MANUFACTURING PROCESS IN METALLURGY

POWDER METALLURGY

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Various types of powder metallurgy products are manufactured depending upon their physical and mechanical properties requirement. These may be classified broadly in three categories. These are:

1. Friction parts – Solid bearings, porous powder products such as porous bearings, porous filters and porous electrodes, etc.

2. Dispersion Strengthen products – SAP, TD-Nickel, etc.

3. Hard metals/Cemented Carbides – Cutting tools, W-filament, magnetic materials, etc.

POROUS POWDER PRODUCTS

Porous products have controlled amount of interconnected pores and extended to the external surface for specific industrial applications. The shape, size and size distribution of pores in the product are most important for its application for various purposes. These pores can be managed by properly controlling the operating parameter at the various stages of its production. The various porous products are porous bearings, porous filters and porous electrodes. These products can not be produced by any other manufacturing process, except the powder metallurgy process.
Porous bearing is a self lubricating bearing, in which, pores are impregnated with lubricating oil. The pores are interconnected and extended to the surface. These type of bearings are used in industrial application, where periodic lubrication is restricted or impractical and its low cost makes them economically viable. These bearings are used in automobile industry, agriculture machines, paper mill, textile industry, food industry, and space applications.
The essential requirement of porous bearing are as follow:

1. Good lubrication properties with minimum maintenance and long service.
2. Sufficient mechanical strength
3. High fatigue strength over a range of temperature.
4. Good wear property.
5. Good thermal conductivity.
6. Capacity to withstand static & impact loads.
7. Must not seize with the moving parts during use.
8. High coefficient of friction.
Advantages of porous bearing:

1. Economical
2. Self lubricating action – overcome the need of oil pipes, pumps etc.
3. Oil drip and possibility of spoiling the products is minimum.
4. Frequent maintenance is overcome.
5. Production rate is higher.
6. Combination of metallic & non-metallic bearing can be produced.
7. Plasticity of bearing is higher, which helps in smoothing out of the dimensional irregularities.
Disadvantages of porous bearing:
1. The presence of porosity results in decrease in mechanical strength. Hence, less useful under conditions of impact loading or fatigue loading.
2. Porosity results in resuction in thermal conductivity.
3. Load carrying capacity at high speed is low.
4. Pores may close down due to oxidation product of lubricating oil or impurities in lubricants.
5. Some oil may be lost at higher speed. Hence, periodical supply of oil on the bearing is necessary at high speed application.
6. The shape of porous bearing is limited because of axial compression during compacting stage.

Various metals and non-metals used for production of porous bearing & their functions:
1. Copper: Good strength  
   High thermal conductivity
2. Fe: Prevent seizing & increase $\mu$
3. Ni: High wear resistance & strength
4. W: High wear resistance & strength
5. Ag: Good lubricant
6. Graphite: Good lubricant
   Decrease friction coefficient
7. MoS$_2$: Good lubricant
8. Sn: Alloy with Cu and results in liquid phase sintering.
10. Silica: Dusting of friction parts.

Combination of one or more of the above metals or non-metals are used to obtain optimum level of properties of porous bearing.
Types of porous bearings:

1. Porous Bronze Bearing: Production steps
- Mixture of 6-20% Sn (electrolytic or atomizing), 0.6% Graphite & rest copper.
- Mixed in ball mill with lubricant.
- Cold compaction at 200-400 MPa.
- Pre-sintered at 400°C (Sn melts & diffusion starts.
- Finally, sintered at 800°C for 5-10 minutes in reducing atmosphere.
- Size operation to produce smooth surface of required shape & size.
- Impregnation: Bearing is put in lubricating oil at 110°C for about 10 minutes. For effective impregnation of lubricant, vacuum may be created.
2. Porous Iron Bearing: Production steps
- Mixture of 2-6% Pb powder (in form of PbO), 0.6% Graphite & rest iron.
- Mixed in ball mill with lubricant.
- Cold compaction at 750-1100 MPa.
- Sintered at 1100° C - 1500° C in fused cryolite salt bath.
- Size operation to produce smooth surface of required shape & size.
- Impregnation: Bearing is put in lubricating oil at 110° C for about 10 minutes. For effective impregnation of lubricant, vacuum may be created.
3. Porous Al-Base Bearing: Light in weight

Production steps:
- Mixture of 5-7% Fe, 3-4.5% Graphite & rest Al or 10% Cu, 3% Graphite & rest Al.
  - Mixed in ball mill with lubricant.
- Cold compaction at 200-400 MPa.
- Pre-sintering.
- Finally, sintered at 800º C for 5-10 minutes in reducing atmosphere.
- Size operation to produce smooth surface of required shape & size.
- Impregnation: Bearing is put in lubricating oil at 110º C for about 10 minutes. For effective impregnation of lubricant, vacuum may be created.
2. Bimetallic Bearing:
To overcome the limitations of strength. In this, alloy steel backing is provided. However, bond is not very good. It has mixture of 29% Pb, 1% Sn, 0.5% Graphite & 69.5% Cu.

2. Trimetallic Bearing:
To overcome the limitations of bond as in case of Bimetallic bearings. It uses Babbitt metal, mixture of 87.75% Sn, 4% Cu, 8% Sb & 0.25% Bi.
Physical characteristics of porous bearing:

1. **Porosity**: Porosity is given by,

   \[ f = 1 - \frac{\rho}{\rho_0} \]

   Where, \( f \) is fractional porosity, \( \rho \) is apparent density and \( \rho_0 \) is density of the metal in the non-porous condition. For a given alloy composition, \( \rho_0 \) is constant and the porosity is specified in terms of apparent density, \( \rho \).

   Weight of the unimpregnated part
   \[ \rho \text{ (dry)} = \frac{\text{Weight of the unimpregnated part}}{\text{Volume of the part}} \]

   Weight of impregnated part
   \[ \rho \text{ (wet)} = \frac{\text{Weight of impregnated part}}{\text{Volume of the part}} \]
2. Oil content:

\[
\text{Oil content} = \frac{\text{Volume of oil}}{\text{Volume of the part}}
\]

The degree of fullness or impregnation factor, I.F. = \frac{\text{Oil content}}{\text{Porosity}}

85 to 95% of theoretical porosity can be impregnated.

3. Degree of sintering:
The effectiveness of the sintering process determines the strength of the finished products as certain minimum strength is necessary.
4. Radial Strength:
Mostly, the porous bearings are a hollow cylinder shape so a minimum radial crushing strength is required.

\[ \text{Approx. Min. radial strength} = K L H^2 \]

Where,
K is strength factor in Psi and vary with composition of bearing.
L is length of the cylinder in inch
H is wall thickness in inch
M is mean diameter in inch \((D + 2H)\)
D is bore diameter
5. Tensile strength:
With porosity between 20 and 35%, the tensile strength of the porous metal is roughly $\frac{1}{2}$ or $\frac{1}{4}$ of that of solid metal. The loss of tensile strength is due to reduced quantity of metal i.e. due to presence of porosity.

6. Permeability:
The size of the pores and the quantity of porosity determines the permeability. Permeability governs the flow of viscous fluid through typical porous bearing materials. The permeability ranges from $100 \times 10^{-12}$ cm$^2$ to $2000 \times 10^{-12}$ cm$^2$. 
7. Stress-Strain characteristics:
When non-porous metal is deform plastically, the volume (density) remains constant. However, with porous metal, the volume decreases with plastic deformation due to decrease in porosity. The density increases with deformation and reaches the value of non-porous metal.

8. Other physical properties:
Thermal and Electrical conductivity of porous metal is less than that of non-porous metal due to presence of pores and limited contact between particles.
Magnetic permeability of iron is also reduced.
The coefficient of thermal expansion is not affected.
Porous bearing performance:

1. Basic Mechanism:
The oil contained in the pores of porous metal bearing last for finite time, even for the life of the machine, to which, it is fitted. Some time, after a specified period, re-impregnation is done.

2. Temperature:
The life of porous bearing is dictated by the life of the oil at the operating temperature. Therefore, design of porous bearing is directed towards a low running temperature. The high temperature has adverse effect on oxidation resistance of the oil and the rate at which it may be lost from the pores.
3. Clearance:
There must be sufficient running clearance at the actual operating temperature. Generally, running clearance is determined at room temperature. Therefore, necessary correction to the room clearance has to be done. The housing material should have low thermal expansion coefficient than porous bearing, otherwise bearing become loose in housing.

4. Quality of oil:
The oil should have high oxidation stability at running temperature. High oxidation stability is achieved by refining & anti-oxidant addition.
5. Life:
The life of a porous bearing is determined principally by the life of the oil in terms of quantity or chemical stability or both. The failure of bearing can also occur due to closure of pores at the entire surface of the bearing.

6. Supplementary Lubrication:
The total volume of oil available for lubrication at the bearing assembly can be increased by the use of some absorbent material in contact with the outside of the porous metal. Wool felt is mostly used for this purpose.
POROUS POWDER FILTERS:

Porous powder filters are used for filtration, flow control, distribution and porosity. These filters are used in automotive, aerospace, biotechnology, chemical, food, and petrochemical industries.

Porous Metallic Filters:

This type of filters remove small hard solid particles from streams of liquid such as oil, gasoline, refrigerants, polymer melts, aqueous suspensions, and from air or other gases better than cloth filters due to multilayer arrangements of pores. It has adequate mechanical strength, and adequate resistance to environment attack.
It can withstand at high temperature. It can be used at low temperature application (below room temperature) for filtering liquefied gases. Various complex filters with long life can also be produced. The materials used for making porous metallic porous filter are; Copper-Tin bronze, Brass, Cu-Ni alloy and stainless steel. For filtering highly corrosive fluids, filters made form monel, inconel, Ti can be used. The various shapes of filters can be produced are discs, cones, cylinders, cups, bushings, sheets, and tubes.

The processes involve in production of porous filter are; loose powder compaction / powder
rolling / die compaction, sintering and finishing operations. In loose powder compaction, hand filling is done in the heat resisting mould, which is vibrated to ensure even packing of powders then it is sintered in a batch or continuous type of furnace. Powders of uniform size is necessary to ensure uniform pores in the filter products. Spherical powder particles are most suitable as it gives high efficiency, good and uniform pores size. However, porous filters made from irregular powder particles are cheaper and used for ordinary purposes. Porous filters of various microns pores sizes and thickness can be produced by controlling the operating parameter.
DISPERSION STRENGTHEN PRODUCTS

This is one of the strengthening techniques to improve the high temperature strength of materials and known as Composite materials. In dispersion strengthen products, oxide phase is finely dispersed in the matrix of metal phase. The volume fraction of such oxide phase vary between 1-15%. These oxide phase prevents the movement of dislocations. The size of oxide phase is 0.01 to 0.1 micron and the interparticle spacing is 0.01 to 0.3 micron. If these criteria are not fulfilled, oxide dispersion strengthening will not take place. Matrix i.e. metal phase acts as a load bearing component. e.g. SAP, TD-Nickel.
Sintered Alumina Product (SAP):

In this product, alumina ($\text{Al}_2\text{O}_3$) is dispersed in Aluminium matrix. For Al-powder production, ball mill is used for comminution (reduction in size) without using any additives. In this process, a large number of small balls are used in ball mill. During the process, comminution and welding of aluminium powders takes place simultaneously. Continuous fracture of aluminium, exposes fresh surface of aluminium for oxidation. This results in the formation of oxide layer (alumina) over the aluminium powders. Continuous breaking and welding for long times, results in alumina embedded in the aluminium or dispersion of
alumina in aluminium. The size of Al-powder particles formed will be 70-140 microns with 6-15% alumina content. The micro-hardness is approximately 140 VPN. These powders are cold compacted at 180-450 MPa and sintered at 500-600°C giving the apparent density of 2.0 gm/cc. After this, sintered mass is hot pressed at 500-600°C by extrusion or rolling or forging resulting high density of 2.7 gm/cc.
Thoria (ThO$_2$) Dispersed Nickel (TD-Nickel):

In this product, 2-10 volume % Thoria (0.02 to 0.03 micron) is finely dispersed in Nickel matrix. For production of TD-Nickel, nickel salt solution [Ni(NO$_3$)$_2$.6H$_2$O], colloidal solution of Thoria particles stabilized with nitric acid and Ammonia hydroxide are mixed maintaining PH value of 0.75. Under this alkaline conditions, a complex Nickel-hydroxide precipitate is formed. Thoria particles acts as a nuclei. Precipitate is filtered, washed & dried at 300°C and decomposed to produced nickel oxide. Then nickel oxide particles are pulverized to 325 mesh size by grinding. These nickel oxide powder particles
are reduced in hydrogen atmosphere at 500°C - 700°C, ensuring that no agglomeration takes place. This will produced with individual thoria particles surrounded by Nickel. Then, it is cold compacted at 300 MPa. Then, sintered in hydrogen atmosphere at 1200°C. To homogenized the product (grain refinement and dense product), it extruded at 930°C. Then, it cold swaged at room temperature. After this. It is annealed at 1100°C for 1-3 hours for rearranging the dislocations in to small sub-grains. The process of cold swaging (10% reduction) and annealing at 1200°C for 30 seconds is repeated to increase the strength of TD-Nickel.
HARD METALS/CEMENTED CARBIDES

These types of product are used as a tool for high speed machining. Such tools have very high hardness at elevated temperature, superior wear resistance, high modulus of elasticity, high compressive strength, high shock resistance, and high corrosion resistance. The metal carbides (tungsten, titanium and tantalum) provide very high hardness and superior wear resistance. Cobalt or Nickel (3 to 30%) is used as binder, present in liquid form during sintering process and dissolves more carbides. On cooling, these liquid phases precipitate out as finely dispersed fine carbides in cobalt.
Tungsten Carbide tools:
Pure tungsten powder is produced by various processes. If tungsten is in compound form (WO$_3$), then it is reduced by hydrogen at a temperature of 800 to 1100ºC. Tungsten powder is mixed with carbon (6.5-7.5 %) in the form of lump and grinded in a ball mill. Grinding results in optimum dispersion of carbon in tungsten. Then, the mixture is heated at a temperature between 900 to 2200ºC, which forms fine tungsten carbide powders. These carbide particles are mixed with 7% Cobalt (0.5 to 10 microns) and ball milling is done for many days
in presence of acetone, which helps in grinding. This operation produces very fine size of 1 to 3 microns. TiC or TaC can also be added during ball milling to improve the mechanical properties of tools. After milling, acetone is removed by filtration and powders are dried. Since WC powder has very poor compressibility, hence, coating of powders with lubricant (2 to 4% paraffin wax or camphor) is done. Then, these powders are cold compacted at 70-100 MPa. Hot pressing or hot isostatic pressing can also be done to improve density of the products. In case of cold compaction, pre-sintering is done at
800 to 1100ºC for about 30 minutes. Then, the product is shaped and sintered in the temperature range of 1350 to 1500ºC for 1 to 2 hours in hydrogen atmosphere or in vacuum. Cooling is done slowly to avoid cracking. Then, the sintered product is shaped in desired dimension.
CERMETS

Cermets are composite materials composed of ceramic and metallic materials (Cermets = Ceramic plus metal). It has been developed to obtain optimal properties of both a ceramic, such as high temperature resistance and hardness, and those of a metal, such as the ability to undergo plastic deformation, toughness and impact strength. It is most suitable tool material for high cutting speed, high temperature materials for airplane jet engines or space rockets, nuclear submarines, and electrical resistors, etc.
Following are properties of cermets:

1. High temperature resistance
2. High hardness
3. Ability to undergo plastic deformation
4. Superior wear property
5. Superior corrosion property
6. More resistance to high velocity impacts
7. Better thermal shock resistance
8. High strength
9. Moderate thermal conductivity
10. Light weight
11. Lower friction
Cermets composition:

(Ti, Ta, Nb, W, Mo, Al) (C, N, O) - (Co, Ni)

The metal (Nickel, Cobalt and Chromium) acts as binder for carbides, borides, nitrides, carbonitrides and oxides, being matrix. Cermets have less than 20% metal by volume. The size of ceramic particles are 1-3 micron. Blending leads to coating of the ceramic particles with metal. Liquid phase sintering takes place due to low melting point of the coated metals, resulting bonding between solidified metal phase and ceramics phase. Carbides, borides, nitrides, carbonitrides and oxides contribute to various properties to cermets.
MICROSTRUCTURE OF CERMETS
For production of cermets, ceramic powders and binders are ball milled. This process results in formation of uniform coating of binders over the fine ceramics powders. These coated powders are screened to obtain desired size ranges. After screening, these coated powders are compacted to get desired shape and dimensions either by slip casting, die compaction, hot compaction, isostatic pressing, and hot extrusion. Presintering is done at a temperature of 450°C in hydrogen atmosphere. Depending upon the composition of green compacts, sintering is done up to a temperature of 2000°C. Finally, finishing operation is done as required.