Powder Metallurgy

Powder Metallurgy is the process of making parts from metal powder that is packed together in a mold to the desired shape, then heated in a furnace under pressure. We use this process for making gears, connecting rods for gasoline engines, brake parts, thrust washers, bearing components, tool materials (all WC tooling is made by PM processes), and many other machine parts.

Why Use PM?

Why do we go to all this trouble? There are several reasons. If you look at this graph of Melting Point from Zn to W, you’ll notice that Al₂O₃ is in the middle of the graph. Aluminum oxide, a.k.a. alumina, is used as a refractory lining for melting metals. If you’re going to melt something, you have to have a pot to put it in. Some metals melt at a higher temperature than alumina, so you have to find a different material for the melting pot...and the different material may be really expensive. We use powder metallurgy if the melting point of the metal is too high to cast the part.

A second reason for using powder metallurgy is if the molten metal is explosive. For example, molten titanium explodes if there’s any oxygen or nitrogen around. The dental casting machine shown on the slide in class has seals on the doors; the titanium alloy is cast under a protective blanket of argon gas.

Foundries that cast titanium alloys often do it in a remote outbuilding with thick walls and a thin roof. The operator sits behind a blast wall. If you use powder metallurgy to make titanium parts, you don’t have to invest in blast walls and an argon supply.

A third reason for using PM is if you want to produce a porous structure, for making filters, or for self-lubricating bushings/bearings for solid or liquid lubricant (an example of solid lubricant is lead). Filter materials can have a differing pore size from outside to inside...they capture the big stuff first, then capture the little stuff, so the filter lasts longer. PM filters can be backflushed to clean them...not always possible with paper or polymer filter materials.

The micrograph shown in class is a bearing. Cu and Cu-Sn alloy powders were mixed and spread onto a steel base (white stripe at bottom). The powders were sintered at high temperature (white globs), then a lead-based bearing alloy was poured on top (dark), which infiltrated the pores.

A fourth reason for using PM is to make cemented carbides. PM is the only way to manufacture this structure. The micrograph shown in class has tungsten carbide (WC) in a Co matrix. When you use “carbide” tooling at work, this is what you’re using. The gray stuff is the WC, and the white material in between is cobalt metal that binds the carbide particles together. WC is very hard and brittle, so you can’t make tooling out of solid WC, or it would shatter under impact loading. The Cobalt is ductile enough to absorb some of the impact.

Look how small these particles are! The marker bar is half a thousandth of an inch. Some of the particles are a tenth of a mil across...these are REALLY SMALL carbide particles.

Another reason for using PM is to eliminate or reduce machining. Many PM parts are produced in their final shape, straight out of the press.

Some metals will not mix in their molten state. For example: copper + graphite brushes in electric motors (sometimes Sn, Pb too). Graphite would burn up in a casting operation.

You might want to mix ceramic fibers with metal to make a metal matrix composite. For example, if you mix 10% Al₂O₃ fibers in an aluminum alloy, you can improve strength by 50-100 ksi, and improve Young’s Modulus by 50%. The micrograph shown in class is a Ni matrix with thorium oxide (thoria), an oxide dispersion strengthened material. Thoria particles are 3µm and less in diameter.
Powder Manufacturing Methods

In 1807, Thomas Jackson opened a shot tower on the New River, in western Virginia. You can see this tower from I-77. Lead, poured through a sieve, falls 150 feet. It forms molten spheres, which solidify during the drop. The kettle of water cushions the fall so the shot doesn’t deform when it reaches the bottom of the shaft.

The lead was mined in nearby Austinville, VA, named after Moses Austin, who operated the mines. His son was Steven Austin, who helped found Texas.

Today, we can make powder metal by:

1. Spraying liquid metal, letting it solidify in an atmosphere.
2. Vaporizing the metal…then it condenses.
3. Mechanically breaking it up.

The textbook lists 9 methods of making PM…all of these fall in one of the 3 categories.

You select the method depending on cost and desired purity. For example, reduction costs 15% per lb. of iron powder vs. electrolytic deposition, which has the highest purity.

Blend & Press

Once you’ve made some powder, you have to blend the powders together. The slide from class shows an industrial V-blender, but there are other shapes available too. The goal is to produce a uniform distribution of powders (therefore uniform in the final product).

Next, you PRESS the powders together in a mold to make a green compact. The circles in this cartoon represent powder particles that have been pressed together.

Density

How dense can we make the powder? It depends in part on the pressure that is applied. The more pressure you apply, the tighter the powder particles are pushed together, and the denser the green compact. You will never get to 100% density, but you can get into the high 90s.

Density also depends on particle size distribution. If all the particles are roughly the same size, they won’t pack as tightly as if you have a range of particle sizes. The particles at the left look like washed gravel. The particles at the right look like large particles of gravel mixed with smaller particles of sand. The density of the material at the right is greater because there is not as much empty space between the larger particles.
Density also depends on how porous the particles are. If they have holes in them, the density will be lower.

Density depends on particle shape. If the particles are perfect spheres, you’ll have more space between them than if they’re a shape that can nest and pack more tightly.

Density depends on the location within the mold. This is a thrust washer with a hole in the center. The thin portion of the washer is denser than the thick part. The thrust washer is used in the differential case of a small SUV.

When I worked at Dana, this part was failing on the assembly line of our customer…vehicles broke down on the way to the parking lot. The supplier claimed that the washer met specification for density, but when my lab measured the density of broken pieces, we found that some portions of the washer did not meet specification for density. The supplier had been measuring the average density based on the whole part, but we found that if the thickest part of the washer fell below a given density, the washer was more likely to fail.

How Do We Press?

Once we’ve stuck the powder in a mold, we have to pick a method for pressing it. The textbook explains the first three of these methods pretty well.

- **Punch & Die:** Apply pressure in *one direction only*. The picture shown in class displays punches and a die for making timing gears for gasoline engines.

- **Cold Isostatic Press (CIP) / Hot Isostatic Press (HIP):** Apply pressure on *all sides at once* (isostatic), using a fluid. Separate the PM part from the fluid with a rubber sheet (CIP) or metal foil / sheet metal (HIP). HIP is pressurized as high as 50 ksi for some applications. The photograph from class is a furnace bell for HIP. Electric heating elements line the inside (the white knobs are alumina insulators). You can see the wall is pretty thick, to withstand high pressure. This particular furnace goes up to 1250˚C.

- **Metal Injection Molding (MIM):** Mix metal & polymer powders, and use injection molding to produce the part shape. The polymer burns off later, during sintering.

- **Explosives:** Not in the textbook…can reach nearly 100% density. Very expensive and dangerous.

Sintering

After you press the compact, you have to *sinter* the powder together. It’s like ice cubes in water…they stick together after a while. With metals, it happens at higher temperatures. Surfaces with small radii of curvature tend to grow rapidly. Particles join together due to diffusion, the movement of atoms along the surface and through the material. Sintering occurs below the melting point of the metal.
In Fe-base PM alloys, sintering is done at 60-80% of the absolute melting point, therefore we can use lower temperature mold materials, saving money. Another way to sinter is above the melting point of one of the metals…this is the method used with Co in tungsten carbide / cobalt tooling. Melt the cobalt…it infuses between WC particles.

**PM Processes**

See the handout for PM processes used for different materials.

- **Tungsten light bulb filaments**: Sintering is done by electrically heating the material.
- **Cemented carbides**: Sintering is done in a hydrogen atmosphere to prevent oxidation.
- **Cu–Sn–graphite**: Need a nonoxidizing atmosphere, so the graphite doesn't burn up. Add oil to make self-lubricating bearings.
- **Porous metal filters**: No pressure is applied, to produce good porosity.
- **Ferrous parts**: Graphite is added as a lubricant which helps with pressing. Graphite burns off later.

There’s a list of *finishing operations* in the textbook. Why do we need to do anything more to a PM part?

1. Improve strength
2. Improve dimensional tolerances
3. Machine features into the part, like side holes
4. Add lubricant for bearings

PM is a good choice for volumes greater than 10,000 parts, and for complex shapes that can be pressed, to avoid machining. PM *is not* so good in fatigue and impact because pores act as stress concentrations. However, with care, it can be used in high fatigue, high impact applications such as connecting rods in gasoline engines.

*Dr. Barry Dupen, Indiana University-Purdue University Fort Wayne. Revised April 2015. This document was created with Apache Software Foundation's OpenOffice software v.4.1.0.*

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