish.
Tool angles	As above ; influence on chip flow direction ; resistance to tool chipping.
Continuous chip	Good surface finish ; steady cutting forces ; undesirable in automated machinery.
Built-up-edge chip	Poor surface finish , thin stable edge can product tool surface.
Discontinuous chip	Desirable for ease of chip disposal ; fluctuating cutting forces ; can affect surface finish and cause vibration and chatters.
Temperature rise.	Influences surface finish , dimensional accuracy , temperature rise , forces and power.
Tool wear	Influences surface finish , dimensional accuracy , temperature rise , forces and power.
Machinability	Related to tool life , surface finish , forces and power

TUNGSTEN CARBIDE CUTTING TOOL

- Tungsten carbide (WC) also referred to as cemented carbide is a composite material,
- Manufactured by a process called powder metallurgy.
- Tungsten carbide powder generally ranging in proportion between 70%-97% of the total weight.
- Mixed with a binder metal usually cobalt or nickel compacted in a die and then sintered in a furnace.
- The term "cemented" refers to the tungsten carbide particles being captured in the metallic binder material and " cemented" together, forming a metallurgical bond between the tungsten carbide particles and the binder (WC - Co), in the sintering process.
- The cemented carbide industry commonly refers to this material as simply "carbide", although the terms tungsten carbide and cemented carbide are used interchangeably.

TUNGSTEN POWDER(94%)+CARBON POWDER(6%)

↓

MILLING(IN ROTATING MILL)

↓

CARBURIZING FORM WC (1500°C)

↓

COBALT(BINDER)

↓

BLENDING

↓

GRANULATING

↓

COMPACTING

↓

PRE SINTERING

↓

SINTERING

↓

INSPECTION

PROPERTIES

- Cemented carbide is the preferred material for parts that must withstand all forms of wear
- including sliding abrasion
- Erosion
- corrosion
- high degree of toughness
- high compressive strength
- resists deflection
- retains its hardness values at high temperatures

PROPERTIES

Density: density of cemented carbides being a measure of completeness of the sintering operation owing to the occurrence of contraction or shrinkage on final sintering, depends on the composition.

Hardness: hardness of cemented carbide tool is used as a measure of wear performance.

Hot hardness: the hot hardness of cemented carbide is of greatest practical importance in high speed machining. A 6% Co grade has hardness of 100 VPN at 750C which is higher than that of hss at R.T.

- Transverse rupture strength: transverse rupture strength of cemented carbides being a good measure of their toughness is determined on bar specimens using cemented carbide supports.
- Compressive strength: compressive strength of WC-Co alloy composition at elevated temperature are outstanding. Co content increase compressive strength decrease.
- Impact strength: impact strength being measure of toughness is of importance particularly in the case of cutting tool employed for intermittent cutting.

CEMENTED CARBIDE IS MANUFACTURED

- cemented carbide is made by a powder metallurgy process.
- The compaction process is performed under very high pressure in a mechanical press as shown in Figure I-1.
- A small amount of wax (paraffin) is added to increase the green strength and help in handling the compacted shape.
- In this "green" state it can be formed or shaped by conventional methods such as turning, milling, grinding, and drilling (Figure I-2).
- The formed and shaped carbide is then sintered placed in a vacuum furnace at a high temperature.

- During the sintering process, the carbide may shrink as much as 20% linearly, or nearly 48% by volume (Figures I-3 and I-4)
- For an "as-sintered" part, it is considered an industry standard to be able to hold a tolerance of ± 0.8% of the dimension or ± 0.005", whichever is greater.
- Tighter tolerances can be held on smaller pressed parts.
- After sintering, cemented carbide has achieved its full density and hardness.
- It can then be fabricated by diamond wheel grinding or electrical discharge machining (EDM) techniques.

Mechanical Press

Figure I-1

Powder Shaping Mill

Figure I-2

Sinter-HIP furnace

Figure I-3

Figure I-4

APPLICATIONS

- **Cutting tools for machining**
- **Ammunition**
- **Nuclear**
- **Surgical instruments**
- **Jewelry**

TITANIUM CARBIDE

- **Titanium carbide**, TiC, is an extremely hard refractory ceramic material, similar to tungsten carbide.
- It is commercially used in tool bits. It has the appearance of black powder with NaCl-type face centered cubic crystal structure. It is mainly used in preparation of cermets, which are frequently used to machine steel materials at high cutting speed.
- The resistance to wear, corrosion, and oxidation of a tungsten carbide-cobalt material can be increased by adding 6-30% of titanium carbide to tungsten carbide. This forms a solid solution that is more brittle and susceptible to breakage than the original material.
- Tool bits without tungsten content can be made of titanium carbide in nickel-cobalt matrix cermet, enhancing the cutting speed, precision, and smoothness of the workpiece..

TANTALUM CARBIDE

- **Tantalum carbides** form a family of binary chemical compounds of tantalum and carbon with the empirical formula TaC_x, where x usually varies between 0.4 and 1.
- They are extremely hard, brittle, refractory ceramic materials with metallic electrical conductivity. They appear as brown-gray powders which are usually processed by sintering.
- Being important cermet materials, tantalum carbides are commercially used in tool bits for cutting applications and are sometimes added to tungsten carbide alloys.
- The melting points of tantalum carbides peak at about 3880 °C depending on the purity and measurement conditions; this value is among the highest for binary.

ALUMINUM OXIDE

- **Aluminum oxide** is a chemical compound of aluminum and oxygen with the chemical formula Al_2O_3.
- It is the most commonly occurring of several aluminum oxides, and specifically identified as **aluminum oxide**. It is commonly called **alumina**.
- Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.

SILICON CARBIDE

- **Silicon carbide** (**SiC**), also known as **carborundum** is a compound of silicon and carbon with chemical formula SiC.
- Silicon carbide powder has been mass-produced for use as an abrasive.
- Grains of silicon carbide can be bonded together by sintering to form very hard ceramics that are widely used in applications requiring high endurance, such as car brakes, car clutches and ceramic plates in bulletproof vests.
- Electronic applications of silicon carbide as light-emitting diodes (LEDs) and detectors in early and today SiC is widely used in high-temperature high-voltage semiconductor electronics.

(vii) depth ... through the furnace, and (v) reduction

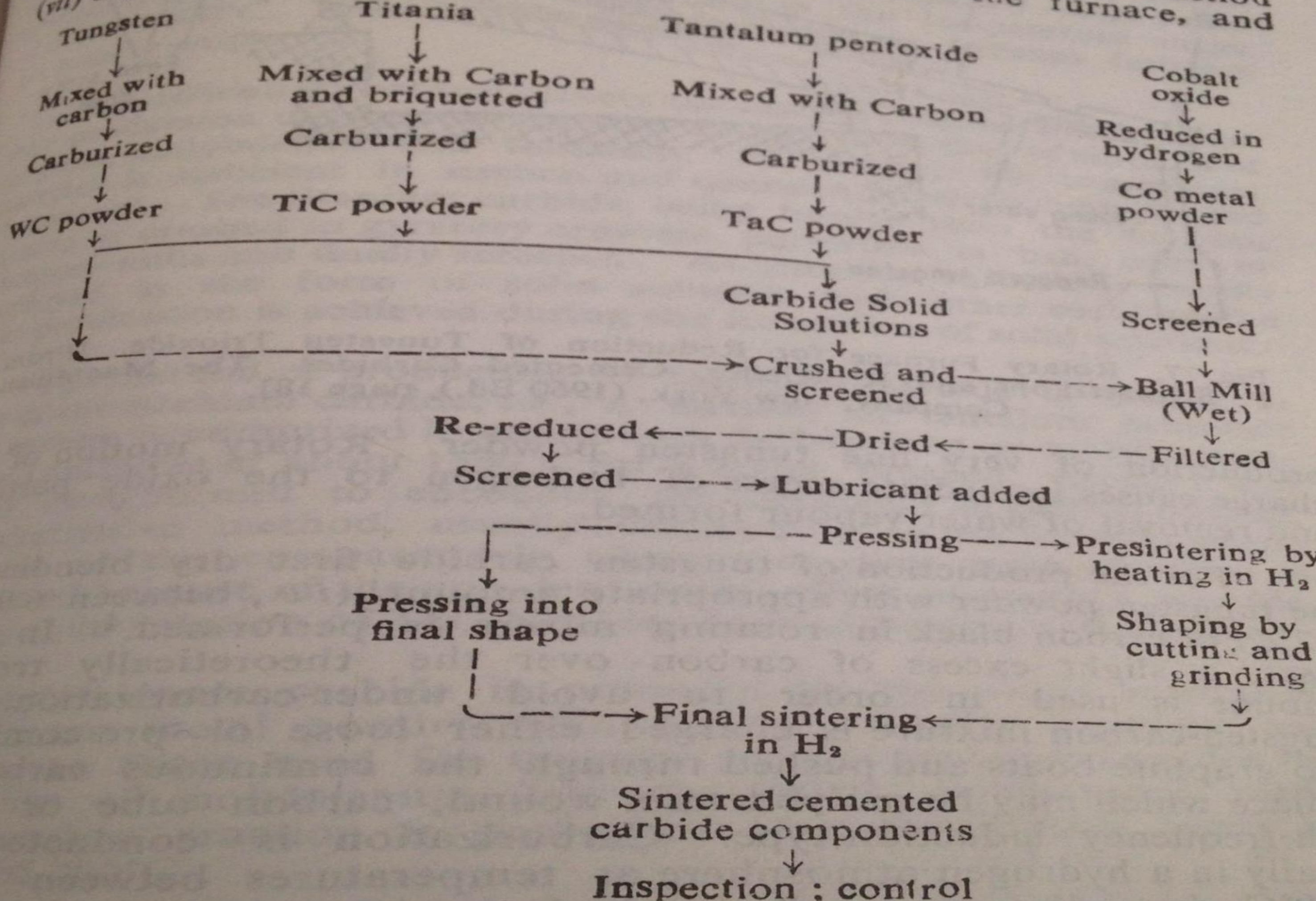


Fig. 76. Production Steps of Sintered Cemented Carbides.

Porous P/M (Filters)

- Porous P/M materials are specified when special characteristics are required such as good mechanical properties, rigidity, corrosion resistance, uniform porosity, and controlled permeability.
- Porous P/M materials are normally sintered to densities between 25 and 85% of theoretical mean density (TMD).
- Porous metal materials have engineered, inter-connected porosity that are fabricated from metal powder particles using powder metallurgy (PM) techniques.

DEFINITIONS:

- **Pores**- The open volume within the metal matrix or network.
- **Interconnected Porosity-** Pores that are connected together and to the surfaces of the component to allow fluid flow from one side to the other. By contrast, isolated pores do not have connectivity to both surfaces to allow fluid flow.

Definitions (Contd.)

- **Percent Porosity-** a rough measure of the open volume equal to 100% minus the part density. The total open volumes of interconnected and isolated porosity are normally included in this value. Pore Shape, Pore Size and Pore Size Distribution are critical factors when describing the open volume available.
- **Permeability**- rate of fluid flow per specified surface area of a porous material at a given pressure differential

Material Selection

- Materials can be selected from a wide variety of P/M materials, depending on the combination of application requirements and economics.
- The porosity depends on:
    - Powder Particle Shape.
    - Powder Particle Size Distribution.
    - Powder Surface Texture.
    - Material Processing Method:

Materials Used:

- Out of many materials available for selection and making of porous materials the most important and most used in industries and having the highest number of applications are:
  - Stainless Steel.
  - Bronze.
  - Nickel and Nickel Based Alloys.
  - Titanium.

Stainless Steel:

- Type 316L
- Typical Composition: 18%Cr, 13% Ni, 2% Mo, 1% Si, 0.03% max C.
- Stainless steel is majorly used to take special advantage of that metal's excellent resistance to heat and corrosion.
- Stainless steel are produced by water or gas atomization
- Water atomization produces powders with rounded, irregular shapes that can be processed by compaction and sintering

Bronze:

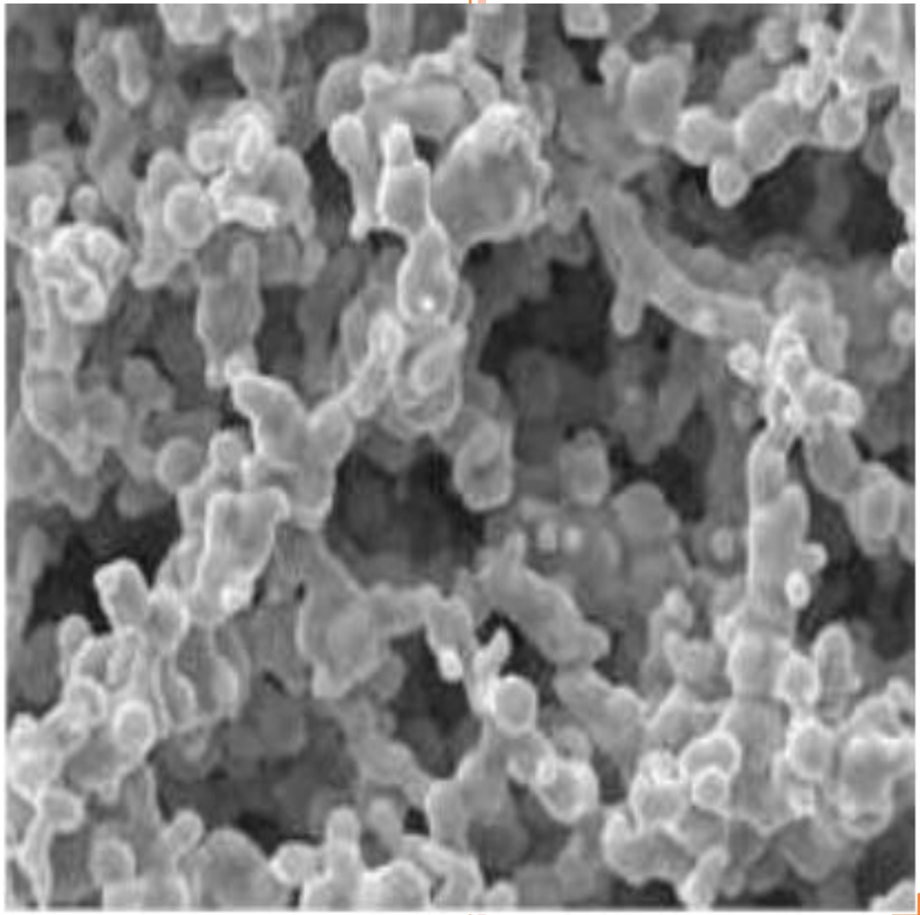
- Bronze powders consisting of 89to90% Cu, 10to11% Sn, and 0.1to0.5% P are the most common material for porous bronze P/M components such as filters and self lubricating bearings.
- Small amounts of phosphorous can be added to improve mechanical strength.
- These 89/11 or 90/10 bronze powders are available from three main processes.
- Gas or air atomization of prealloyed bronze yields fine, spherical particles that can be processed to low densities by gravity sintering

Ni & Ni-Based Alloys:

- When special corrosion- or heat-resistant properties are required and stainless steel is not good enough, nickel-base alloys may be applicable.
- Filter grade powders are usually available in nickel, standard Monel and Inconel and some of the Hastelloys

Ni Based Alloys:

Carbonyl or water atomized nickel powders are rapidly growing in acceptance for use as porous P/M products. The thermal decomposition of nickel carbonyl produces very fine (0.5 to 10μm)particles attached in a filamentary chain-type structure



Ni & Ni-Based Alloys Applications:

- Applications:
  - a) Monel or Hastelloy may be used in acidic waters, where stainless steel will rust from crevice corrosion;
  - b) Inconel and the Hastelloys serve in high temperature and severe corrosion applications.
  - c) Nickel finds special applications not only in battery and fuel cell plates, but also in submicron particle filtration for high purity gas filtration applications

Titanium:

- Porous Titanium offers excellent corrosion resistance and is ideally suited for filtration applications in harsh environments. Titanium porous materials are available in sheets, tubes and components with controlled porosity ranging from 100 Micron Grade down to 0.5 Micron Grade
- Processing and Manufacturing is difficult and high control parameters are must.
- Titanium of higher purity is normally specified for medical, chemical or aerospace applications

Processing Method:

Powder Preparation :

- Starts with the proper size distribution of the Powder Particles.
- Vibratory or ultrasonic screening methods are normally used for particles greater than 20µm (600meshscreen) and other separation methods such as air classification are used for particles less than 20µm.
- Proper blending is required to avoid segregation and maximize uniformity.

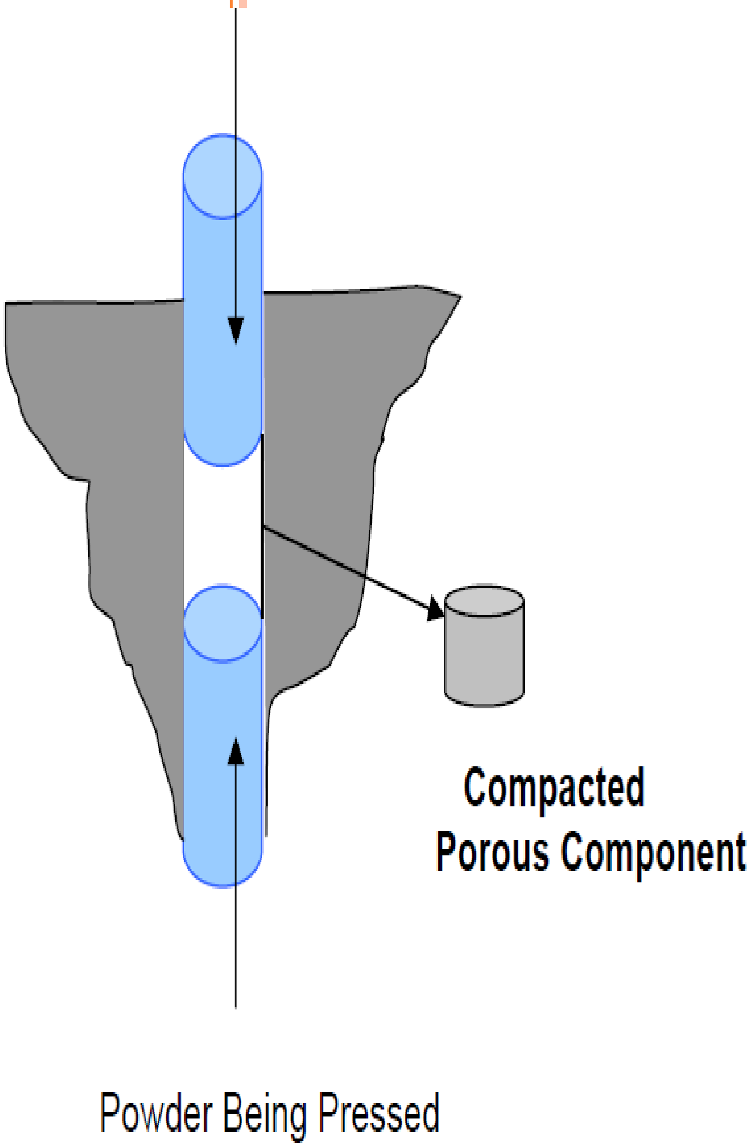
Manufacturing Methods:

- Depending on part size, configuration, and material as well as the degree of porosity required, most porous sintered metal products are fabricated by one of the following processes:
  - Axial Compaction and Sintering.
  - Gravity Sintering.
  - Powder Rolling and Sintering.
  - Isostatic Compaction and Sintering.
  - Metal Spraying.
  - Metal Coating and Sintering.
  - Metal Injection Moulding and Sintering.

Axial Compaction and Sintering

Metal powder is pressed in a die at sufficient pressure that the powder particles adhere at their contact points with adequate strength for the formed part to be handled after ejection from the die.

Porous metal parts differ from standard PM structural parts in that they are pressed at lower pressures and may tight mesh cuts of powder in order to achieve specified porosity requirements



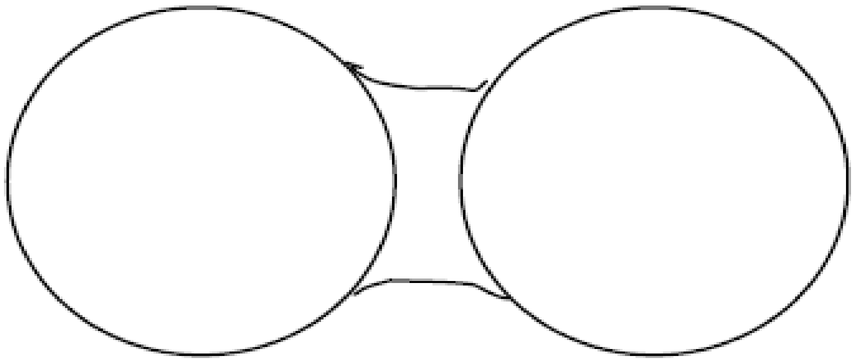
GRAVITY SINTERING

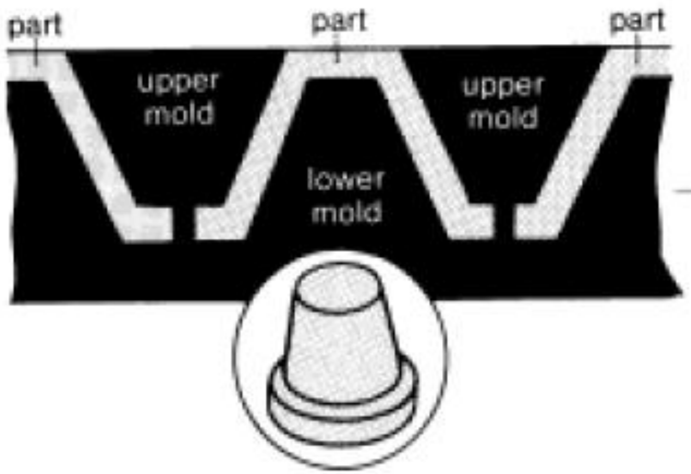
Gravity or "loose powder" sintering is used to make porous metal parts from powders that diffusion-bond easily

In this process, no outside pressure is applied to shape the part

These metal particles are then heated to their sintering temperature at which point a metallurgical bonding takes place, and joining "necks" are formed at contact points

Metallurgical Bonding





GRAVITY SINTERING

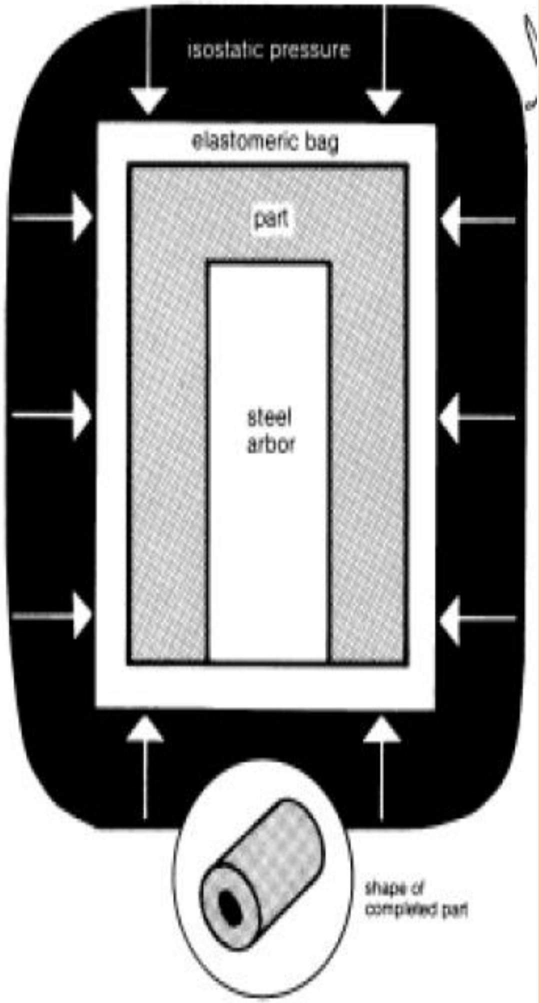
Powder Rolling and Sintering.

- The sheet material is made by direct powder rolling or by gravity filling of molds and calendaring before sintering. Specified porosity is achieved by selecting the proper particle size of the powders.
- Depending on the density and material, the PM sheet is available in a variety of thickness, from 0.25 mm (0.010") to 3 mm (0.12") and in area dimensions up to one square meter or several square feet.
- The sheet can be sheared, rolled and welded into different configurations.

Isostatic Compaction and Sintering

Isostatic Compacting is a process by which pressure is applied uniformly to a deformable container holding the metal powder to be compacted.

This technique is especially useful in the manufacturing of parts having a large length-to-diameter ratio.



ISOSTATIC COMPACTING

Metal Spraying

- Metal powders may be the source of a porous metal structure created by spraying molten metal onto a base with porosity control achieved by spraying conditions or by the co-spraying of a second material, which may later be removed.

Metal Coating and Sintering

- Metal powders can be mixed with special binders to form slurry that can be applied to porous substrates or used to form net shape components.
- Special care and equipment is normally required to insure appropriate binder removal and uniform porosity.

Metal Injection Molding and Sintering:

- Porous materials can be fabricated by MIM processing by mixing metal powders with significant amounts of specially formulated binders to form a viscous material for high pressure injection.
- Depending on the material characteristics and MIM tool design, unique components with controlled density can be formed.
- Due to the large amount of shrinkage that occurs during binder removal, special debinding and sintering equipment is required for processing materials by this method

SINTERING:

- Sintering of porous metal is a critical balance between maximizing material properties and maximizing the open porosity and permeability.
- However, because permeability and material properties such as strength and ductility are generally inversely related, the desired balance of these characteristics normally occurs in a very small processing window.
- Sintering requires the proper compromise of temperature, time at temperature, and atmosphere to arrive at the desired porosity characteristics.

Sintering temperature

- Sintering temperature must be selected by considering the material, the powder shape, and the powder particle size distribution.
- Sintering is normally accomplished at 70 to 90% of the material melting temperature.
- Finer powder particles require a lower sintering temperature because the surface energy driving force to initiate bond growth is much higher than for a coarser particles.
- Sintering at too high a temperature also causes the formation of very large pores and non-uniform porosity just prior to melting

Sintering time:

- Sintering time must be monitored to allow for a minimum exposure time at the desired sintering temperature.
- Sintering for at least 30 to 60 min at the maximum sintering temperature is recommended for most materials for sufficient bond formation and growth.
- Inadequate sintering time can lead to large variations in part shrinkage and final density, causing porosity and permeability variations.
- Excessive sintering unnecessarily reduces permeability due to pore size reduction and pore closure without significantly improving mechanical properties.

Sintering atmosphere:

- Sintering atmosphere selection is critical for determining the metallurgical properties of the porous metal product.
- Because porous materials have much higher surface area than a similar-size structural part, the atmosphere has more contact with surfaces throughout the part rather than just near the surface.
- Porous parts also contain relatively large amounts of trapped air in the pores that must be removed by purging or good atmosphere circulation in the furnace.

Secondary Operations:

- **Press Fitting and Sinter bonding.**
- **Machining.**
- **Welding, Brazing and Soldering.**
- **Epoxy Bonding.**
- **Cleaning.**
- **Storage and Handling.**
- **Insert Molding**

Porous Metal Characteristics:

- Material density.
- Pore characteristics such as size, shape, and distribution.
- Permeability.

Mechanical Properties:

Material[a]	Filter grade[b] μm	Density, %	Minimum ultimate tensile strength		Elongation, %	Shear strength[c]	
			MPa	ksi		MPa	ksi
Bronze	10	75	48	7	8	130	18.8
	20	68	41	6	6	110	15.9
	40	62	35	5	4	100	14.5
	90	57	28	4	3	75	10.9
	150	54	21	3	2	40	5.8
	250	52	14	2	2	30	4.3
316L SS	0.2	80	180	26	6	250	36.2
	0.5	75	159	23	6	230	33.3
	2	65	117	17	5	190	27.5
	5	62	90	13	5	160	23.2
	10	60	69	10	4	130	18.8
	20	55	48	7	3	100	14.5
	40	50	31	4.5	2	80	11.6

Typical mechanical properties of bronze and 316L SS filters

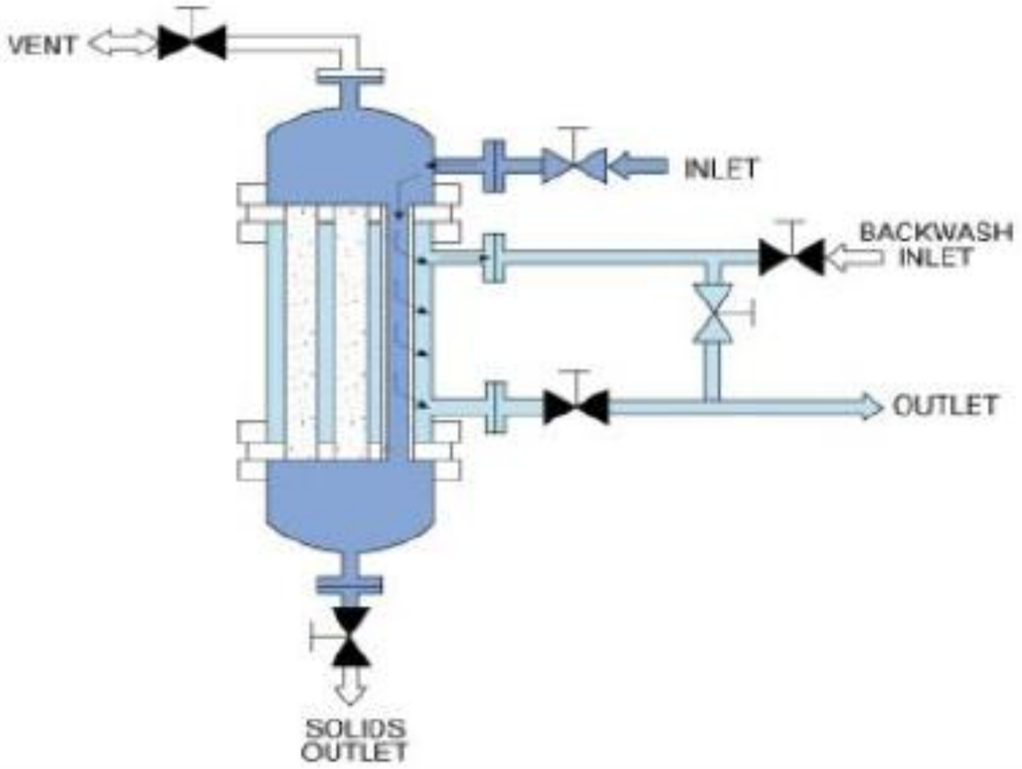
FILTRATION:

- Porous sintered products are a depth-filtration medium with distribution of pore size and length of passage qualities that are a factor of particle size, shape, and part dimension.
- The depth-filter not only has more dirt-holding capacity that a screen filter, but also has a higher pressure drop than a screen of equivalent porosity rating.
- Porous PM parts are capable of extremely fine degrees of filtration.

Filtration (Contd.)

- Porous PM filter parts are sturdy and rigid, not as susceptible to mechanical damage as fine screens, not as fragile as ceramic filters, nor as deformable as organic felted materials.
- The designer with a filtration problem should look at all functional aspects with a value analysis technique.

Schematic Diagram of Liquid Filtration



Applications:

- **Filters for Separating Solids from Liquids and Gases**: filters for catalyst retention, fuel oil burners, polymer processing, instruments, pressure regulators, cryogenic fluids, medical drug delivery systems.
- **Fluid Flow Metering and Pressure Control:** flow restrictors, calibrated leaks, breather vents, pneumatic delays, timing devices, gauge snubbers, and pressure equalization.
- **Storage Reservoirs for Liquids**: self-lubricating bearings, wicks, cooling devices, heat exchange elements

Applications (Contd.)

- **Flame and Spark Arrestors for Safe Handling of Flammable Gases**: welding/cutting torch flame arrestors, electrical enclosures
- **Sound Dampening and Attenuation**: pneumatic mufflers and silencers, microphone attenuators
- **Gas Distribution and Sparging**; fluidized bed surfaces, air bearings, vacuum plates, spargers for carbonation, oxygen stripping, ozone injection
- **Media Retention**: permeable barriers for desiccants, getters and purifiers

Friction Materials

- Components of a mechanism that converts mechanical energy into heat upon sliding contact.
- The conversion product, heat, is absorbed or dissipated by the friction material.
- The coefficient of friction, an index of shearing force of the contacting parts, determines the degree of performance of the friction material.

MANUFACTURING METHOD

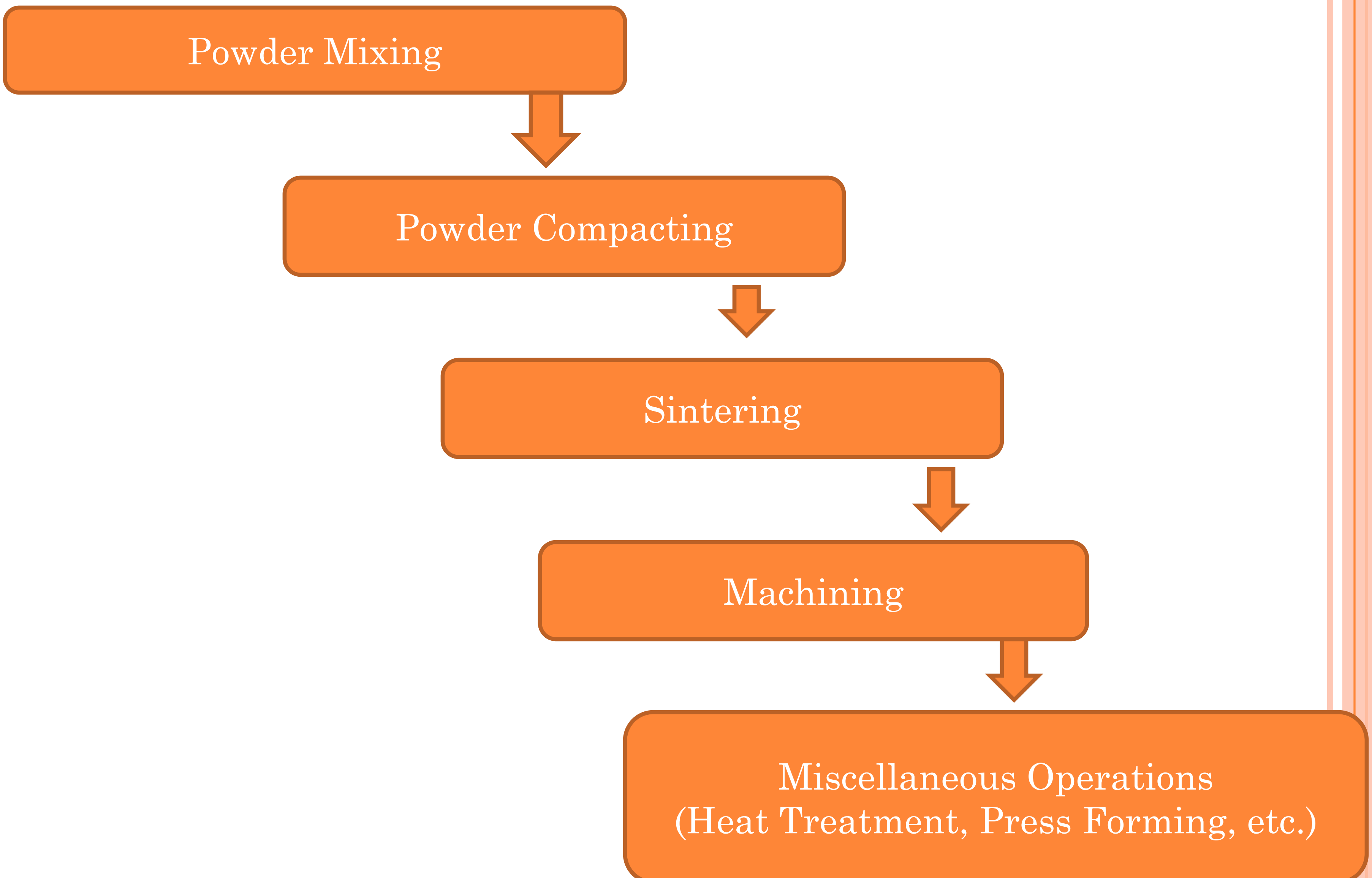


FIGURE 1: FINISHED PRODUCTS OF SINTERED FRICTION MATERIALS

PROPERTIES

1) High static coefficient of friction
2) High dynamic coefficient of friction
3) Proper static : dynamic friction ratio
4) Longer life
5) Very little wear
6) Constant friction with increasing temperature
7) Constant friction with time
8) Formability or Fabricability

9) High energy-absorption capacity
10) Minimum cost
11) Adequate mechanical strength
12) Corrosion stability & resistance to contaminants
13) Relatively high thermal conductivity
14) Freedom from noise

Anti Friction Materials

- Anti Friction Materials employed for machine parts e.g. bearing, bushing etc which operate with sliding friction and which under certain conditions have a low co-efficient of friction.
- The antifriction capability of materials becomes apparent under imperfect lubrication conditions.
- Antifriction capability is displayed under dry friction conditions by a material containing components that have a lubricating action and make for low friction by being present on the friction surface
- The most common antifriction materials are the bearing materials used for sliding bearings.

BEARING

- The main function of a rotating shaft is to transmit power from one end of the line to the other.
- It needs a good support to ensure stability and frictionless rotation. The support for the shaft is known as “bearing”.
- Besides antifriction properties they must possess the requisite strength, resistance to corrosion in lubricating medium, suitability for production, and economy.

BEARING

- SELF-LUBRICATING BEARINGS are one of the oldest industrial applications of porous P/M parts.
- They remain the highest volume part produced by the P/M industry.
- The major advantage of porous bearings is that porosity in the bearing acts as an oil reservoir.
- The pores are filled with a lubricant that comprises about 25 vol% of the material.

FUNCTION

- When the journal in an oil-impregnated self-lubricating bearing starts to turn, friction develops, the temperature rises, and oil is drawn out of the press because of the greater coefficient o expansion of the oil compared with the metal and because of the hydrodynamic pressure differential in the oil film between the journal and the bearing.

- When rotation stops and the bearing cools, the oil is reabsorbed by capillary action.

TYPES OF BEARING MATERIALS

- Steel-backed materials with non-porous sintered lining to form engine bearings & wrapped bushes.
- Steel-backed materials with porous sintered lining impregnated with plastic for dry operation or operation with a limited supply of lubricant.
- Unbacked porous sintered metallic parts impregnated with oil for self lubricating bearing, bushes or washers.
- Unbacked non-porous sintered metallic parts containing graphite as a dry lubricant for use under poor lubrication condition.
- Sintered P.T.F.E parts incorporating metal powder to form a material suitable for non-lubricated applications.

Properties of Bearing Material

- Adequate mechanical strength above the operating temperature.

- Adequate superficial heat conductivity to assure rapid heat dissipation over the bearing housing through the shaft by conduction.

- Low wear rate of both bearing and journal

- Low superficial shear strength to cause lower friction loss at local metal-to-metal contacts.

Steel-backed materials with non-porous sintered lining

- Lining materials for engine bearings:
  - Pb or Sn-based white metal (Babbit)
  - Cu-based alloys
  - Al-based alloys

- Manufacturing Method:
  - Blowing the gas-atomized Cu-Pb or Pb bronze powder
  - Spreading the powder on Cu-plated steel strip
  - Sintering at 800-850 ^{0}C in reducing atm
  - Sinter strip is then passed through rolling mill-resintered
  - Final size rolling operation

Copper-lead bearing

- Most imp bearing of two phase class(40-45% lead)
- Fatigue strength of these bearing is 50% greater than that of similar thickness of white metal lining
- Surface properties are quite good for automobile engines, and they have replaced most of conventional solid phosphor-bronze bushes
- Properties depends on the amounts & distribution of two phases which form as a result of negligible solubility of Cu and Pb in each other in the solid state.

Copper-lead bearing

Tensile strength and Hardness of Sintered Cu-based bearing lining

Composition, wt%			Average U.T.S., p.s.i.	Average Hardness, HV
Cu	Pb	Sn		
60	40	-	11,000	32
70	30	-	12,500	37
74	22	4	17,000	50
80	10	10	26,000	70

Steel-backed materials with porous plastic-impregnated lining

- Two types of material

1. Impregnated with a mixture of P.T.F.E & lead
2. Impregnated with thermoplastic acetal copolymer

- Manufacturing Method

1. Sintering a layer of tin bronze appox. 0.01 in. thick on Cu-plated steel strip
2. P.T.F.E/lead mixture in form of thick paste is roll impregnated into this layer
3. Resintering at 327 ^{0}C
4. Final size roll to the strip

Oil-Impregnated Porous Bearing

- Most imp bearing manufactured by P/M
- Capacity of working under self-lubricating regime with the lubricant present in the pores of the bearing which may be operated under condition of day friction.

Porous bearing must contain the following characteristics:

1. Sufficient porosity content to contain and retain in use the max. possible amount of oil.
2. Major proportion of porosity must be distributed through-out the material in the form of interconnecting channels and reservoirs.
3. The bearing must have minimum strength values to sustain stresses during its working life.
4. It must be manufactured finished to close limits of dimensional accuracy.

Oil-Impregnated Porous Bearing

- Advantages

1. Capacity of working without lubricant
2. Corrosion resistance
3. Problem of machining are simplified
4. Easily fitted and more economical(due to mass production) than those produced by casting & machining method
5. Recommended where regular supply of lubrication is difficult or impossible, where there is dirt contamination in the surrounding atm. ,and where the lubricant must not get into the products(e.g. in food and textile industries)

- Applications

May find application in position which are Very difficultly accessible & frequent maintenance is not required

Bearing Compositions

- Porous self-lubricating bearings are divided into four groups:

· Sintered bronze bearings

· Iron-base sintered bearings

· Iron-bronze sintered bearings

· Iron-graphite sintered bearings

Sintered bronze bearings

- The original and most widely used P/M bearing material is **90%Cu-10%Sn** bronze with or without the addition of graphite

- **1%** fine natural graphite is often added to enhance processing as well as improve bearing properties and bearing operation.

- The **90%Cu-10%Sn** bronze material is superior in bearing performance to the iron-base and iron-bronze compositions, which are lower in cost and used in less severe applications.

Sintered bronze bearings

- They are made primarily from elemental copper, tin, and graphite powders.
- These bearings are available in two grades 1.Plain bronze 2.lead bronze, which consist of the basic bronze material with different percentages of graphite.
- Typical composition is as under:

Copper	**87.5-90.5%**
Tin	9.5-10.5%
Graphite	1.75% max
Iron	1%
TOE	0.5%max

Iron-base sintered bearings

- They are available as
  iron-carbon grades or
  iron-copper-carbon grades.
- Typical composition is as under:

Iron	**95.9%**
Combined carbon	**0.25-0.60%**
Silicon	**0.3%max**
Aluminium	**0.2%max**
TOE	**3%max**

Iron-bronze sintered bearings

- They are iron-copper-tin-graphite bearings with following chemical composition

Copper + Tin	**38-44%**
Total carbon	**0.5-1.3%**
Iron	**53.5-59.5%**
TOE	**1.25%max**

Basic step in production of porous bearing

Blending & Mixing

↓

Compacting

↓

Sintering

↓

Sizing

↓

Impregnation

Impregnation

- Powder metal bearings appear solid, but are actually 20 to 25% porous.
- Porosity consists of thousands of small capillaries that are interconnected throughout the structure of the bearing and act as a built-in reservoir for the lubricant.
- The pores are impregnated with oil normally under vacuum.
- Bearings are placed in the tank or autoclave, the lid is closed, and the vacuum pump is turned on. Pressure is reduced to at least 709 torr before oil is permitted to flow over the bearings.
- Oil is introduced into the tank without shutting off the vacuum pump, and the tank, now filled with bearings and oil, is evacuated for another few minutes or until the pressure is again reduced to 709 torr.
- After obtaining the desired vacuum, the vacuum pump is shut off, a valve is opened, and the oil is forced out of the impregnating tank to the storage reservoir.
- Finally bearings are taken out.

Application of porous bearing

- ***Automotive***: *Heater motors, window lift motors, air conditioners, windshield wiper motors, power* antenna motors, trunk-closing motors, seat adjuster motors, and tape deck motors

- ***Portable power tools:*** *Drills, reciprocating saws, jigsaws, and sanders*

- ***Home appliances:*** *Washing m/c, dryers, refrigerators, blenders, mixers, food processors, fans, and clocks*

- ***Consumer electronics:*** *Phonographs, stereo equipment, tape players, and video* recorders

- ***Business machines***: *Typewriters, computers, and copiers*

- ***Farm and lawn equipment:*** *Tractors, combines, cotton pickers, lawn mowers, string cutters, and chain* saws

- ***Marine equipment:*** *Outboard motors*

FRICTION MATERIAL FORMULATION

- Sintered Friction materials are complex mixtures of metallic & non-metallic powders containing at least three & as many as seven ingredients.
- The constituents are :
  1. Matrix Materials
  2. Friction agents
  3. Lubricants
  4. Wear resistors
  5. Fillers

1. Matrix Powders

- Available as Primary & Secondary Matrix Materials.
- Primary matrix materials comprises of constituents which constitute to about 50-80 wt% (40-50 vol%) of a mixture.
- Secondary matrix metals (or Alloying elements) are low melting point metals which amount to 5-15 vol%.

- Most widely used powders for primary matrix are Copper & Iron but copper based matrix possessed several disadvantages:
  1. High wear at high loads
  2. Inadequate coefficient of friction in presence of a lubricant
  3. Possess costly deficient Sn
  4. Unsuitable at temperatures above 350 ^{o}C.

- Secondary matrix metals such as Sn or Zn are added to promote liquid phase sintering & to develop compact/backing or compact/core bond.
- Also hardens the matrix, particularly for Copper based materials.

2. Friction Agents (or) Modifiers

- Can vary up to 28% of mixture.
- Most common are friction agents are silica, alumina, mullite, silicon nitride, silicon carbide, bentonite, asbestos, feldspar, etc.
- Max. amount for dry applications can be tolerated but disastrous results can be obtained with as low as 0.1% alumina in oil.

3. Lubricants

- Ranges from 5-25 wt.% (or up to 36 vol.%)
- Two types:
  i. Metallic Lubricants
     - Low melting point metals like Pb having no solid solubility in matrix
  ii. Non metallic Lubricants
     - Galena, natural or artificial graphite and MoS_2 due to their low and constant coefficient of friction and low wear rate.

4. Wear Resistors

- Can constitute up to 10 wt.% of the friction mix.
- Mainly restricted for dry applications.
- Most common is Cementite in the form of cast iron shot or grit.
- Can be mixed metal-oxide solutions or spinels.
- Used in high energy applications.
- Characterized by low coefficient of friction and very long life.

5. Fillers

- Varies between 0-15 wt.% of the mixture.
- Iron in Cu- base mixes, various minerals and some forms of carbon are few examples of fillers.
- In recent years, use of these components seem to be decreasing.

Table 1: Typical Compositions of Sintered Friction Materials

Sr. No.	Friction Material	Fe	Cu	Pb	Sn	Graphite	Others
1	Dry clutches & brakes	56%	-	-	-	18%	14% Zn 8% Chromite 4% SiC
2	Aircraft Brakes	63%	-	-	-	-	4.5% Sb 6% SiC 3% Fe Silicide 2.5% PbO 4% Chilled Fe
3	Oil clutches & Brakes	-	74%	-	3.5 %	16%	2% Sb 4.5% Galena
4	General Purpose	3%	73%	6%	7%	-	3% Sand 4% Molybdic oxide

APPLICATIONS

- The major applications for friction materials occur in the following application environments:

A. On Highway Applications

- Brake and clutch products for passenger, light commercial and heavy -duty vehicles

B. Off Highway Applications

- Brake products for trains
- Brake and clutch products for earth moving and agricultural equipment

C. Industrial and Mining Applications

- Brake and clutch products for headgears, conveyor belts, forklift trucks, etc.

Dry friction materials

- Earth moving equipment
- Agricultural equipment
- Cranes and hoists
- Lift trucks
- Highway trucks (clutches)
- Aircraft (brakes)

Wet friction materials

- Earth moving equipment
- Agricultural equipment
- Military
- Lift trucks (clutches)

ELECTRICAL CONTACT MATERIAL

- Electrical contact are the devices that make and break electrical circuits.

- The Ideal material should have good electrical and thermal conductivity and resistance to arcing and abrasion.

MATERIALS USED

- SILVER
- COPPER BASE METAL
- COPPER
- PLATINUM GROUP METALS
- TUNGSTEN
- MOLYBDENUM
- MERCURY

Different Systems

1. Metal – Metal System

- Ag - Ni
- W – Ag
- W – Cu

2.Metal – Metal Compound

- Silver with oxides of Cd, Zn, Sn and Cu

3. Metal – Non Metal

- Al – 10% graphite

Manufacturing Process

1. **Infiltration Process**

- Metal powder or carbide powder is first blended to the desired composition with or without a small amount of binder to impart green strength, then is pressed and sintered into a skeleton of the required shape.
- Silver or copper is then infiltrated into the pores of the skeleton. This method produces the most densified composites, generally 97% or more of theoretical density.
- After infiltration, the contact is sometimes chemically or electrochemically etched so that only pure silver appears on the surface. The contact thus treated has better corrosion resistance and performs better in the early stages of use.

2. **Press Sinter**

•For small refractory metal contacts a high-density material can be obtained by pressing a blended powder of exact final composition into shape and then sintering it at the melting temperature of the low-melting-point component.

•In some cases, an activating agent such as nickel, cobalt, or iron is added to improve the sintering effect on the refractory metal particles.

3. Press Sinter Repress

- The press-sinter-repress process is used for all categories of contact materials, especially those in the silver-base category.
- Blended powders of the correct composition are compacted to the required shape and then sintered.
- Afterward, the material is further densified by a second pressing (re-pressing). Sometimes the properties can be modified by a second sintering or annealing. The versatility of this process makes it applicable for contacts of any
- configuration and of any material.

4. Press Sinter Extrude

- Blended powder of final composition is pressed into an ingot and sintered.

- The ingot is then extruded into wires, slabs, or other desired shapes. The extruded material may be subsequently worked by rolling, swaging, or drawing.

- Material made by this method is usually fully dense.

Applications

- Auxilliary Motors
- Alternators
- Starters
- Food Mixtures
- Power Tools
- Vaccum Cleaner
- Generators
- DC Motor
- Invertors

Selected PM application

- P/M porous filters
- porous filters made by P/M route can be classified into four types based on their applications like filtration, flow control, distribution, porosity.
- Filtration is the separation process involving the removal of gas, liquid or solid from another gas or liquid. Flow control involves regulation of fluid flow in a system with controlled pressure drop. Distribution involves providing a uniform flow over a wide area.

Production of porous metal filters:

- Typical filter shapes that can be produced from the powder include discs, cups, bushings, sheets, tubes. The major advantages of porous filters include high temperature resistance, good mechanical strength, corrosion, long service life.

MADE BY GRAVITY SINTERING:

- - Bronze filters are produced by this method. This sintering, as discussed earlier, involves pouring of graded powders in to a mould prior to sintering operation. Then sintering is performed and metallurgical bonding is achieved by diffusion

BRONZE FILTERS

- are made by gravity sintering using either atomized spherical bronze powder or from spherical Cu powder coated with Sn layer. The powders are sintered in graphite or stainless steel moulds at temperatures near the solidus temperature of the bronze composition. Porosities of the range in 50% is formed.
- Porous nickel filters are made in the same fashion. Hollow, cylindrical stainless steel filters with thin wall thickness can be fabricated by cold extrusion of the plasticized mixture.

- These products are available in corrosion resistant alloys like stainless steel, Ti, Ni, and nickel base alloys.
- Desired porosity is obtained by using specific particles size and shape.
- Compaction and sintering is performed under controlled atmosphere to obtain good green compact part.

Made by powder rolling:

- porous strips of Ni, Ti, Cu, bronze and Ti alloys are prepared by powder rolling. Strips having thickness from 0.25 to 3 mm and length of several meters can be successfully made by this technique.

MADE BY DIE COMPACTION & SINTERING:

- porous filter parts can also be made by die compaction, but with only low compaction pressures. Once achieving the green compact, the parts are heated to the desired temperature under protective atmosphere to promote bonding between atoms. Porous parts from bronze, nickel, stainless steel, titanium powders can be produced by this method.

Made by powder spraying:

- spraying of metal powders on a substrate under controlled conditions can be used to produce porous material. It is also possible to co-spray the material along with a second material and removing the latter to obtain the porous part

Secondary operations on P/M part

- : Machining – In general, machining is not necessary for porous parts. But it can be done to produce specific shape and size in which case a very sharp tooling with a slight rake is employed. The machined surface is then treated to remove the cutting fluids. EDM and laser cutting are also performed to obtain specific shape and size.
- Insert moulding, sinter bonding, press fitting are other secondary operations.

JOINING –

- Joining of porous parts can be done with one another or with solid part mainly in the case of stainless steel porous components. TIG, LASER or electron beam welding are recommended for satisfactory joining of porous parts. Soldering and brazing are not used. Epoxy resins are also used for bonding of porous parts.

Applications of porous parts:

- porous metallic filters – porous filters remove solid particles from streams of liquid such as oil, gasoline, refrigerants, polymer melts and from air or other gases. The important characteristics of filter materials are, adequate mechanical strength, retention of solid particles up to a specified size, fluid permeability, adequate resistance to atmosphere attack.
- Typical pore sizes are 0.2, 0.5, 1, 2, 5, 10, 20, 40, 60 and 100 microns. The most widely used metallic filter materials are porous copper-tin bronze and porous stainless steel.
- For filtering highly corrosive fluids, filters made form monel, inconel, Ti can be used.