Powder Metallurgy:

fine powdered materials are blended, pressed into a desired shape, & heated to bond surfaces

- small intricate parts w/ high precision
- greater flexibility & control
- near net shape
- tailored porosity

properties of interest: flow rate, apparent density, compressibility, green strength

Mechanical properties: high strength/wear & fatigue resistance
Physical properties: enables heat transfer/fluid flow
Corrosion resistance: some PM materials vs alloys.
Biocompatibility: some PM materials: medical implants
Sustainability: ↓ material wastes due to near-net shape

Advantages:

Complex shapes, wide material selection (metal/metal-ceramic), tailored porosity (filtration devices), mass production, cost effective

Disadvantages

Higher initial tooling costs (complex dies/molds), limited part sizes (smaller), anisotropy (props. depend on pressing directions), process complexity, sintering limitations

Process / Stages:

1. Powder mfg: fine metal particles via atomization, milling, or chemical reduction
2. Mixing / Blending: homogenizing diff powder for desired properties.
3. Compacting: pressing powder mixture into a shape mold under high P.
4. Sintering: heating (NOT melting) the powder to bond particles (↑ strength/density).

Starting Powders:

→ direct impact on final product, tailoring mat. prop.s, optimizing process efficiency

Properties:

- Particle size (packing density, flowability, sintering behav)
- Particle shape (compaction efficiency, final microstructure).
- Surface area (faster sintering / but also oxidization)
- Chemical composition (mat. props/potential impurities).
- Flowability (dimensional accuracy)
- Compressibility (final part dimensional accuracy)

Melt Atomization:

disintegrates molten metal into fine droplets, & rapidly solidifying them into individual powder particles

1. Molten metal in a furnace/crucible
2. High-velocity gas jets (argon) impact molten stream, breaking down into particles
3. Droplets rapidly solidifies in flight due to large surface area exposed to cooling gas
4. Collected powder is sieved to achieve desired size dist.

Advantages over other powder-mfg methods:

Uniform & spherical shape (efficient packing & compaction), wide material range, fine particle size, purity & cleanliness (minimizes oxidization/contamination).

Rapidly Solidified Powders:

$> 10^5$ K/s, significantly faster than conventional methods, resulting:

Microcrystalline: extremely fine grains (nanometer scale)

Amorphous: lacking any long-range crystalline order (glassy).

Advantages:

novel mat. props (enhanced strength, hardness, wear/corrosion resistance, magnetic props), processing benefits (lower sintering temp & shorter time)

Applications:

high-performance components, magnetic materials, biocompatible materials.

Techniques:

Gas atomization w/ high cooling rates, Melt-spinning, Plasma spraying, Sputter deposition

Wet Mixing:

- improved mixing efficiency, reduced dust generation, tailored functionalities (enhancement solvents).
- more complex process, potential compatibility issues btwn. liquids & powders, costs w/ emissions & drying processes

Mechanical Method:

Milling: grinds bulk materials into powder using various mills; precise control over particle size/shape; suitable for brittle metals

Chemical Methods:

Chemical Reduction: metal oxides/salts converted into powder through chemical reaction; wide mat. range, but could be complex.

Electrolytic Methods:

Electrodeposition: deposits metal ions onto a cathode, forming powder particles; high purity/quality but limited production rate & potential shapes.

Factors of Selecting Powder Production Methods

Desired material, required powder characteristics, production vol. & cost, environmental considerations.

Powder Mixing & Blending:

homogeneous dist. of various comp., impacting final product's performance

sufficient diffusion during sintering ⇨ uniform chemistry
wet/dry mixing

Mixing Methods:

Tumbling: rotating drums or tumblers mix powders through gravity & friction; simple or large batch blends

Shear Mixing: utilize impellers/paddles to create turbulence to promote mixing; quick homogeneous blends

Fluidized Bed Mixing: suspends powder in a stream of air → uniform, degradation-less mixing.

Ribbon Blenders: rotating helical ribbons gently fold & blend powders; for fragile powders

Cone Blenders: V-shaped cones w/ counter-rotating arms promote gentle tumbling & blending; large batches/varying densities

Dry Mixing:

- Simpler & potentially cheaper (no liquids), wider mat. compatibility (no reactivity concerns), minimal environmental impact (no waste-water/solvent emissions).
- Risk of electrostatic charge build-ups (uniformity ↓), dust generation.

Powder Compacting:

loose powder is transformed into a shaped object under high pressure; this determines the final shape / density / green strength of PM product.

Common Compacting Techniques:

Die Pressing: powder is compressed within a rigid die cavity using punches; precise control over shape / dimensional accuracy; various shapes & volume 

Cold Isostatic Pressing (CIP): applies uniform hydrostatic pressure from all directions in a flexible mold; achieves high density & minimizes internal stresses: complex / near-net shape 

Hot Isostatic Pressing (HIP): combines CIP w/ elevated temps., enhancing densification & microstructure; high-perf. comp. - superior properties 

Sequence:

Factors: compacting P., filling method, lubricants, powder props., die design.

1. Cycle Start:
   equip. initialized, sensors calibrated, safety checks.

2. Die Positioning:
   lower punch moves into initial position, ready for power filling; preheat possibly.

3. Powder Charging:
   a metered amount of powder dispensed into die cavity; filling method ensures uniform dist. & density control.

4. Lower Punch Movement:
   applies initial, controlled pressure to compact the powder loosely.

5. Main Compaction:
   upper punch applies high P. to achieve desired density

6. Dwell Time:
   optional; maintaining P. for set time can enhance bonding

7. Pressure Release:
   gradual decompression avoids residual stress & part dmg.

8. Upper Punch Withdrawal
   moves up for part ejection

+

9. Part Ejection
   lower punch pushes ↑

10. Die Cleaning & Preparation: clean & lubricated

Green Strength:

Strength in shaped powder before sintering; crucial for handling / moving delicate shapes & performing secondary processes (e.g. machining).

Factors influencing G.S.

- Compacting Pressure (high P → high GS)
- Particle Interlocking: shape & size of parts
- Lubricants: can reduce G.S., weakens bonds.

Effects on powder shape:

- Strength & Hardness: denser part, stronger
- Dimensional accuracy: min. shrinkage
- Porosity: improves corrosion resistance.