Powder Metallurgy

Training Objective

After watching the program and reviewing this printed material, the viewer will gain a knowledge and understanding of the basics of powder metallurgy.

- Types of particles are explained.
- Mechanical pressing is detailed.
- Injection molding processes are discussed.
- Both C.I.P. and H.I.P. processing are explained.

This technology uses metal powder to produce a wide variety of metal parts found in an equally wide variety of manufactured products, ranging from automobiles and aircraft to electronic and consumer items. Powder metallurgy is also used to produce ingot and billet that are made into plate, sheet, and other shapes. The technology provides an alternative to the use of cast and wrought materials.

The primary advantage of powder metallurgy is in design flexibility, producing parts of high structural density as well as of controlled porosity for use as filters and self-lubricating bearings. Parts produced are also of net or near net shape reducing material waste and post forming operations.

The metal powders used include iron and steel, which are the most common, along with copper, aluminum, nickel, cobalt, molybdenum, tungsten, tungsten carbide, titanium, tantalum, and magnesium. These powders may be produced by either physical or mechanical means.

The primary physical method is atomization. A stream of molten metal is subjected to a jet of high-pressure water or inert gas, usually nitrogen or argon. The resulting droplets settle as a powder in the bottom of a holding tank. Water atomized particles are irregular in shape, while gas atomization produces more spherical particles. Another similar process uses helium as an inert gas and is called the Rotating Electrode Process. There is also Soluble Gas atomizing.

Mechanical methods include milling in hammer, rod, ball, grinding, or attrition mills. Such methods are used to produce hard and brittle powders that would be used in alloying, blending, and work hardening, or as oxide powders.

Parts produced may be of various elemental powders or pre-alloyed powders to which binders and lubricants may be added. After being consolidated or formed in molds or dies, the part is called a “compact” and is said to be in a “green state.” This means that the particles of the part are lightly joined allowing handling but having no real service strength. To achieve final strength and density, the parts are “sintered” in ovens that heat the parts below melting temperatures but high enough to metallurgically bond the individual particles.

Part shaping or consolidation can be accomplished by mechanical pressing, injection molding, or isostatic pressing. Most parts are produced by mechanical pressing and oven sintering. Particles are gravity fed into a die of a mechanical press and formed by the action of punches, either downward, upward, or action in both directions. Pressing is usually done at room temperatures and with pressures of 10 to 60 tons psi.

Depending on the part's metallurgy, the atmosphere of the sintering oven may be "endothermic" consisting of hydrogen, nitrogen, and carbon monoxide. Other atmospheres include the "exothermic" being composed of mainly hydrogen and dissociated ammonia, or entirely of hydrogen. Still other options include an inert gas atmosphere or a vacuum. In the oven, time, temperature and cooling rates must be closely controlled.

Final net shape is achieved after sintering and by a variety of secondary operations that can include:

- Repressing - to achieve higher densities
- Forging - hot forming partial shapes
- Machining - for details such as holes, slots, etc.
- Heat treating - for additional hardening
- Steam treating - to obtain an oxide surface coating
- Plating - to obtain specific surface finish and color
- Joining - to assemble related parts with typical joining methods, welding, brazing, etc.

Any coolant used in machining porous parts must be carefully selected to avoid base metal reactions. Also porous parts must be adequately sealed before plating.

Injection molding is used to produce very complex and intricate parts. The injection molding process can create many of the parts details that would otherwise require secondary operations. The parts produced are typically small with very high density, usually in the 95 percent range and higher.

Steps in the injection process include:

- powder mixing with a thermoplastic binder added
- injection - at predetermined temperatures
- debinding - binders removed by either solvents and heat or by evaporation
- sintering - the heat treating phase

The molded part is actually an oversize replica of the desired part. Thus, shrinkage during subsequent processing must be accurately calculated. Total debinding and sintering time can range from 8 to 24 hours. Identical parts can be batched in the ovens to increase production.

Isostatic pressing can apply very high pressures uniformly in all directions producing parts which are consistent in density throughout their cross sections. When the process operates at room temperatures it is called cold isostatic pressing or "C.I.P." At elevated temperatures the process is termed "H.I.P." or hot isostatic pressing. HIP will produce parts that will exhibit higher densities without subsequent processing.

Presses for cold isostatic pressing include:

- a pressure chamber
- a pressure generator
- depressurizing equipment
- machine controls

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Powder is placed in flexible and pre-shaped molds, also called a “bag” in
which the particles are consolidated by high pressure water or oil, typically from 10,000 to 70,000 psi. Dwell time at full pressure is a few minutes. The molds may be removable or fixed in the press. The removable molds are filled and sealed outside the press and then immersed in the consolidating fluid. This is called the “wet-bag” process. Fixed molds are filled and sealed within the press. Pressure is then applied behind a membrane built into the mold. As fluid never touches the mold, this is referred to as the “dry-bag” process.

A press for hot isostatic pressing consists of:

- a pressure vessel
- a gas storage and pumping system
- a resistance heated furnace
- required machine controls

Powder is placed in pre-shaped sheet metal molds, usually of mild steel. Molds for complex shapes are usually welded assemblies. The filled molds are lowered into the pressure vessel and the furnace is placed over the entire vessel and sealed. Heat and gaseous pressure are applied, consolidating and sintering the powder in a controlled atmosphere. Depending on the metal being processed, temperatures can range up to 2500 degrees Fahrenheit with pressures of 45,000 psi and higher. The gas is usually argon. Processing cycles can range from several hours to more than a day. After processing the molds are removed by machining or chemical leaching. The HIP process can produce dual-metal parts through diffusion bonding or by cladding.

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Review Questions

1. Parts produced by powder metallurgy:
a. require final machining
b. cannot be heat treated
c. require subsequent forging
d. are of net or near net shape

2. The most common powders used are:
a. aluminum and magnesium
b. copper and copper alloys
c. titanium and cobalt
d. iron and steel

3. Water atomized particles are:
a. symmetrical
b. irregular
c. very coarse
d. very fine

4. Powders produced by mechanical method means are:
a. hard and brittle
b. soft and malleable
c. used only for work handing
d. cannot be heat treated

5. Parts in a “green state” are:
a. anti-magnetic
b. at maximum strength
c. at minimum strength
d. ready for plating or finishing

6. An endothermic atmosphere includes:
a. oxygen
b. argon
c. hydrogen
d. CO2

7. Parts produced by injection molding have densities in the range of:
a. 50% or more
b. 50% or less
c. 75% or less
d. 95% or more

8. Total debinding and sintering time can range:
a. 5 to 10 minutes
b. 5 to 10 hours
c. 8 to 24 hours
d. 15 to 30 hours

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Answer Key

1. d
2. d
3. b
4. a
5. c
6. c
7. d
8. c