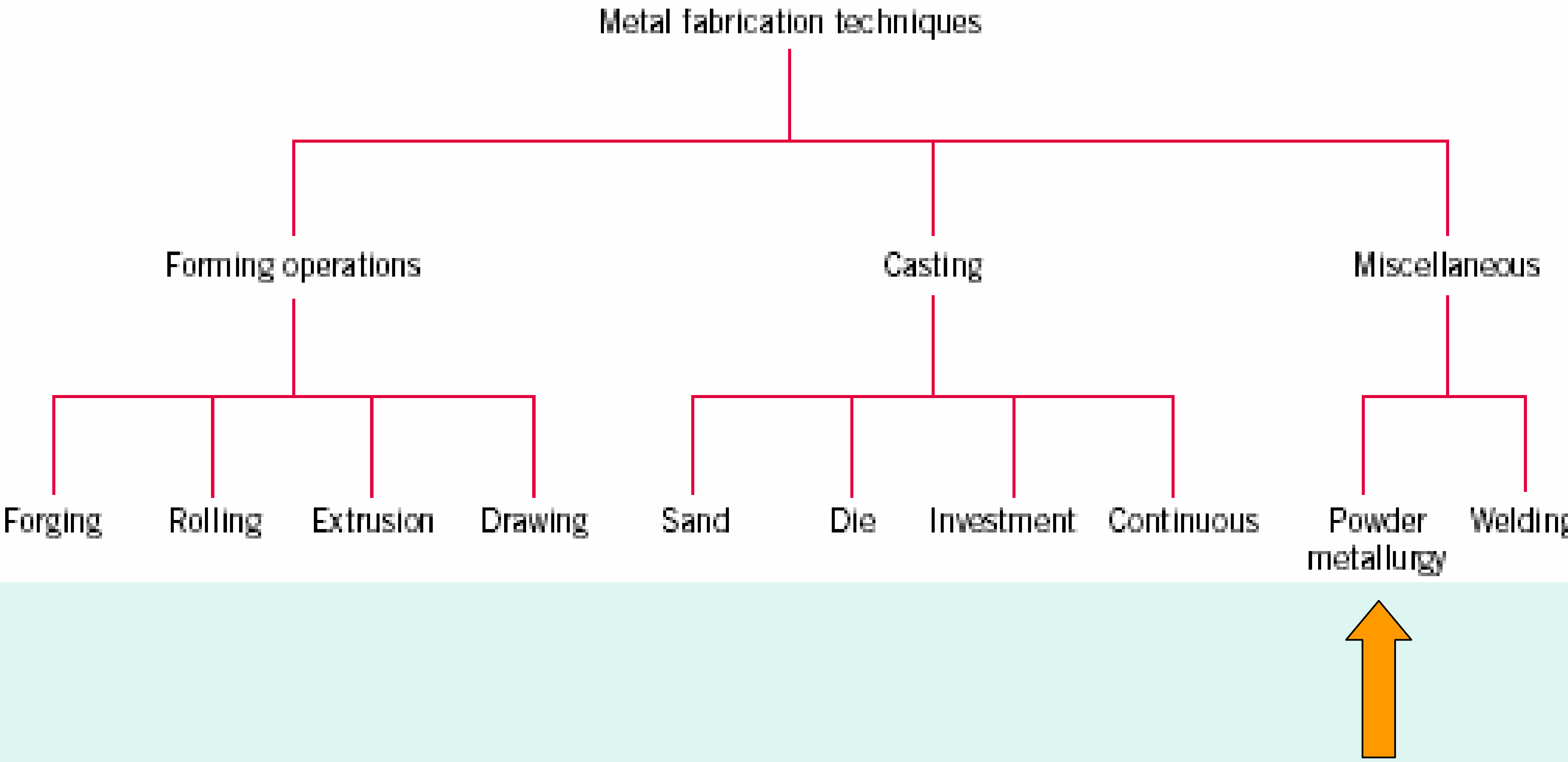
Processing of Powder Metals

Classification of Metal Fabrication Techniques

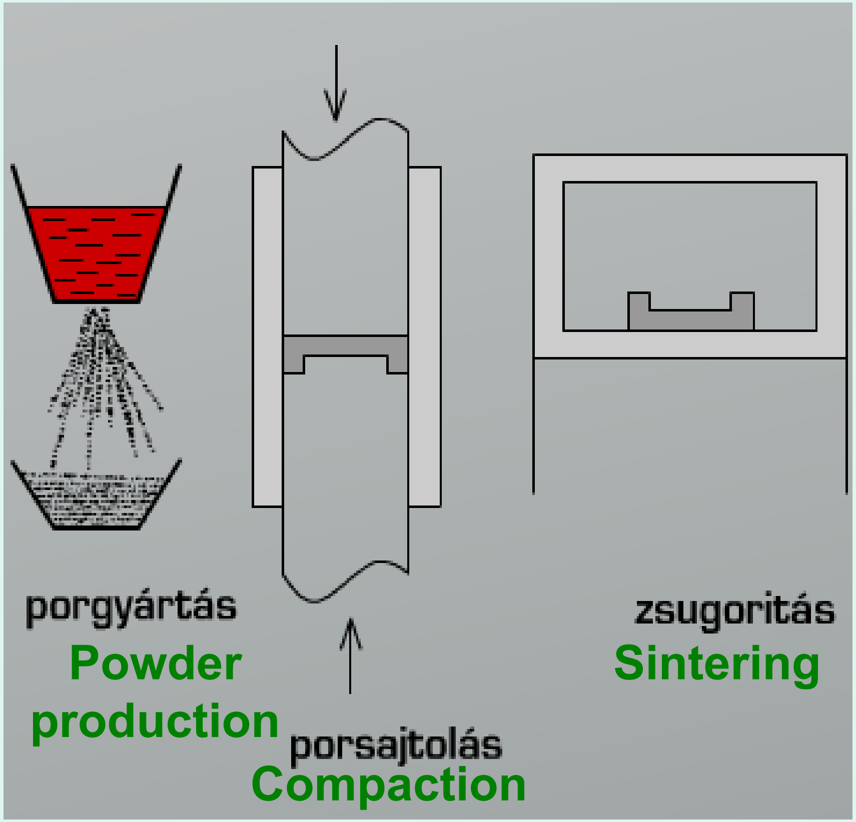


Powder Metallurgy (P/M)

- A fabrication technique involves the compaction of powdered metal, followed by a heat treatment to produce a more dense piece.
- Powder metallurgy is especially suitable for metals
  - having low ductilities
  - having high melting temperatures

Operations of PP

1. Powder production (metals, alloys, metalloids)
2. Blending and mixing of powders
3. Compaction
4. Sintering
5. Finishing operations



Process Steps

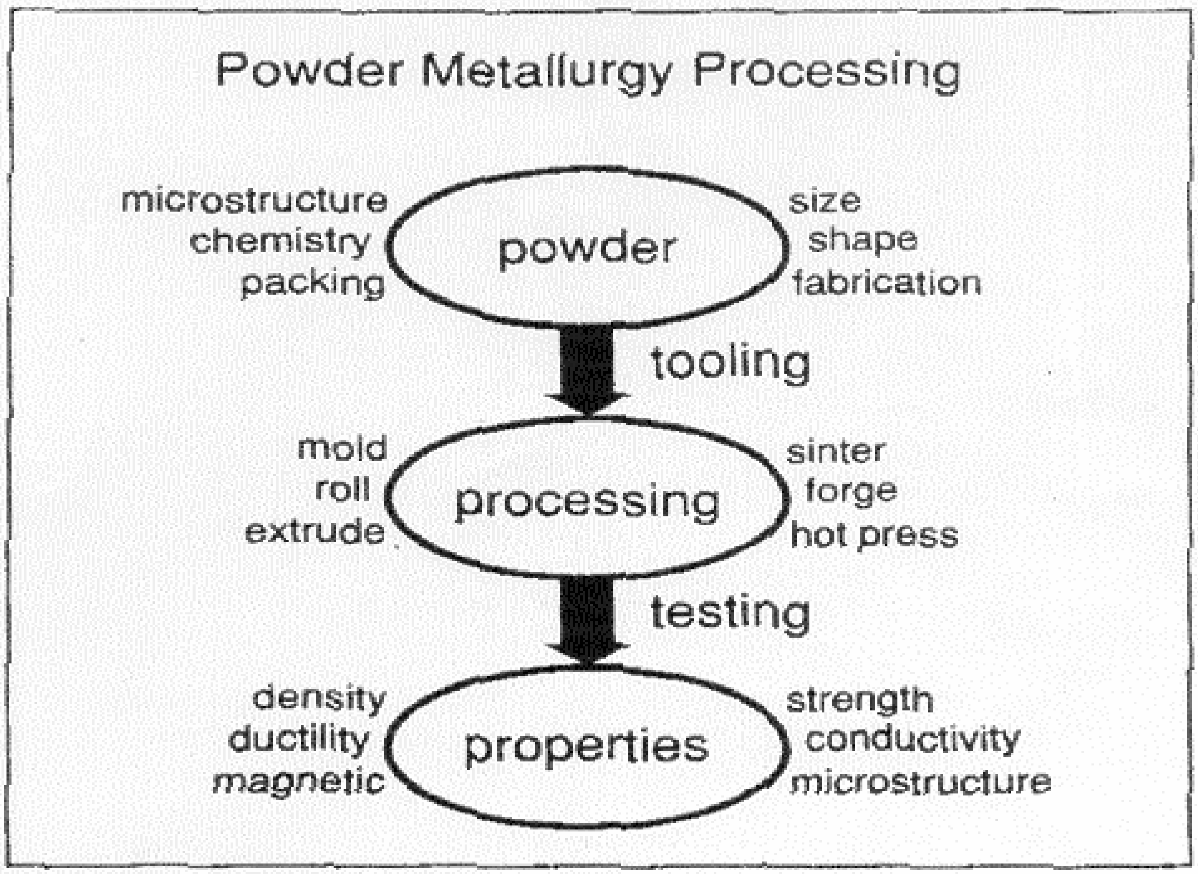


Figure 1.1. The conceptual flow for powder metallurgy from the powder through the processing to the final product. Example concerns are given for each of the three main steps.

Why PP?

- The capability to produce parts to near net shapes
- Properties of components can vary in a wide range (eg. porosity, electric conductivity, strength, …etc.)
- The economics of the overall operation
- Alloys with special properties

Advantages of powder metallurgy

PRECISE CONTROL : properties of end products can be suited to the demands of applications

CUSTOM-MADE COMPOSITION : widely different characteristics can be compacted

PHYSICAL PROPERTIES : properties can be altered easily by this method(e.g. density,porosity)

NEAR NETT SHAPING BECOMES NETT SHAPING : eliminating the further processes (e.g. machining)

REPRODUCIBILITY : the dies are the most repetitively accurate

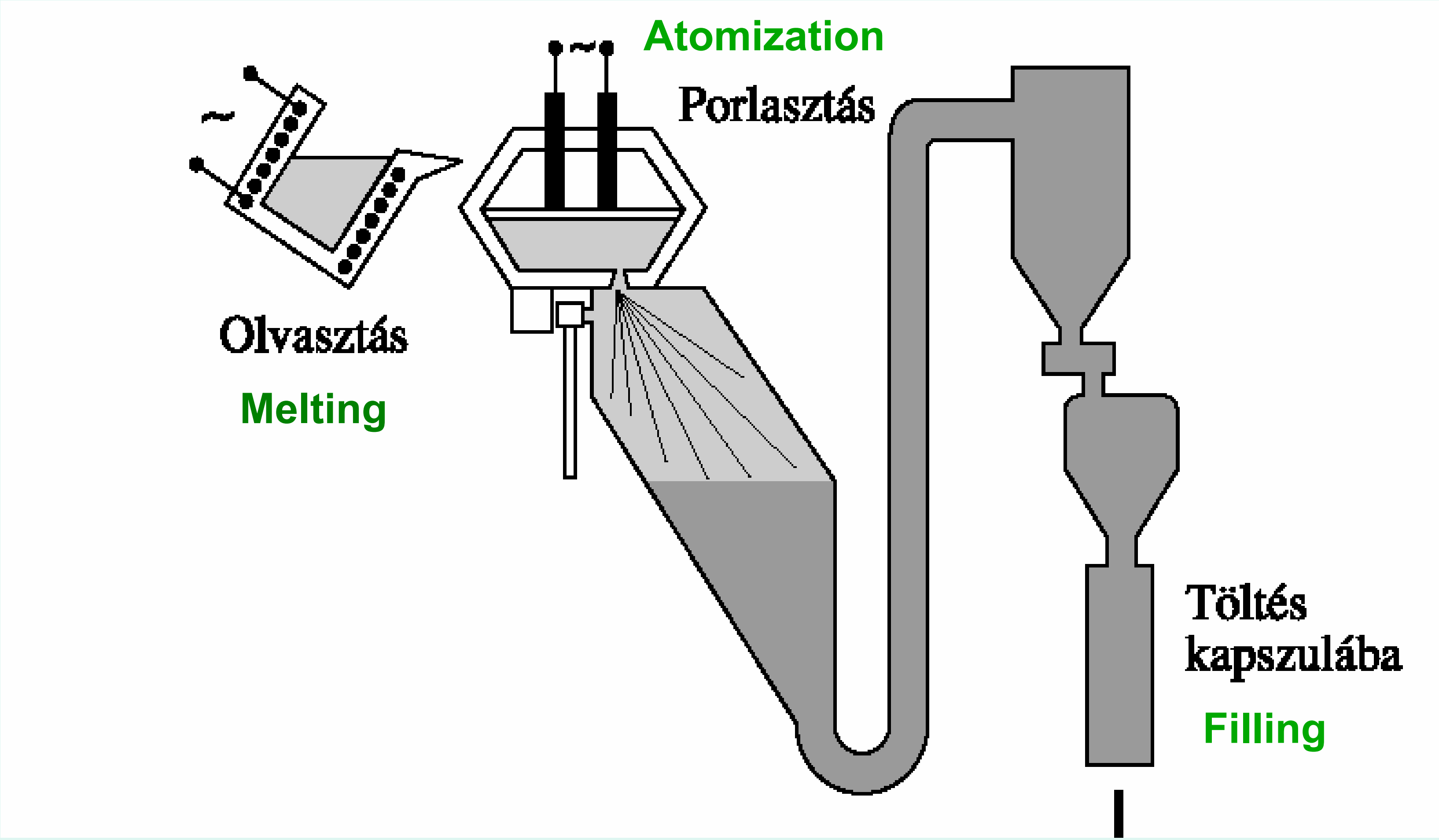
Materials for PP

- **Metal powders (Fe, Cu, Ni, Ti, Co, W, Mo, …stb.)**
- **Alloys (HSS, bronze, stainless steels, …etc.)**
- **Non-metallic powders (graphite, metal carbides, oxides, …etc.)**

Production of metal powders

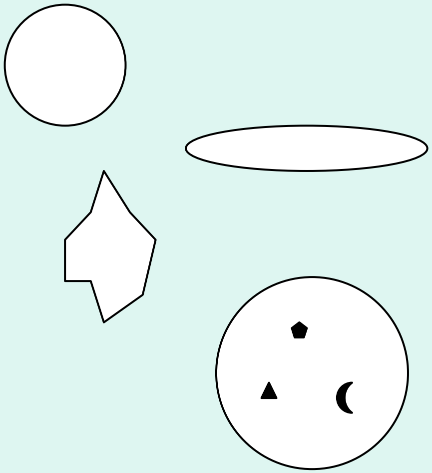
- Mechanical comminution (pulverization)
  - Crushing, milling
- Atomization (melting and breaking by gas, air, water jet)
- Reduction of metal oxides using gases
- Carbonyls (iron-, nickel carbonyl) reacting with CO
- Electrolitic deposition

Example: atomization



Shape and size of powders

- Shape and size of powders depend on the metod of production
- Particle size range: 0,001…1 mm
- Shapes (one-, two, three dimensional):
  - spherical
  - elongated
  - irregular
  - porous



Powder Sources

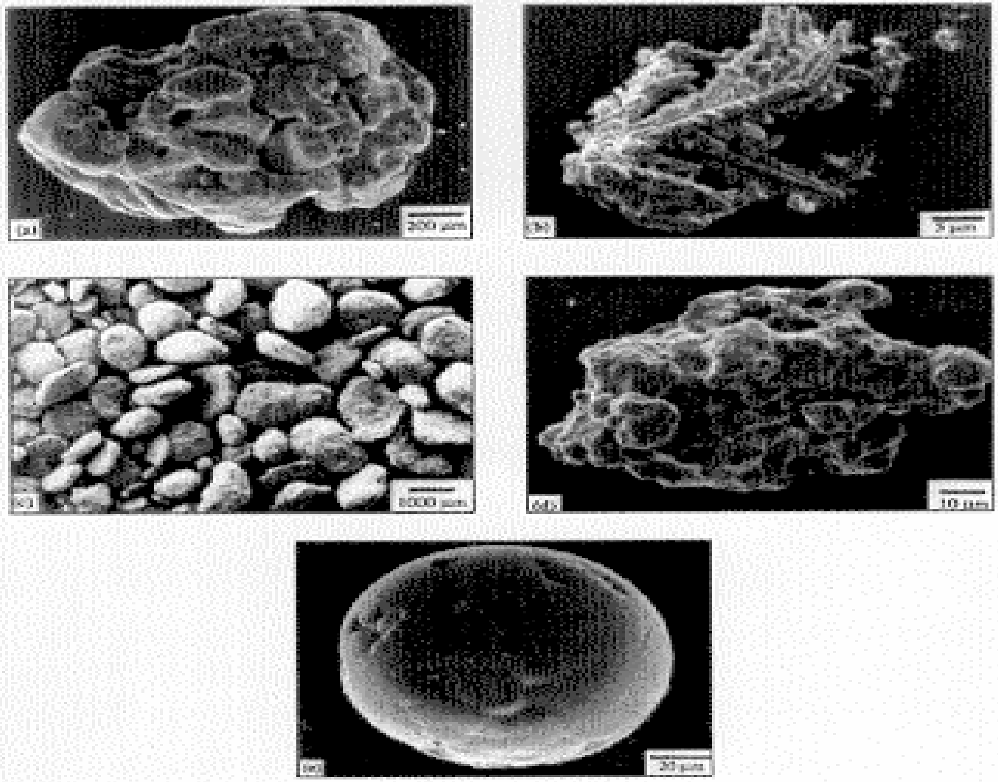


Figure 1. Representative metal powders: (a) chemical: sponge iron-reduced ore; (b) Electrolytic: copper; (c) Mechanical: milled aluminum powder; (d) Water Atomization: iron; (e) Gas atomization: nickel-base alloy (3).

Blending metal powders

- Screening by screens of various mesh sizes
- Mixing by size and by material to uniform distribution of components
- Lubrication
- Objective:
  - Favourable composition
  - Better properties
  - Lower friction at compaction

Consolidation

- Consolidation = to impart shape or form
- Net shape methods
  - Pressing, die compaction (hot or cold)
  - Metal injection molding (MIM)
  - Cold isostatic pressing (CIP)
- Bulk shape methods
  - Hot isostatic pressing (HIP)
  - Cold isostatic pressing (CIP)
  - Roll
  - Extrude
  - Spray form

Compaction

- **Blended powders are pressed into shapes in dies**
- **The pressed powder is known as green compact (rigid, low strength)**
- **Tooling:**
  - **Single acting punch**
  - **Floating container**
  - **Two counteracting punches**

Compaction – *Net Shape*

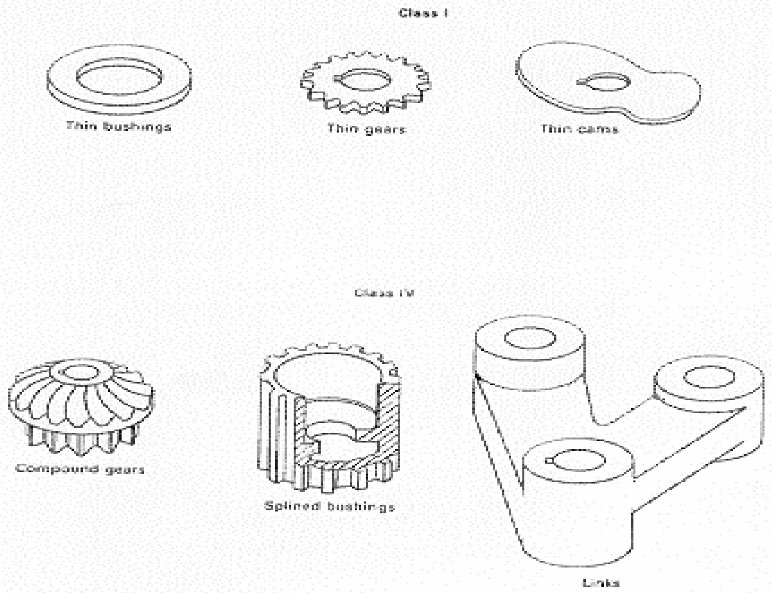


Figure 3. Typical geometries of die-pressed parts (27).

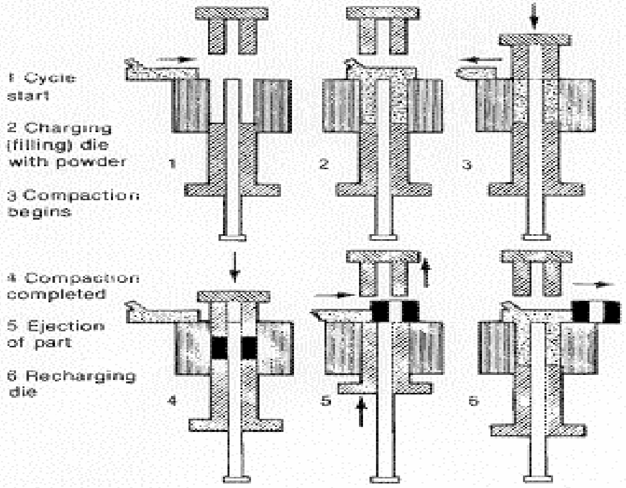
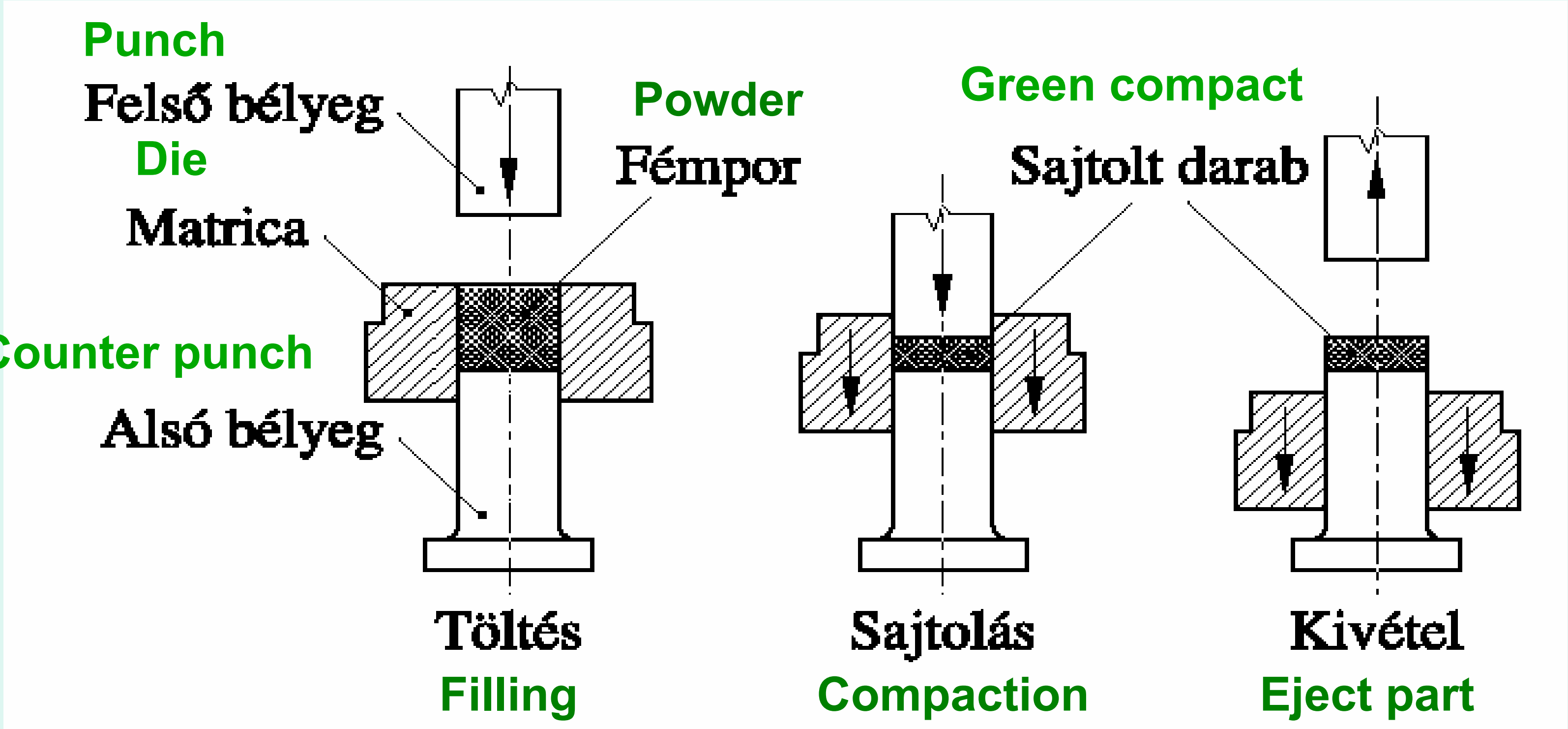


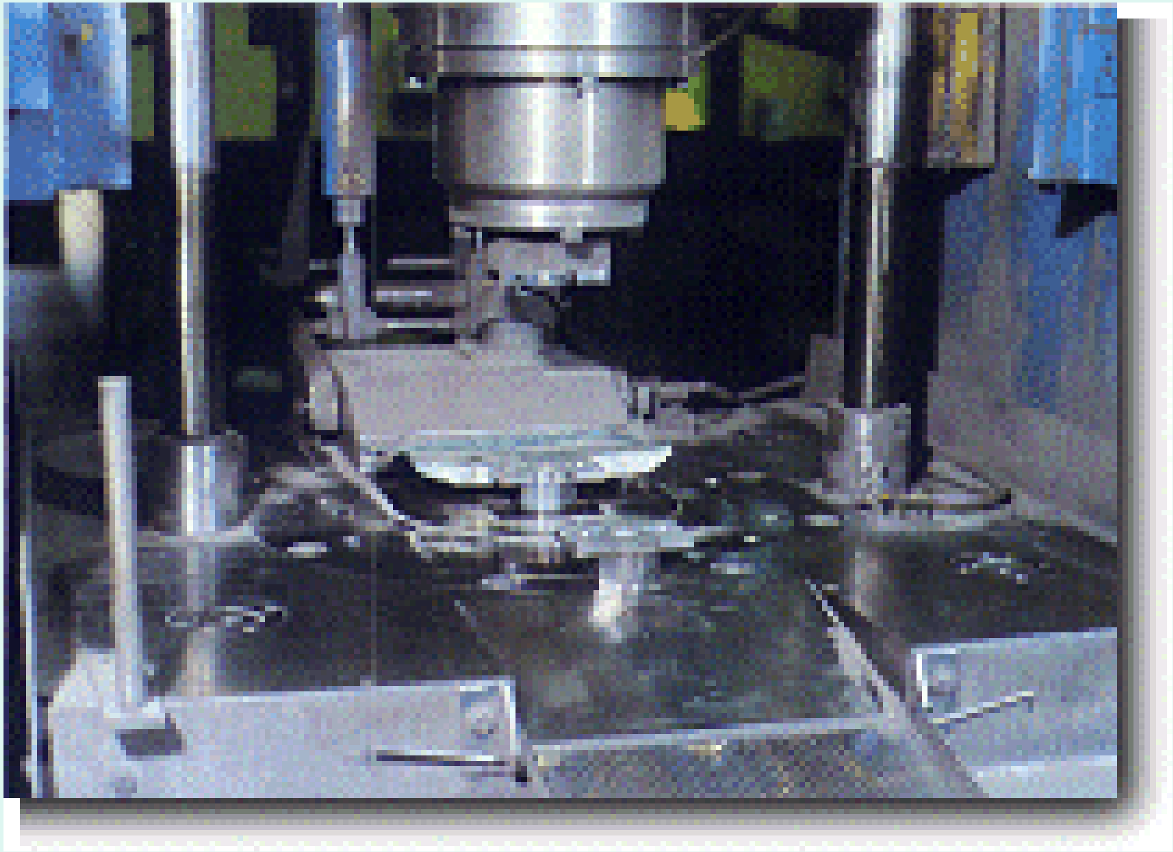
Figure 2. Typical die pressing operation (27).

Compaction example: floating container



- Density distribution is better than that of using single acting punch

Compaction – *Net Shape*



Consolidation – *MIM*
Metal injection molding

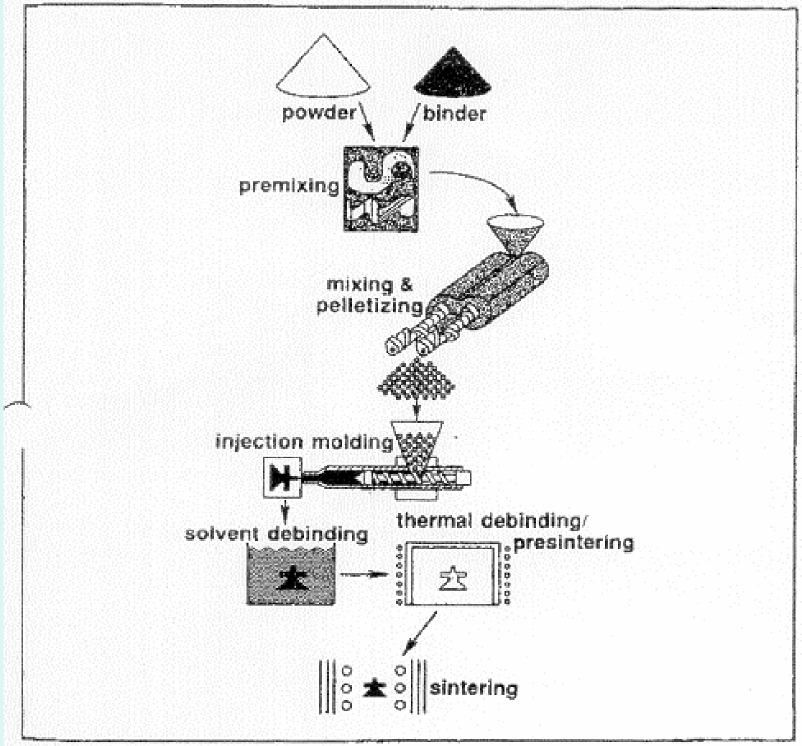


Figure 6.1. The conceptual sequence of steps involved in powder injection molding, where a binder and powder are mixed to form a feedstock which is molded, debound, and sintered. Injection molding relies on the thermoplastic for shaping at slightly elevated temperatures, typically near 150°C.

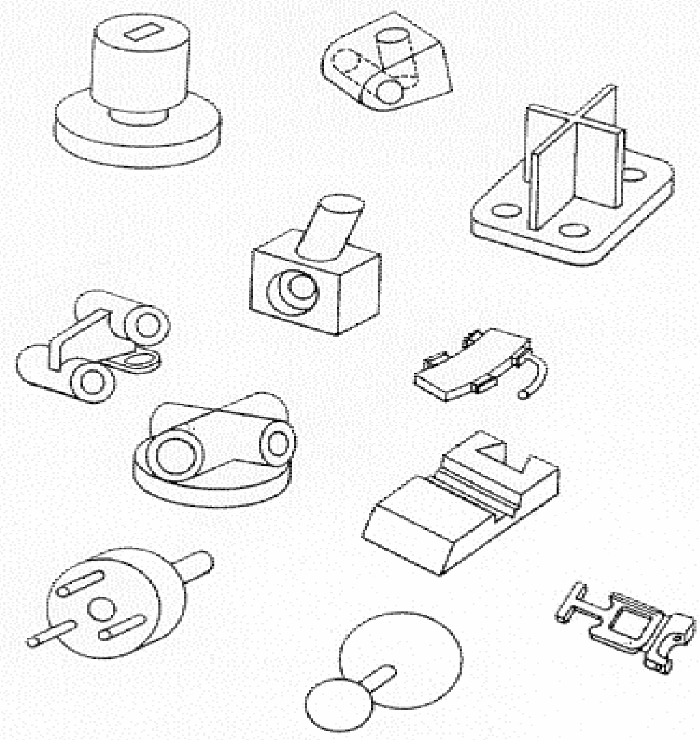


Figure 6. Examples of possible geometries for MIM parts (27).

Consolidation – *Bulk forming*

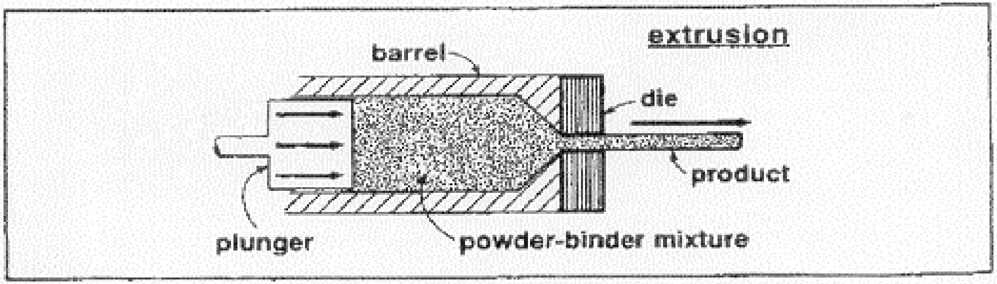


Figure 6.15. The extrusion process forces a slurry of powder and binder through a constriction to shape a continuous product such as a rod, tube, or honeycomb.

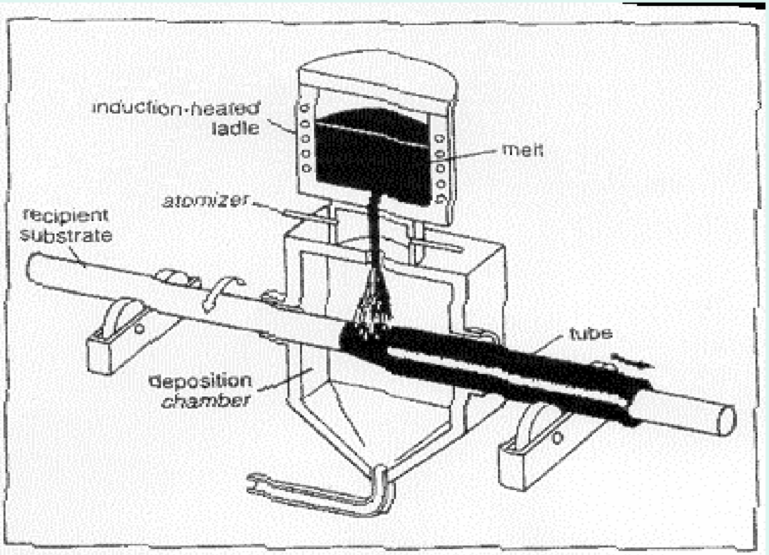


Figure 8.34. The spray forming process uses a gas atomizer to generate a spray of particles deposited on a moving substrate to form a rapidly solidified, nearly full density structure.

Isostatic pressing

- **Green compacts are subjected to hydrostatic pressure in order to achieve more uniform compaction**
- **Two variants:**
  - **Cold isostatic pressing (CIP)**
  - **Hot isostatic pressing (HIP)**
- **The metal powder is placed in a flexible container (rubber or sheet metal), then pressurised by hydrostatic fluid or gas**

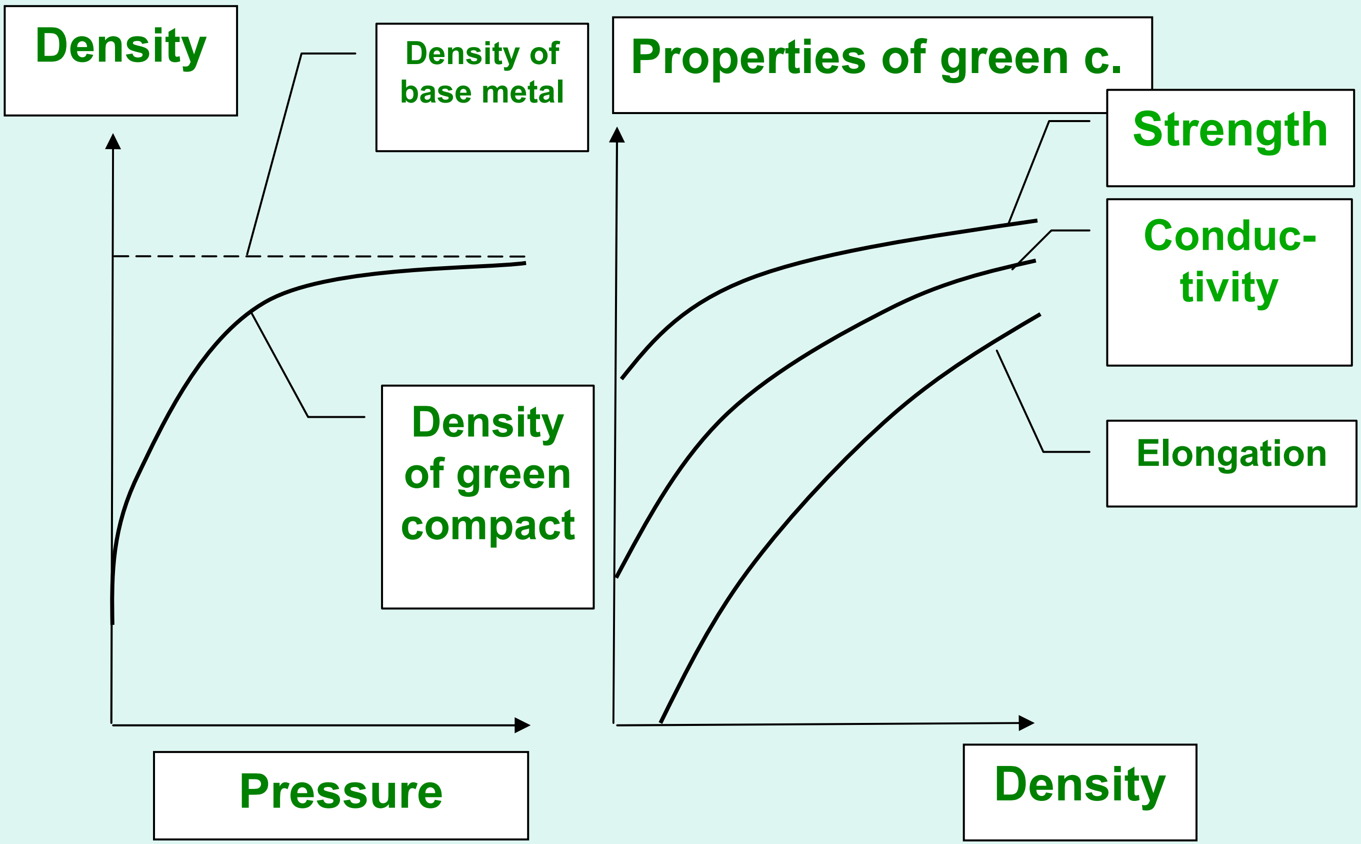
The effect of compaction on the green compact (1)

Size-density, pressure-density functions:

- **Optimal size distribution of powder increases density (amount of fine particles)**
- **The higher the compaction pressure, the higher will be the density**

  => high density increases the strength and elastic modulus

The effect of compaction on the green compact (2)



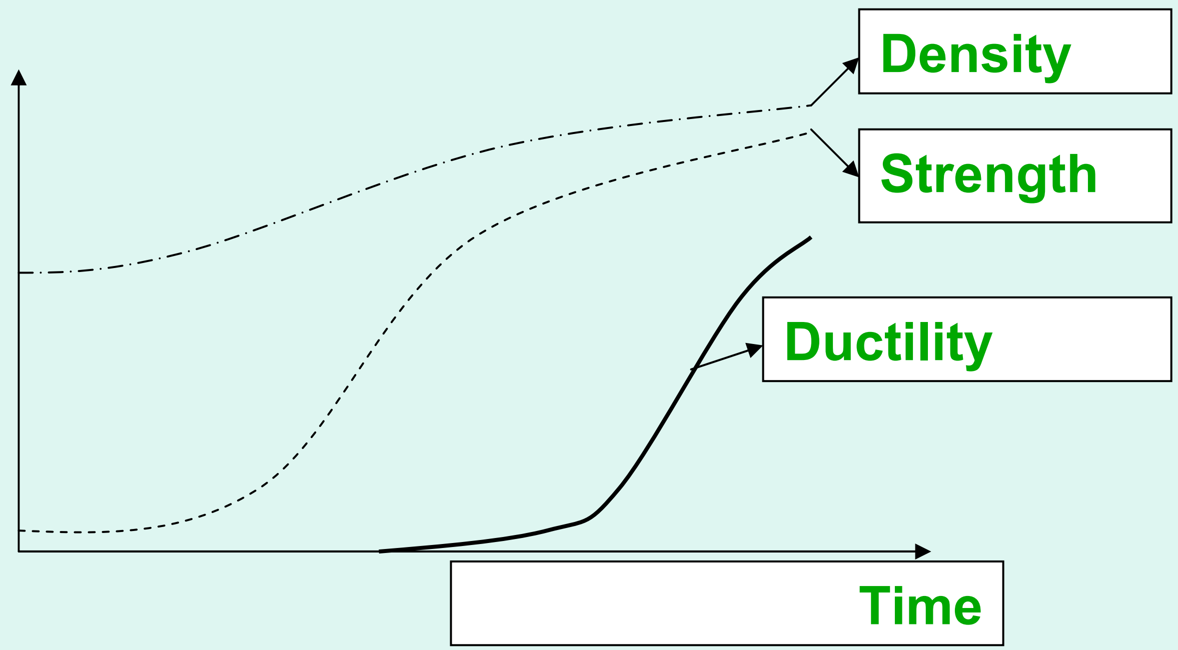
Sintering (principle)

- Metallurgical bonding of powder particles
  - Solid state diffusion
  - Liquid phase
- Thermal activated event
  - Atomic transport
  - Particle rearrangement
  - Particle growth
- Results
  - Densification, yield useful physical properties (UTS, YS, ductility, and fatigue strength)

Sintering (process)

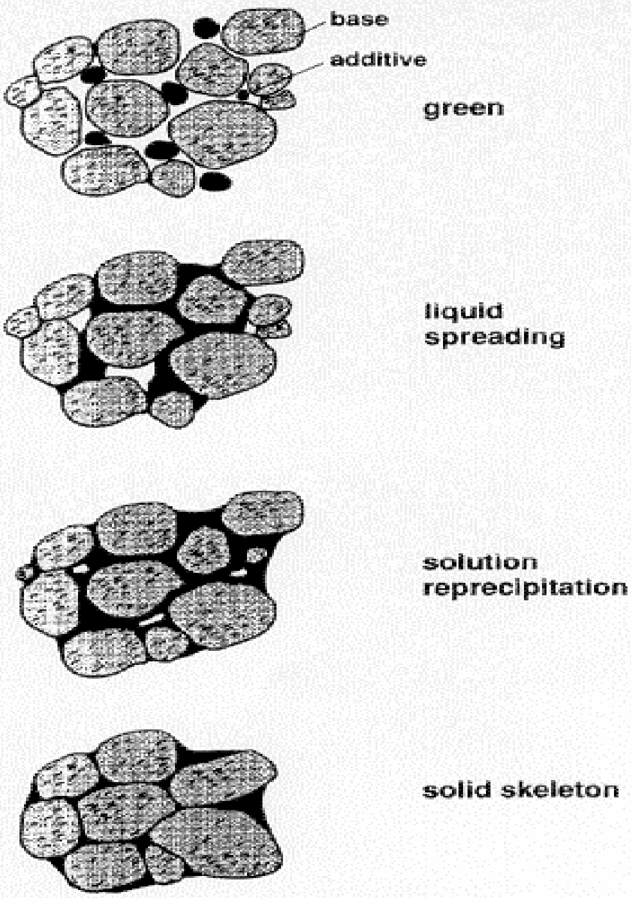
- Compressed powder is heated in controlled atmosphere
- Variables: temperature, atmosphere and time
- Result: increasing strength and thoughness, lowering porosity.

Sintering process parameters



Green com-pact	Necks formed	Particles bonded, pore size reduced	Fully sintered

Sintering (microstructure)



The conceptual stages to liquid phase sintering

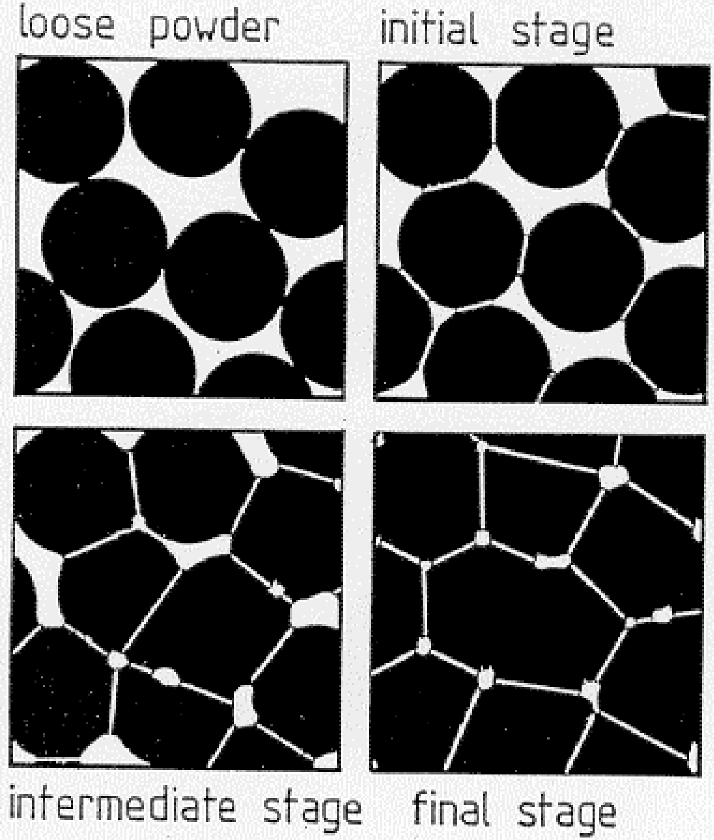


Figure 1: Schematic of loose powder sintering (20).

Sintering (infiltration)

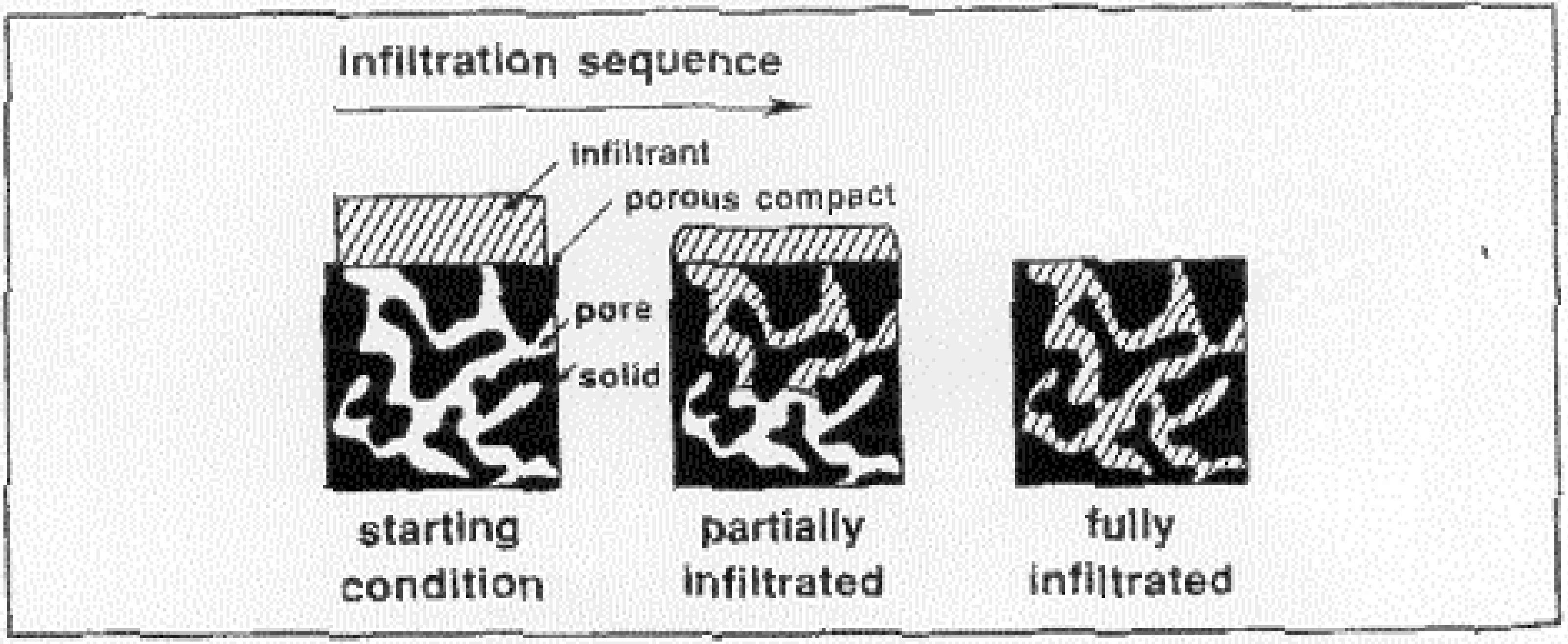


Figure 6.9. *A sketch of the infiltration sequence where capillary forces pull a molten metal into the open pores of a sintered compact.*

Sintering: process variables

- **Temperature:**
  - **Metallic powders: T=0,7…0,9 T_{melt}**
- **Sintering time: 0,5…8 hours**
- **Atmosphere: vacuum, inert or reducing gas**
- **Processes: diffusion, microstructural changes, solid-state bonding of particles, pore size reduction**

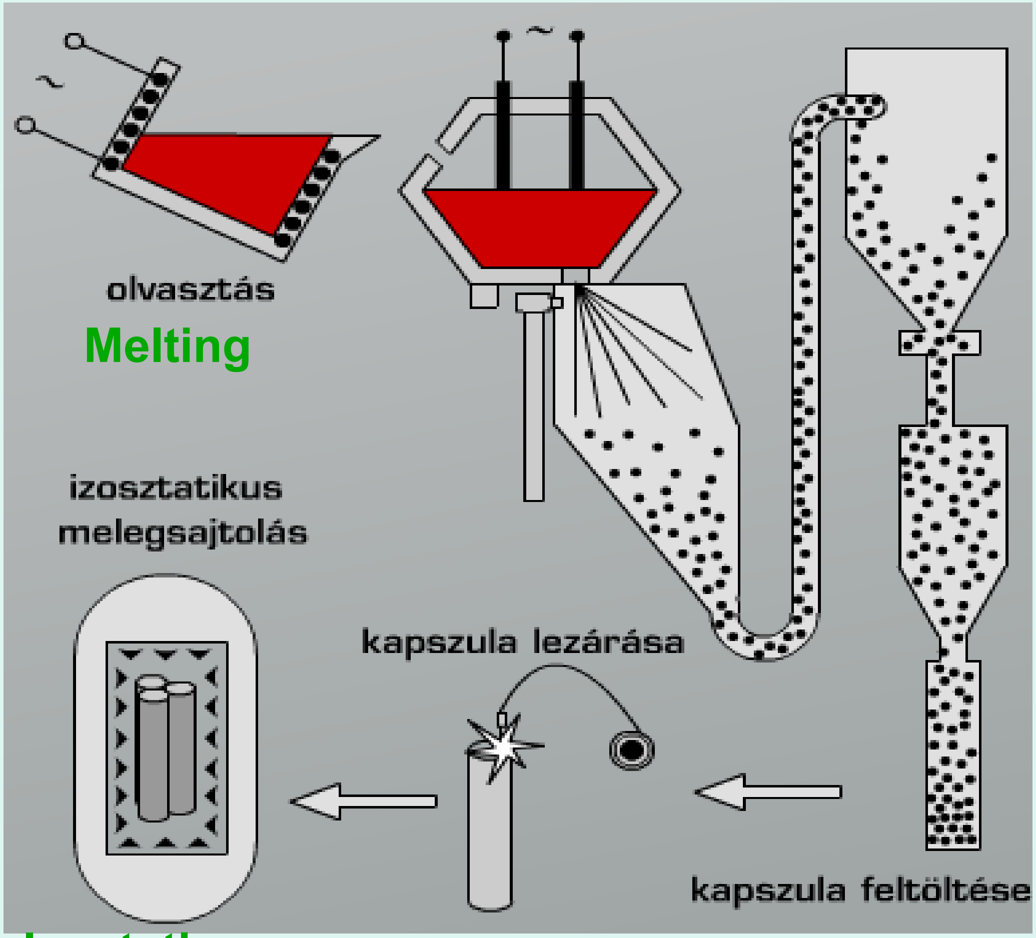
Sintering temperature and time

MATERIAL	Temperature (°C)	Time (min)
Copper, brass	760…900	10…45
Iron	1000…1150	8…45
Stainless steel	1100…1290	30…60
Molybdenium	2050	120
Tungsten	2350	480

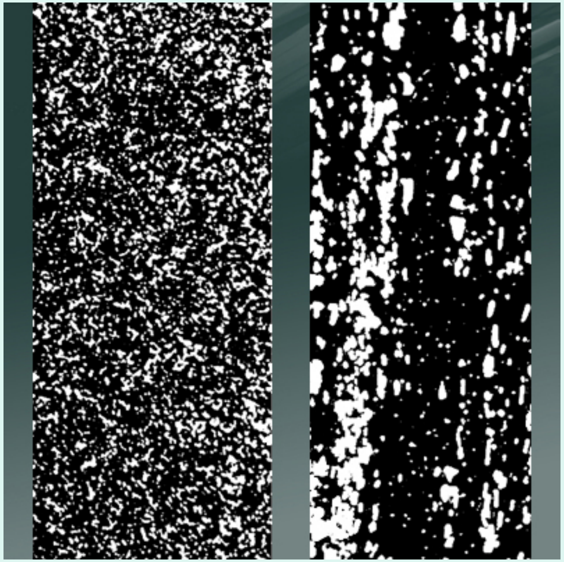
Finishing operations

- **Coining and sizing: improve dimensional accuracy, strength and surface finish**
- **Cold forging, upsetting: modify shape, increase strength**
- **Impregnating with fluid: bearings and bushes**
- **Infiltration: molten metal infiltrates the pores**

Application: High Speed Steels (1) Hot Isostatic Pressing



Isostatic compression



Carbide distribution of HSS

a.) powder metallurgy

b.) conventional

Application: High Speed Steels (2)

Process:

•Welding

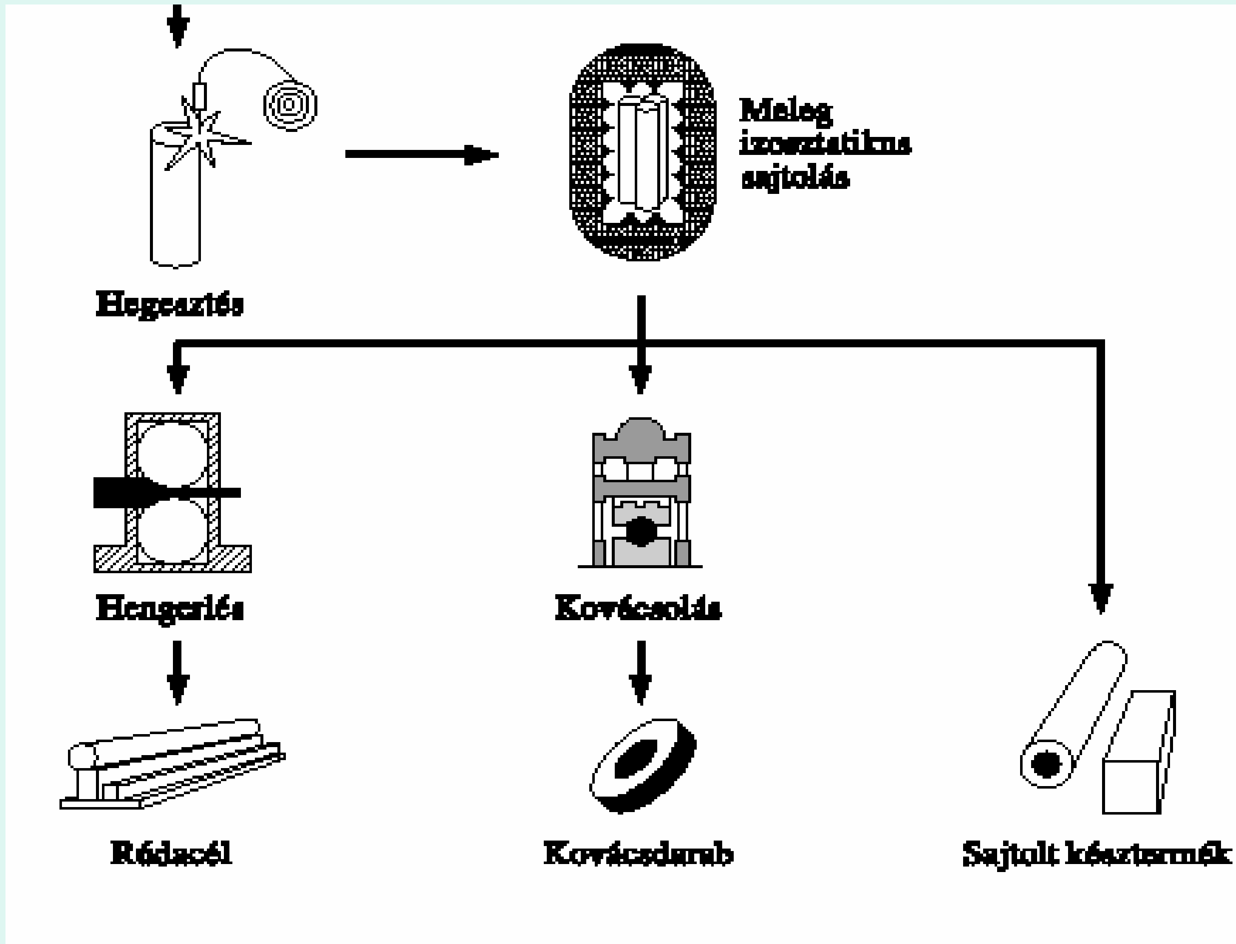
•Hot isostatic compaction

•Rolling

•Forging

Product:

Bars, forged parts



Application: cutting tools

W- and Ti-carbide plates for high-speed cutting

Example (1)

Example (2)

Example (3)

Example: gears

By cutting

- Forging
- Turning
- Milling of teeth

Material yield: 31%

By powder metallurgy

- Sintered part
- Finishing operation

Material yield : 86%

Applications

- Competitive with casting, forging, machining
- Excellent material yield
- Limitations in shapes
  - No sharp changes in contour, no sharp radius
  - Avoid thin sections, high length-to-diameter ratios, reentry corners

Example: connecting rod

- **Manufacturing methods:**
  - Forging (low alloyed steel)
  - Casting (spheroidal graphite cast iron)
  - Powder metallurgy (low alloyed iron powder)
- **Comparison:**
  - Material cost
  - Manufacturing cost
  - Mechanical properties

Connecting rod: powder metallurgy

- Atomized iron powder
- Blending: graphite + lubricant
- Compaction: volume ratio 2,5:1; density ratio 80%
- Sintering: 1120 °C; 30 min; reducing atmosphere, porosity 3…5%
- First manufacturers:
  - Porsche 928 (V8 engine) 1976
  - Toyota Camry (4 cyl. 1,9 l engine) 1981

Comparison: 3 production methods

	Forging	Casting	Powder process
Material cost	Good 5	Good 5	Medium 3
Cost of primary process	Medium 3	Good 5	Week 1
Cost of secondary operations	Week 1	Medium 3	Good 5
Strength	Good 5	Medium 3	Good 5

Summary

- **Production steps of powder products: powder production, blending, compacting, sintering, finishing**
- **Advantages:**
  favourable structure, near net shape, materials of unique properties
- **Wide range of applications**