TA201A
Manufacturing Processes

Week-11

01 Nov, 2022

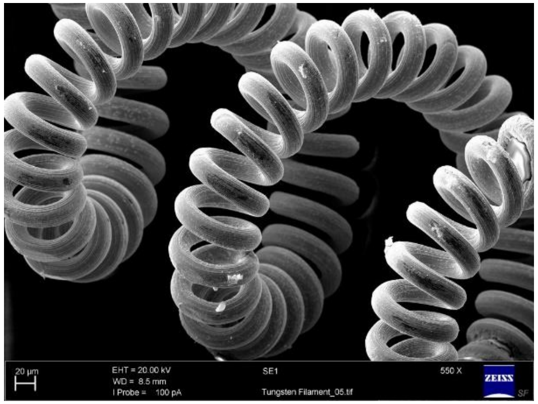
2022-2023 Semester-I

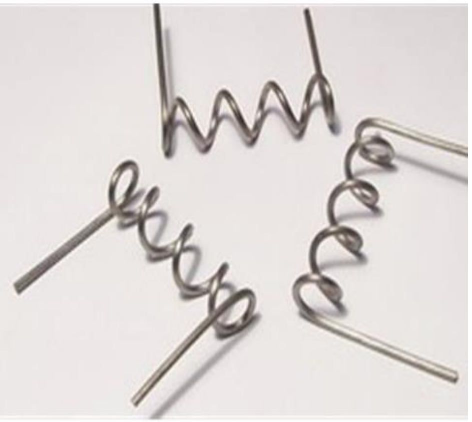
Lecture 11

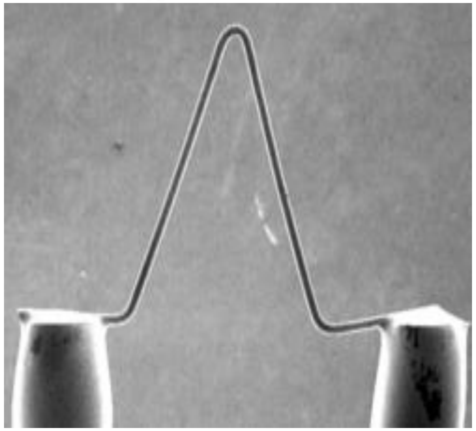
Powder Metallurgy

Tungsten Filament

W: $T_m = 3422\ ^{\circ}C$







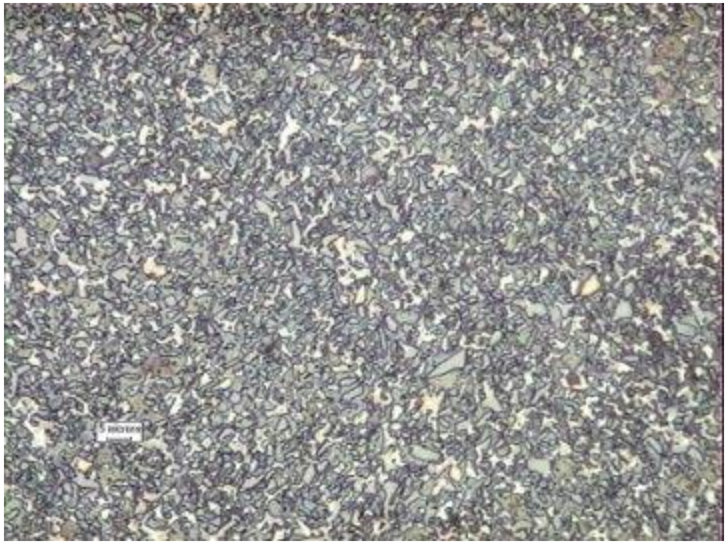
Powder metallurgy

Courtesy: Google Image

Cermet cutting tools
(Ceramic-metal composite)

Microstructure:
ceramic particles in metal matrix

Cermet-tipped saw blade for long life



Courtesy: Google Image

Powder Metallurgy

Porous Metals

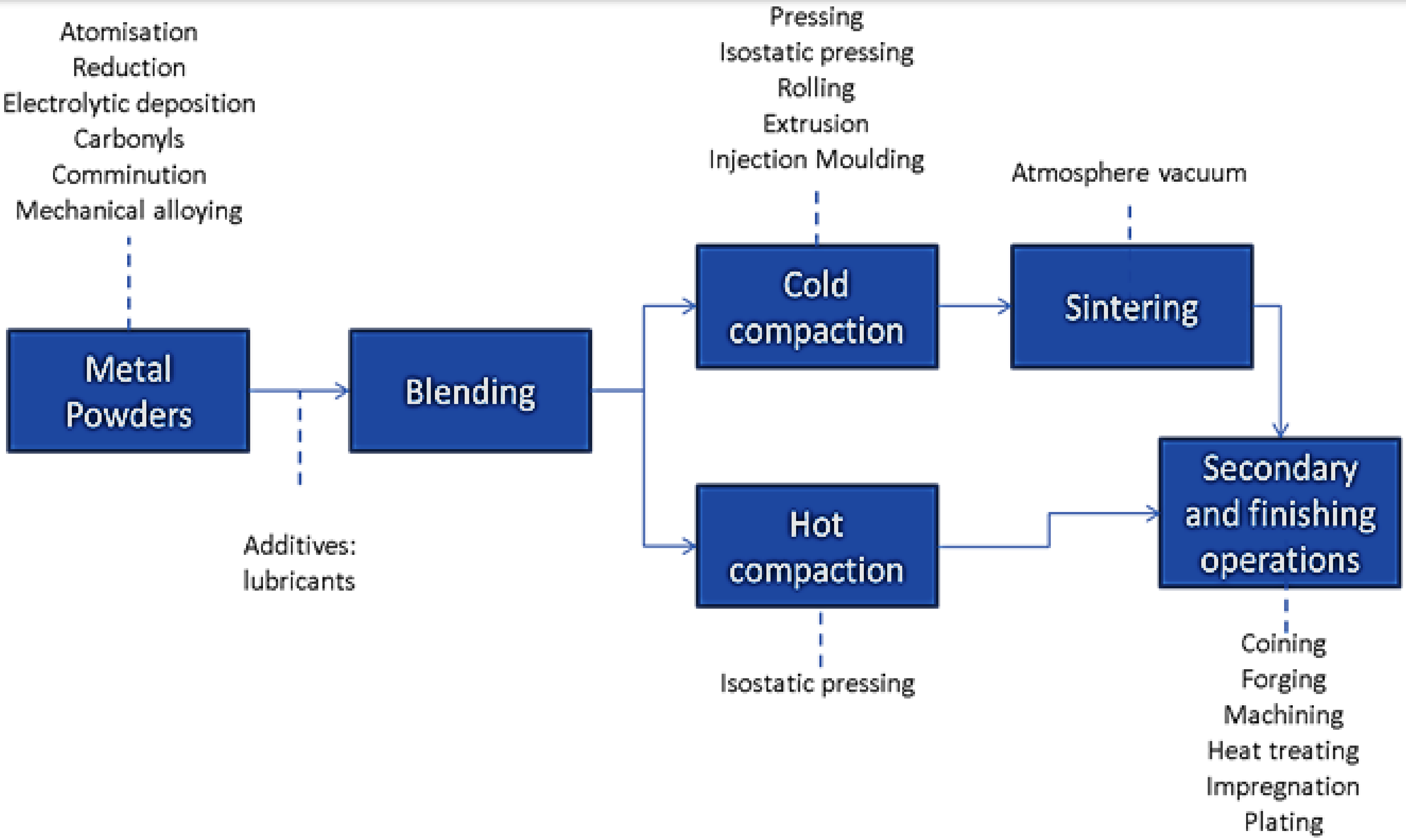
Metal filters

Oil-impregnated Porous Bronze Bearings

Importance of P/M

- Versatile and used in numerous industries
- Eliminates or minimizes machining
- Minimizes scrap
- Maintains close dimensional tolerances
- Permits a wide variety of alloy systems
- Facilitates manufacture of complex shapes which would be impractical with other processes*
- Provides excellent part to part repeatability
- Cost Effective
- Energy and environmentally efficient

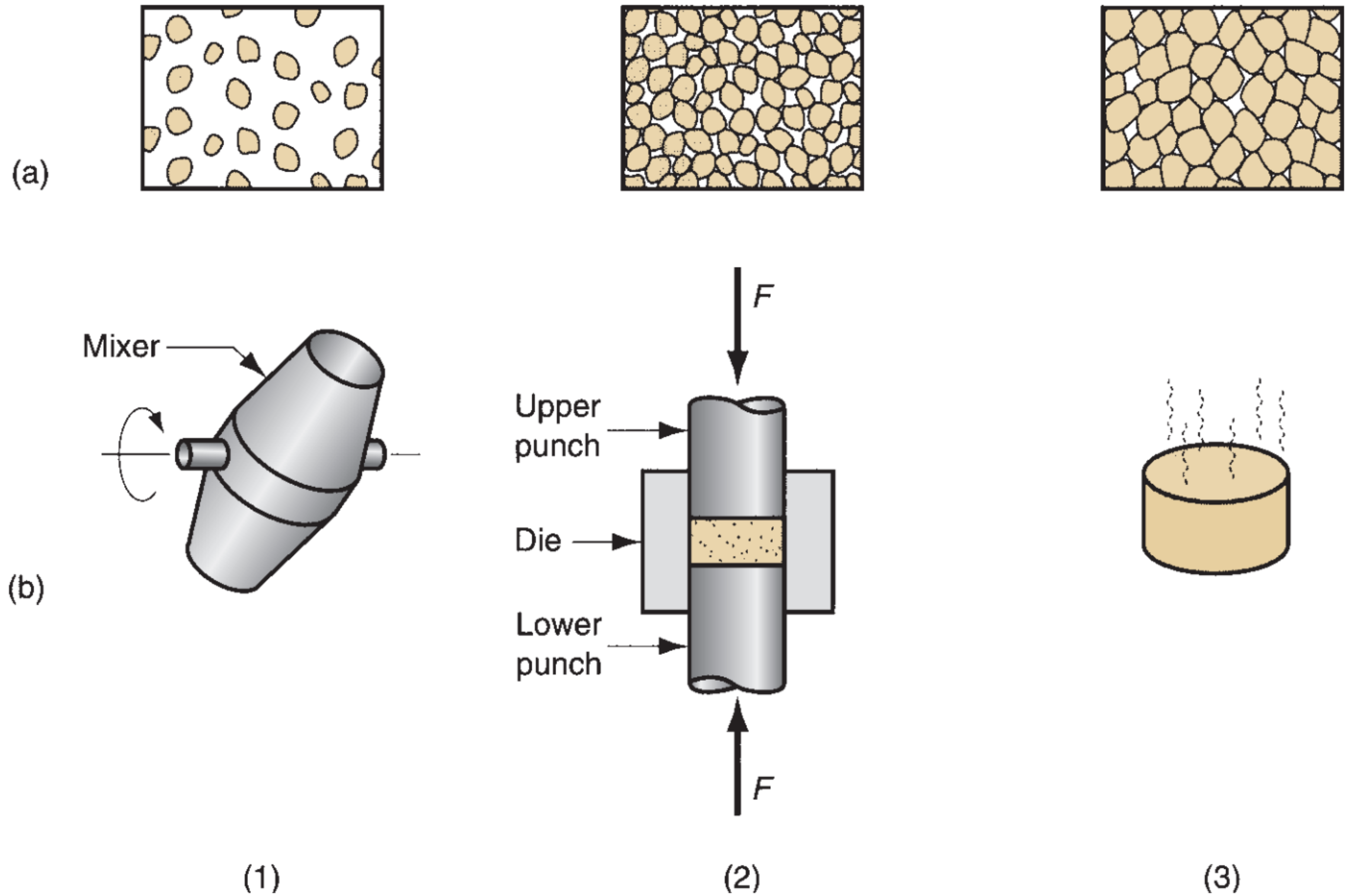
Powder Metallurgy: Flow Chart



http://www.autoinspectproject.eu/project/index.jsp

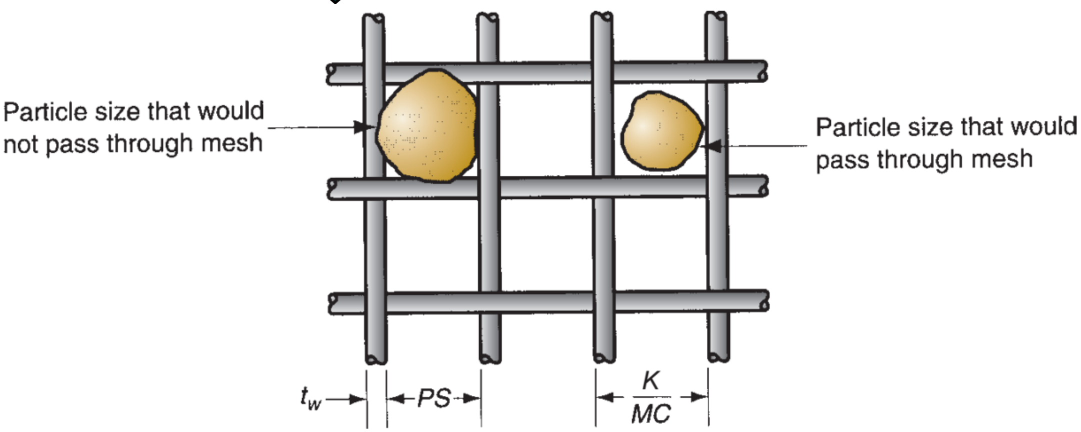
Conventional powder metallurgy route

Blending | Compacting | Sintering



Powder characterization

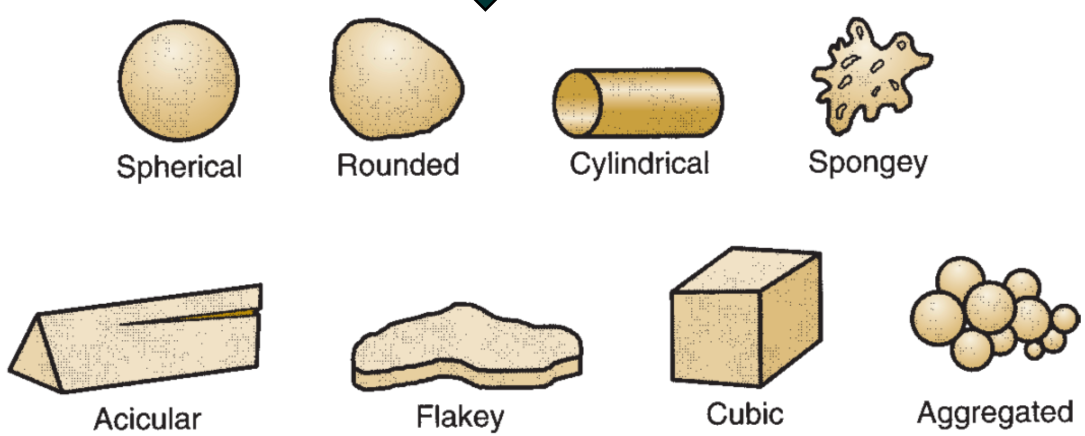
Particle size and distribution



$$PS = \frac{K}{MC} - t_w$$

PS - particle size, mm (in);
MC- mesh count, openings per linear inch;
tw - wire thickness of screen mesh, mm (in);
K : a constant whose value 25.4
when the size units are mm
(and *K* = 1.0 when the units are inches)

Particle shape and structure



Particle surface area

$$A = \pi D^2$$

$$V = \frac{\pi D^3}{6}$$

$$\frac{A}{V} = \frac{6}{D}$$

$$\frac{A}{V} = \frac{K_s}{D} \quad \text{or} \quad K_s = \frac{AD}{V}$$

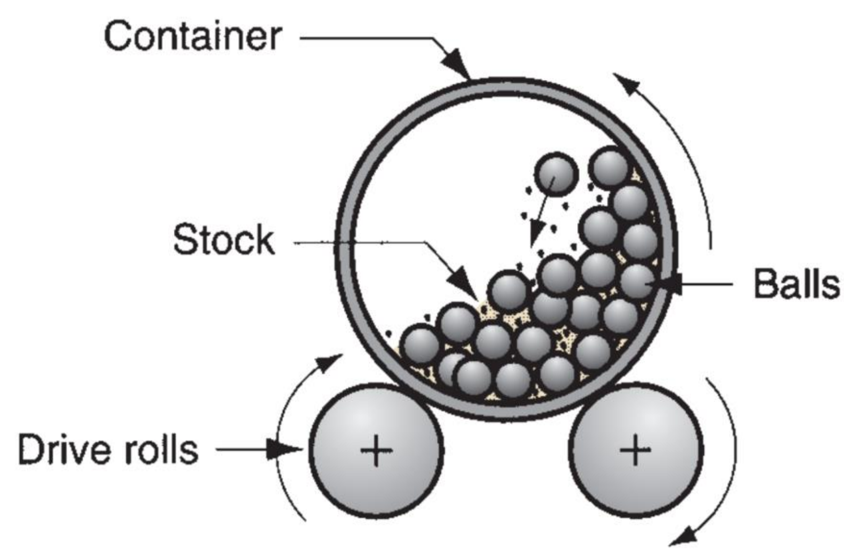
K_s =shape factor

Powder fabrication techniques

- These can be classified into following main categories
  - Mechanical
    - Milling
    - Attritioning and Mechanical alloying
  - Physical
    - Atomization
  - Chemical
    - Decomposition of a solid by a gas
    - Thermal decomposition
    - Solid-solid reactive synthesis
  - Other
    - Electrolytic techniques
    - Microorganism Synthesis

Powder fabrication: Milling

- Milling implies mechanical impaction using hard balls, rods, or hammers and is a classic approach to fabricating ceramic powders
- Material must be brittle.
  [What can you do if a material is ductile like metal?]
- The impact stress required for fracture increases with decreasing particle size
  [So How should the size vary with time?]



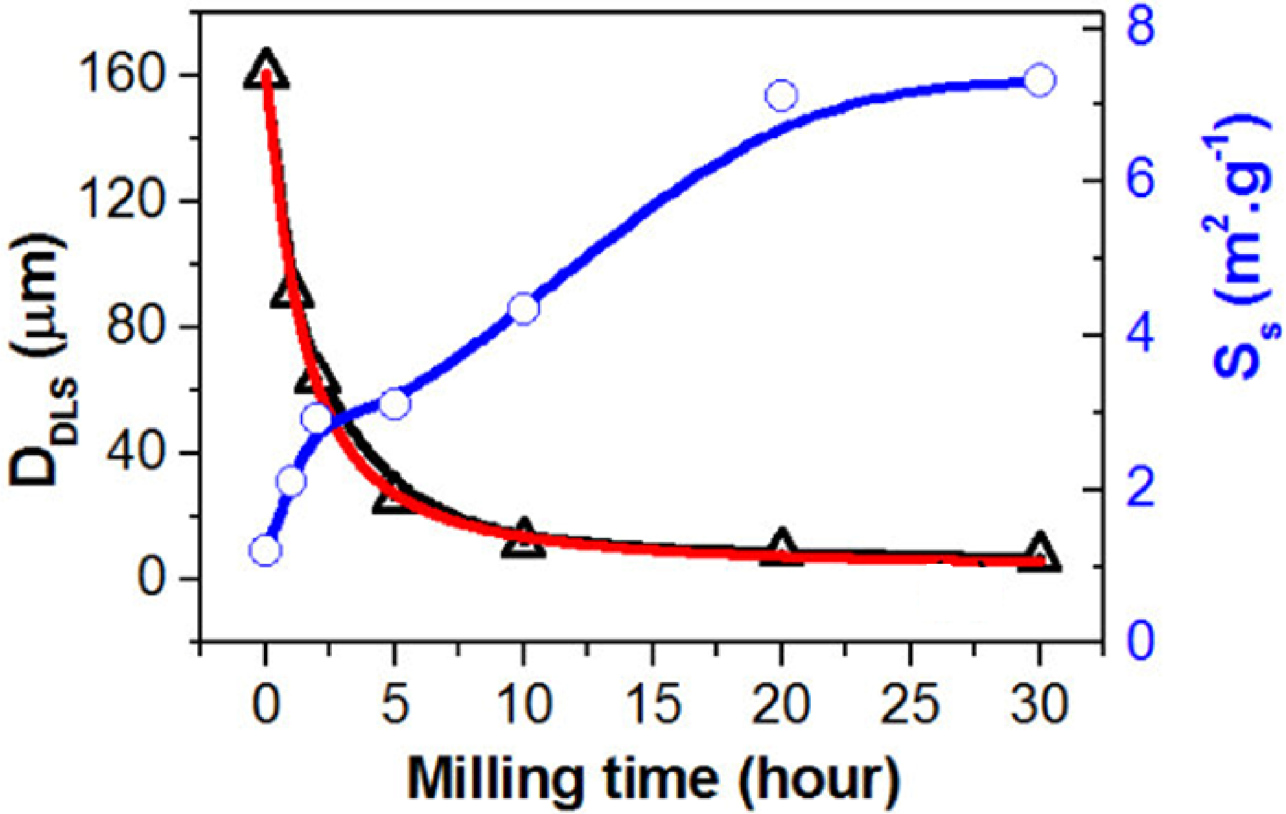
[What will happen if the speed of the mill is too low or too high?]

Powder fabrication: Ball Milling

- Ball milling is inefficient because most of the energy goes into noise and heat
- For optimal milling
  - The ball diameter should be approximately 30 times the diameter of the powder
  - The balls should fill about half of the jar volume
  - The particles should be about 25% of the jar volume
- Fluids or protective atomosphere are used to reduce oxidation and aid grinding
- When wet, liquid clings to the media surface.

  How can this influence the particle size that can be obtained?

Powder fabrication: Ball Milling



Grain size, specific surface area variation with milling time.

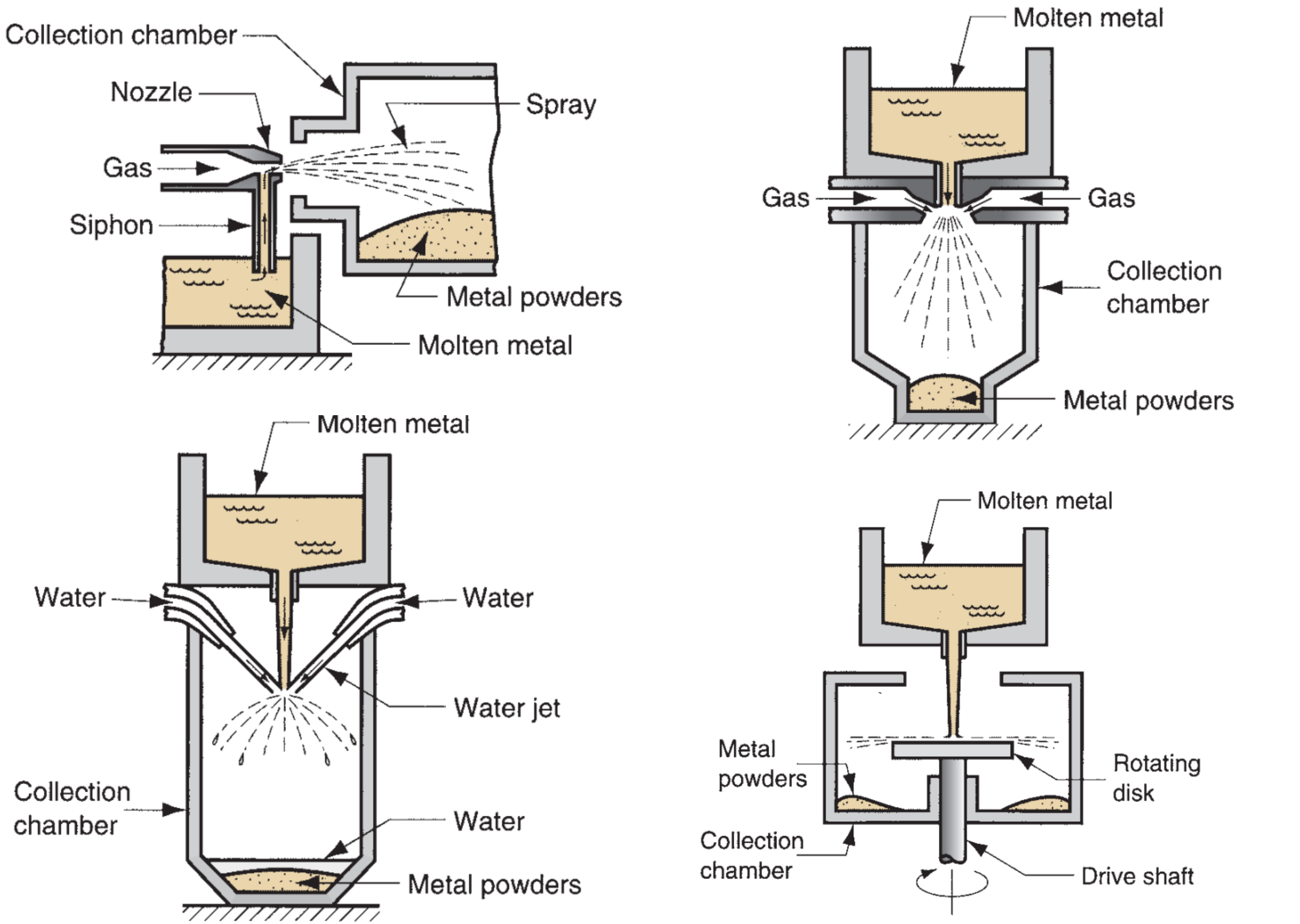
[What will be the change when you add liquid to increase adhesion?]

•DOI:10.1088/2043-6262/4/4/045003

Powder fabrication: Atomization Techniques

- Relies on disintegration of melt into droplets that freeze into particles
- Commercial atomization units operate at production rates as high as 400 kg/min
- Mostly used for metals, alloys and intermetallics with recent applications in polymers and ceramics
- Two main methods of atomization
    - Gas atomization
    - Liquid atomization

Powder fabrication: Atomization - Powder production



Gas vs Liquid Atomization

Gas Atomization

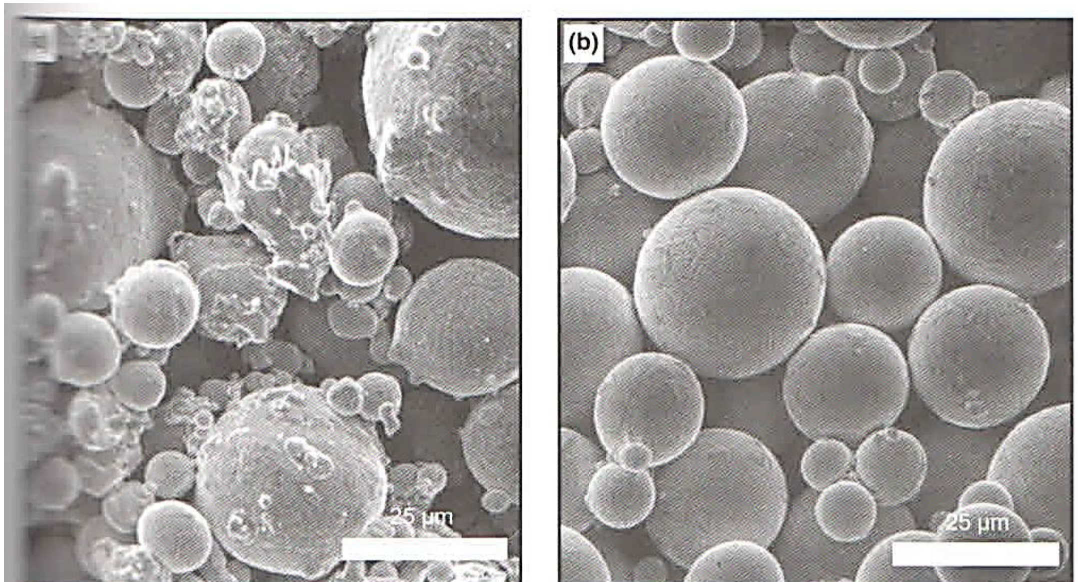


Figure 3.19. Scanning electron micrographs of roughly 25 µm inert gas-atomized powders. Although the particles are nearly the same median size, there is a dramatic difference in particle agglomeration and satellite formation associated with control of turbulence and particle reentry in the atomization zone; a) exhibits splats, agglomerates, and satellites and b) is free of satellites.

Water Atomization

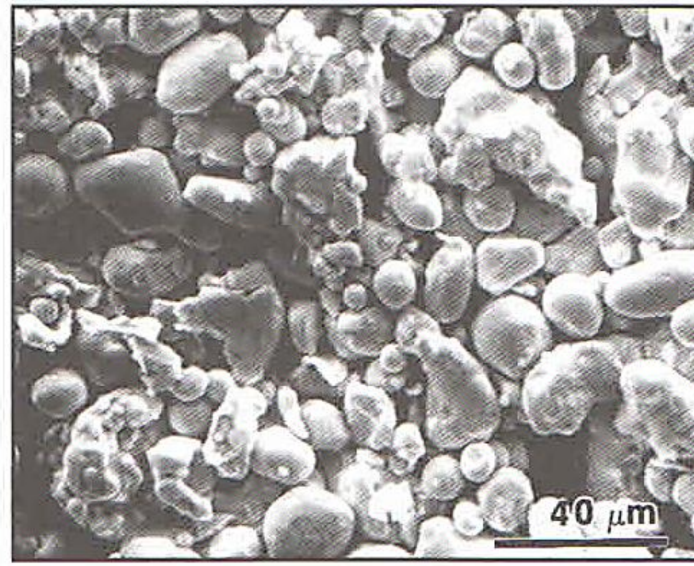


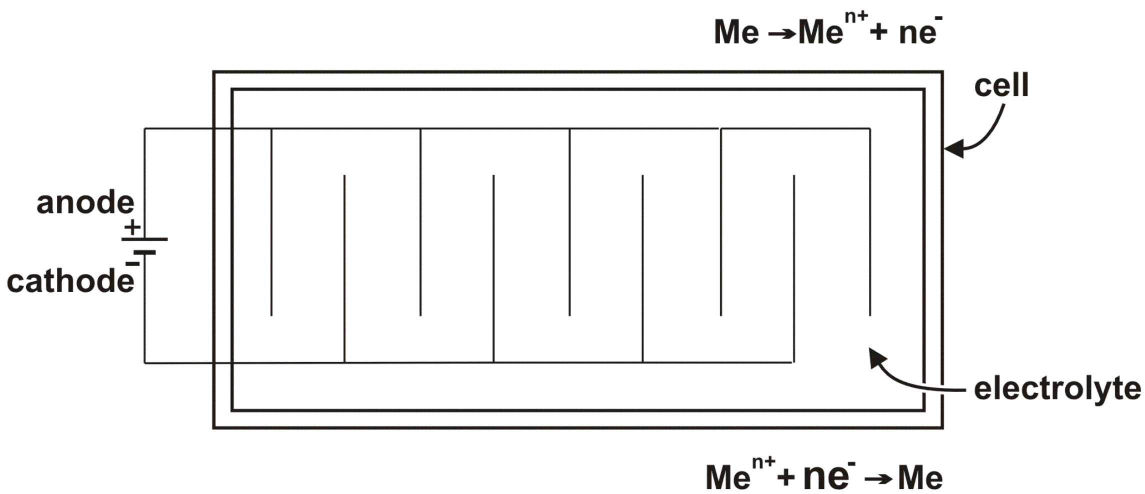
Figure 3.24. *A scanning electron micrograph of -325 mesh water-atomized stainless steel powder intentionally produced with a rounded shape.*

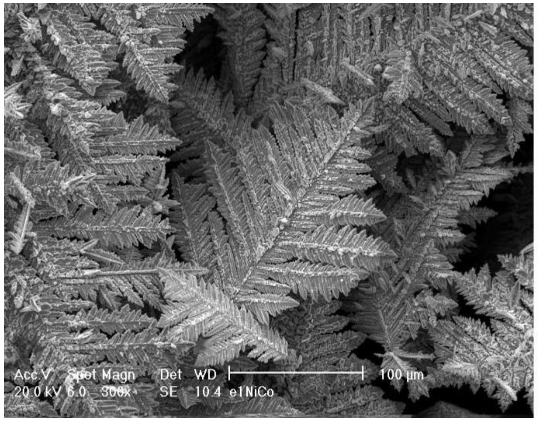
Difference due to turbulent vs not-so-turbulent flow of gas from the nozzle

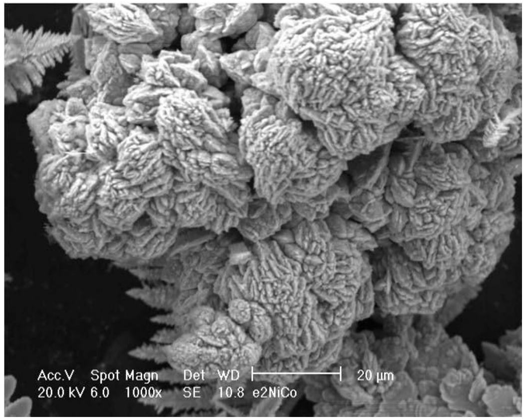
Turbulence causes particles to reenter the gas expansion zone, leading to the formation of satellite particles

Randall M. German - Powder Metallurgy & Particulate Materials Processing-Metal Powder Industry (2005)

Powder fabrication: Electrolytic Technique



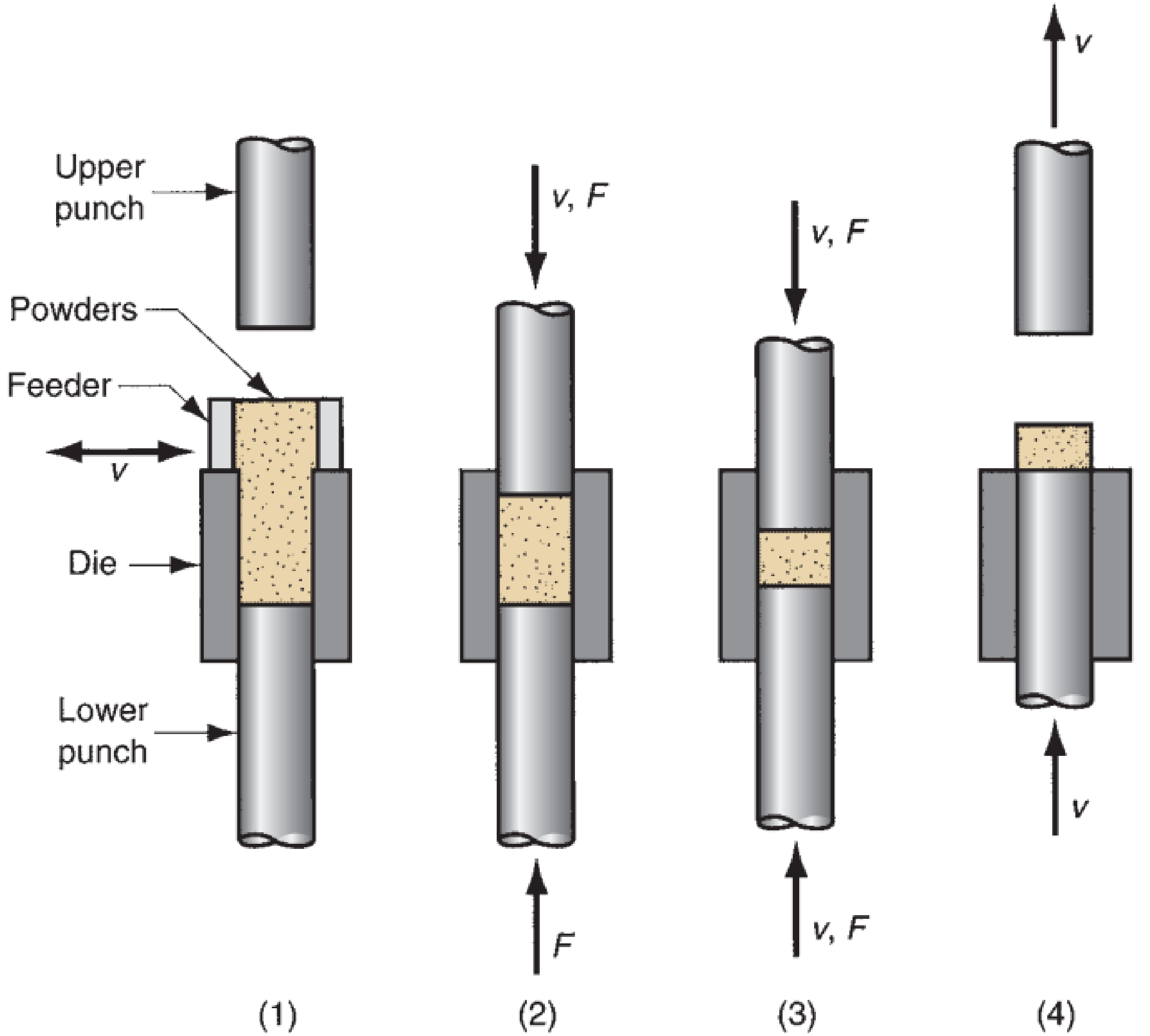




- Elemental powders can be deposited at the cathode of the electrolytic cell
- Raw metal is dissolved at the anode and deposited at the cathode
- After deposition, the cathode deposit is washed, dried, ground, screened, and annealed to form a powder
- Very high purity particulates are obtained
- Most common examples are palladium, chromium, copper, iron, zinc, manganese, and silver

https://knowledge.electrochem.org/encycl/art-p04-metalpowder.htm

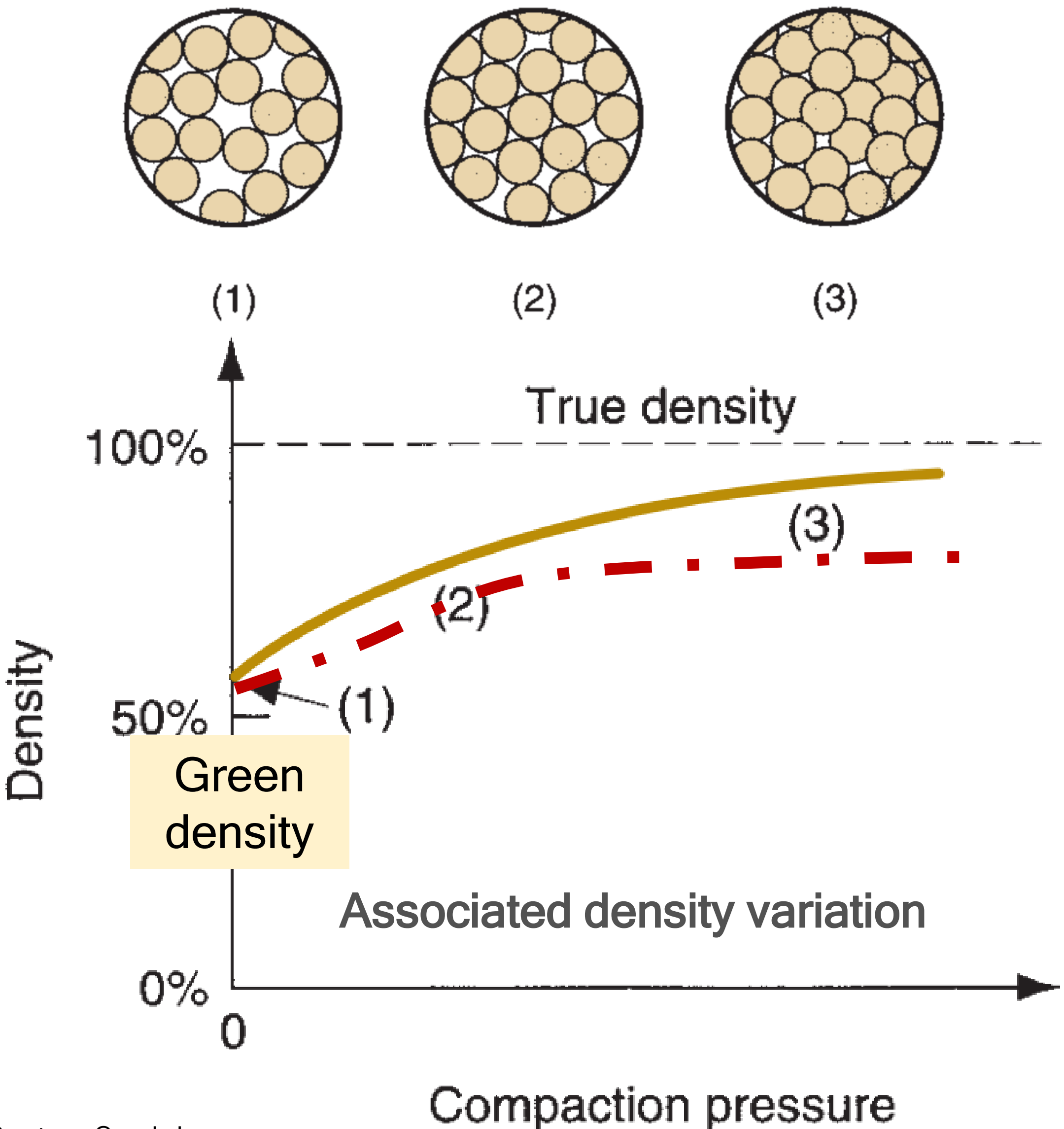
Powder Compaction (Dry Pressing)



Green compact

Green strength

Compaction: Stages and density of green compact



Courtesy: Google Images

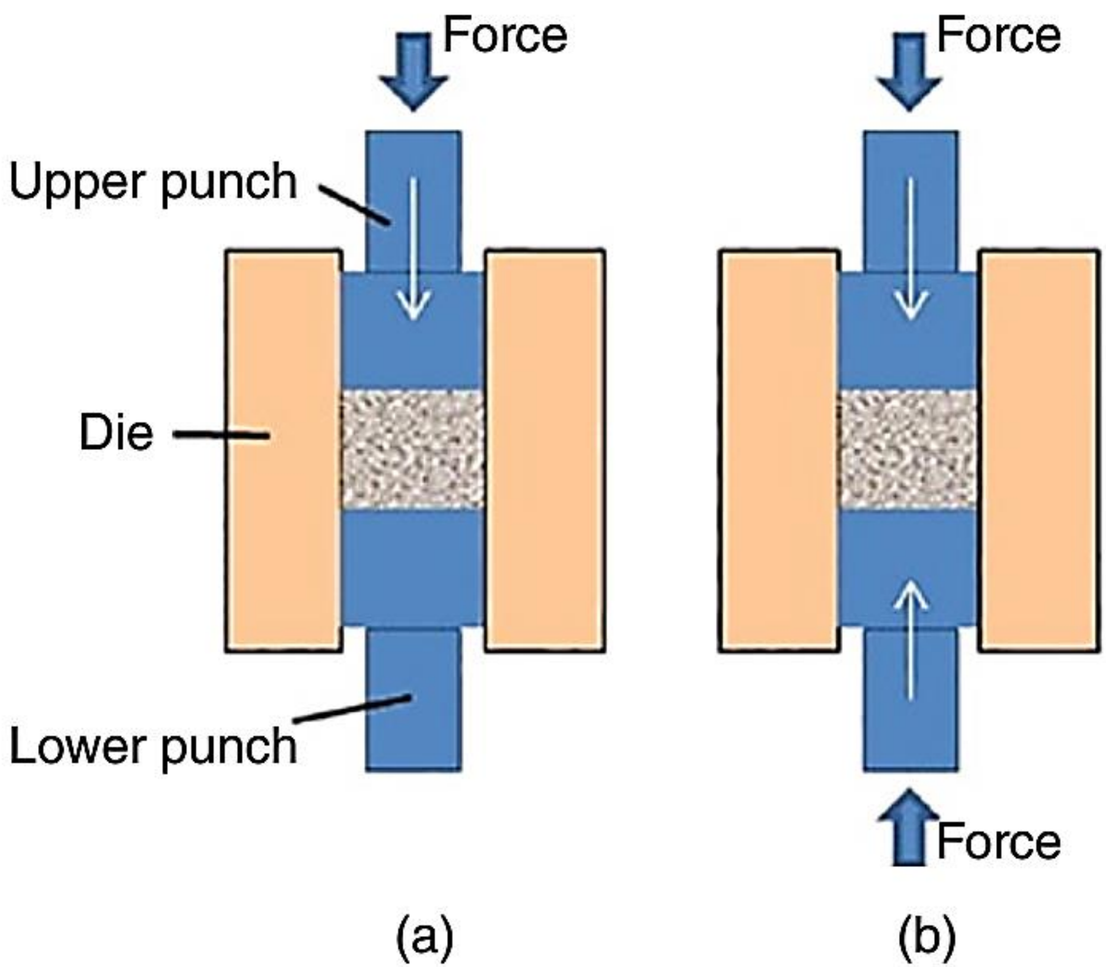
1. Loose compact after filling
2. Rearrangement
3. Particle deformation and reduction in pores

[How will the plot be different for ceramics?]

Figure 7.6. This scanning electron micrograph shows the flattened shape of spherical particles subject to severe compaction. The spheres have been deformed into polygonal shapes with a coordination number approaching 14.

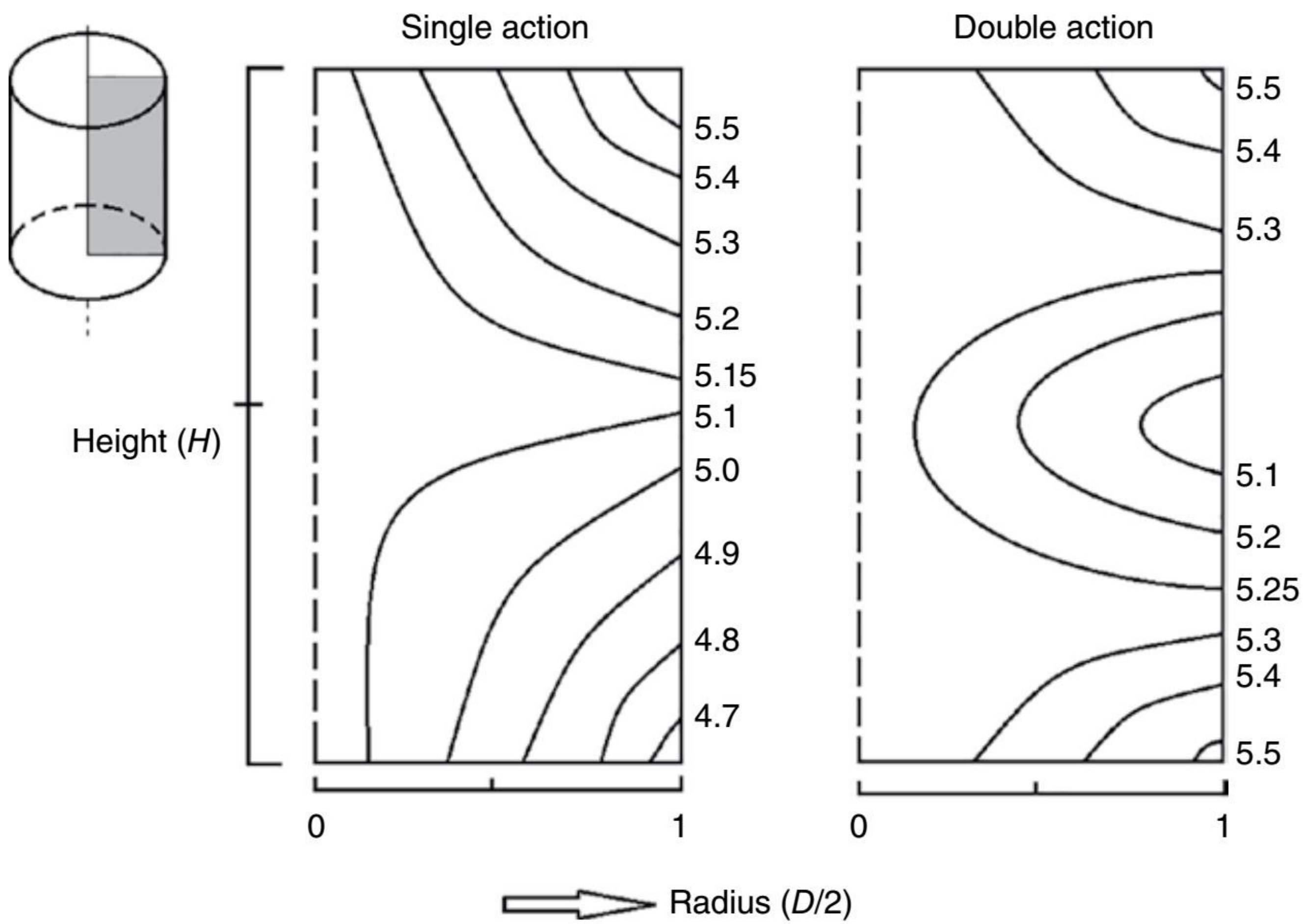
Compaction: Action

Single Action Compaction	Double Action Compaction



Koç, Muammer_ Özel, Tuğrul - Modern manufacturing processes-John Wiley & Sons (2019)

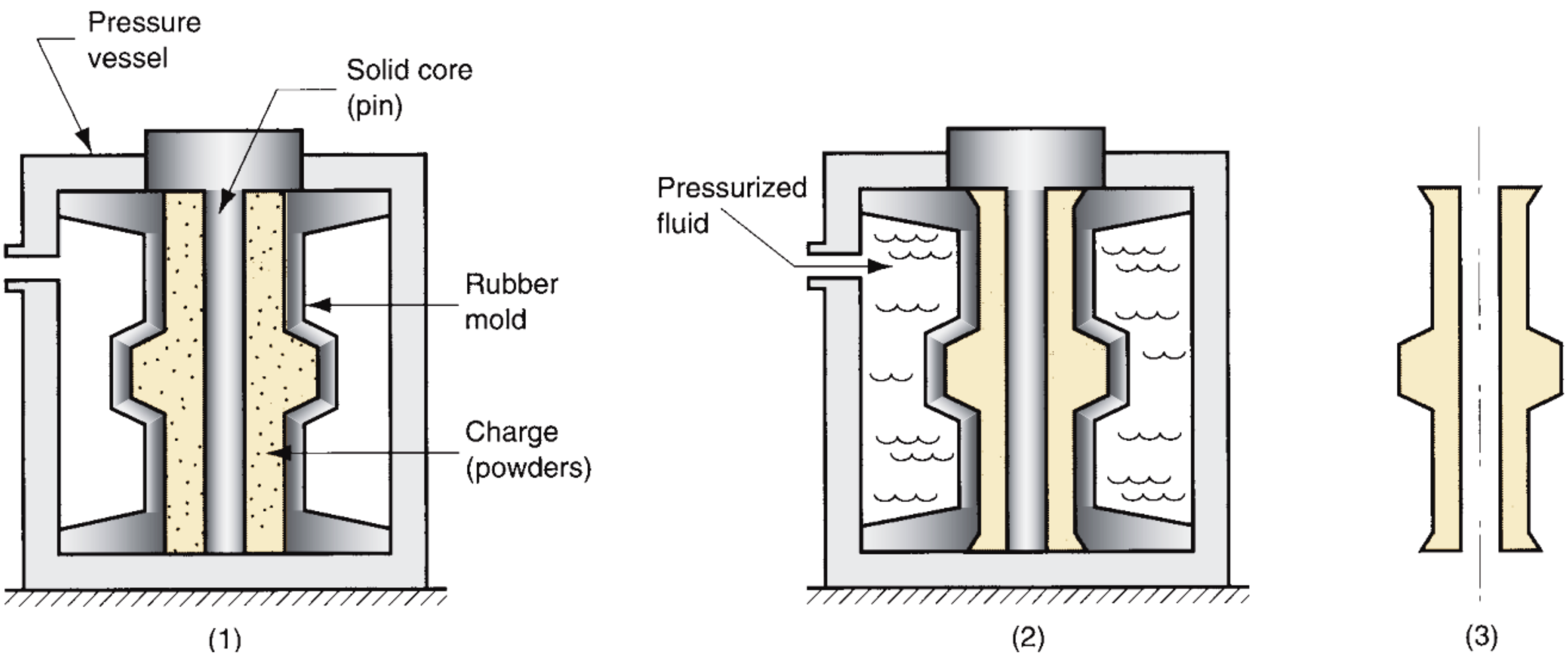
Compaction: Die-wall friction



Constant density lines in cylinders of compacted copper powder.

Koç, Muammer_ Özel, Tuğrul - Modern manufacturing processes-John Wiley & Sons (2019)

Compaction: Cold Isostatic Pressing



Cold isostatic pressing:
(1) powders are placed in the flexible mold;
(2) hydrostatic pressure is applied against the mold to compact the powders; and
(3) pressure is reduced, and the part is removed.

Sintering

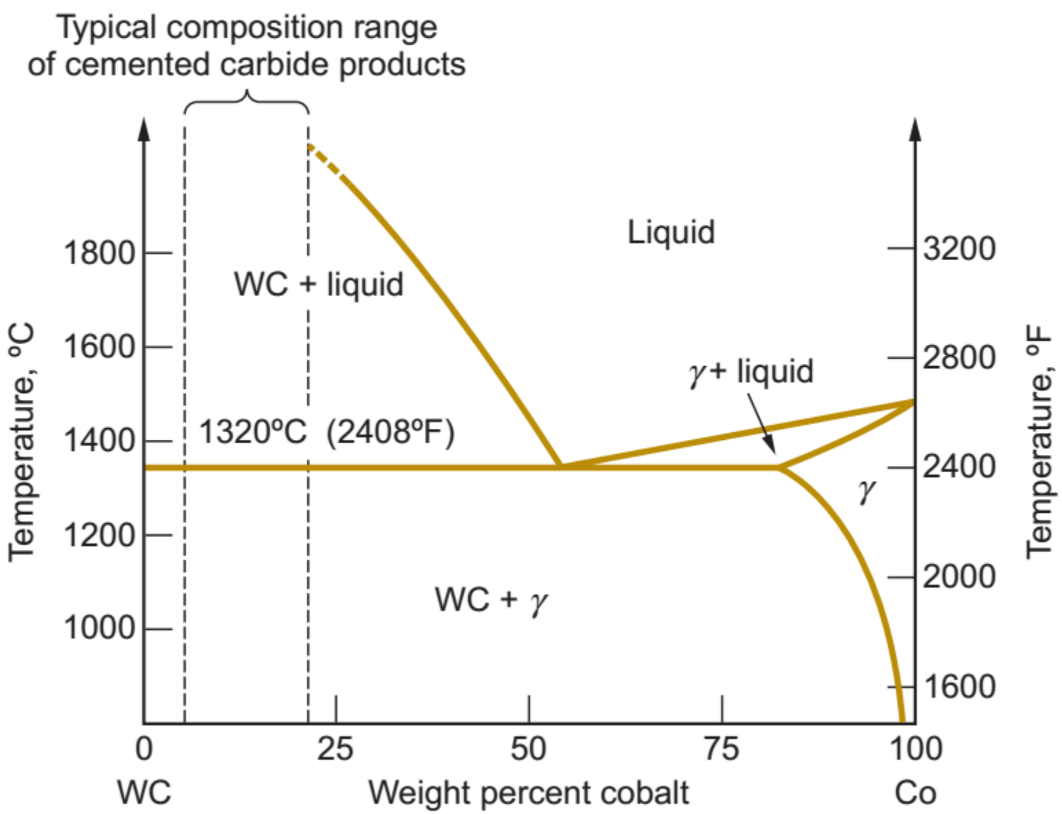
Sintering (Firing)

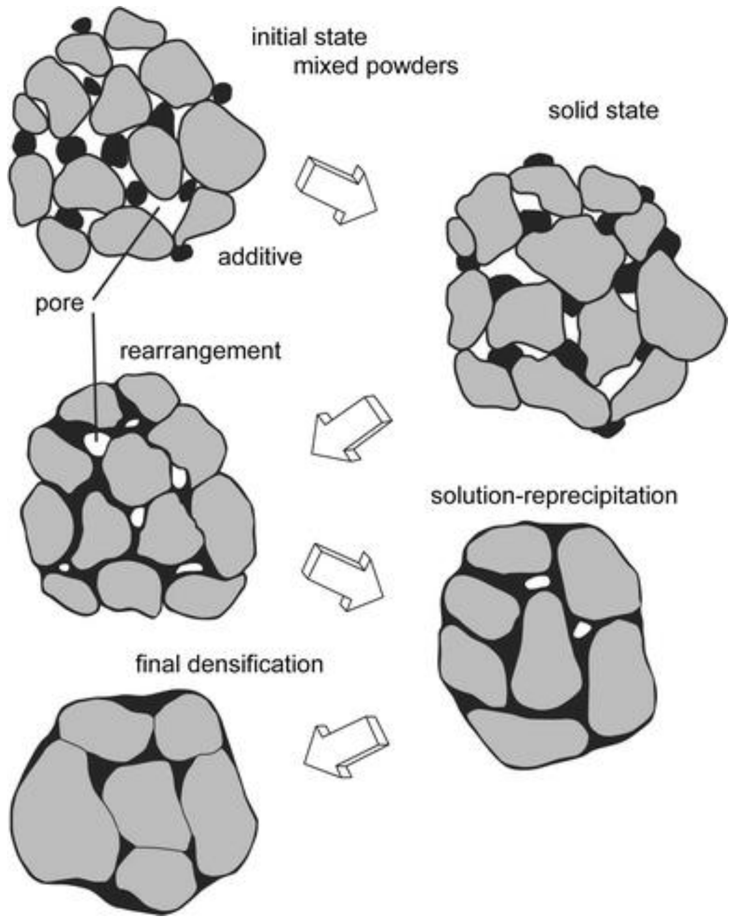
Solid phase sintering
(all in solid state)

Liquid phase sintering
(One is in liquid state)
eg: WC+Cu, Cu-Sn bearings

- It is an heat treatment process for attaining strength and density in the green compact
- Sintering - Green compacts are heated in a furnace to a temperature below melting point (0.7-0.9Tm)
- Improves the strength of the material
- Proper furnace control is important for optimum properties
- Part shrinkage occurs during sintering due to pore size reduction

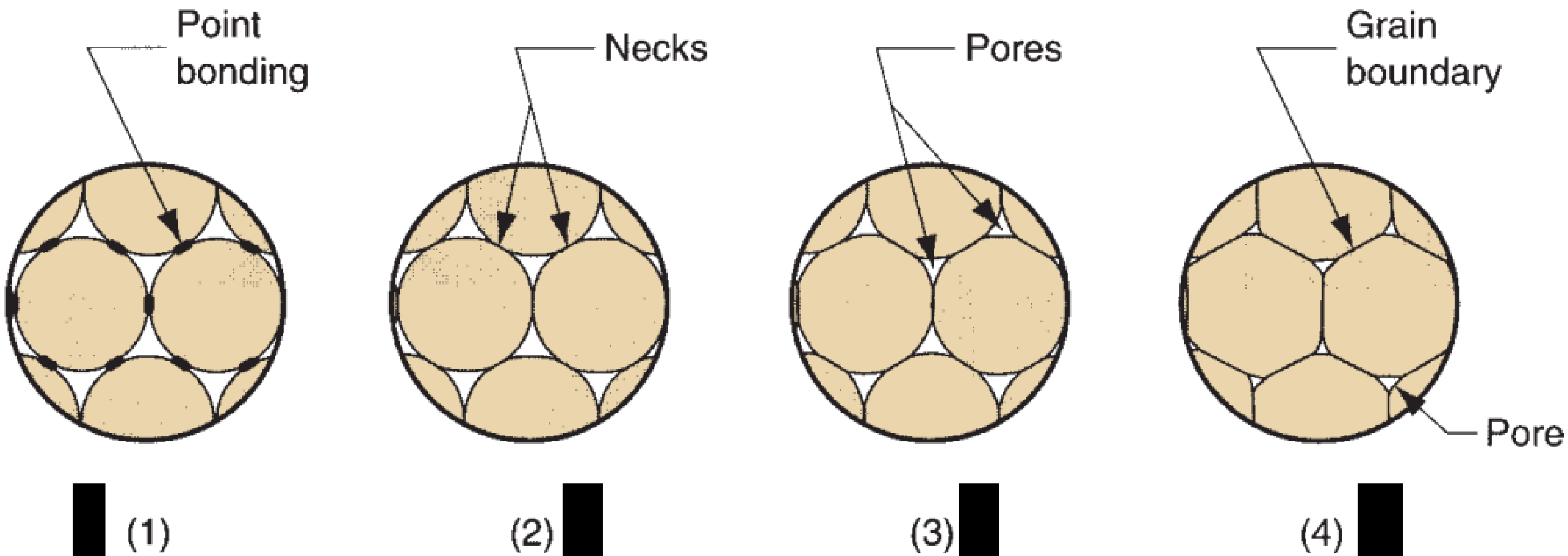
Liquid Phase sintering





German, R.M., Suri, P. & Park, S.J. Review: liquid phase sintering. *J Mater Sci* **44**, 1–39 (2009).

Solid State Sintering: Stages



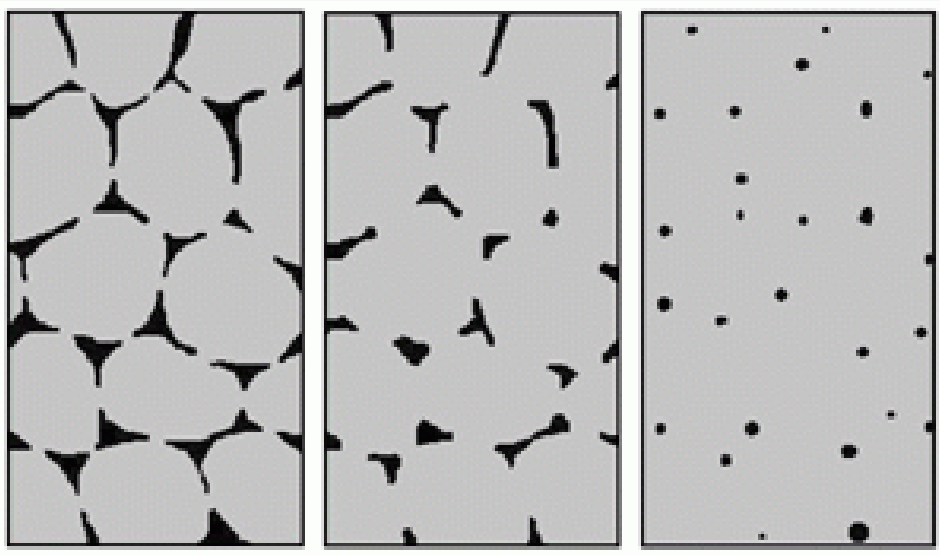
Particle bonding is initiated at contact points

Contact points grow into necks

Reduction in pore size

Grain boundaries develop between particle

Solid State Sintering: Stages



1. **Initial stage:**
   Formation of inter-particle neck
2. **Intermediate stage:**
   Transition occurs from open porosity to closed porosity. Typically, when the overall porosity in the compact is less than 8%, the pores are predominantly closed type
3. **Final stage:**
   Reduction/ elimination of closed pores.

Note that despite sintering at such high temperature, there is still some residual porosity

https://www.pm-review.com/introduction-to-powder-metallurgy/sintering-in-the-powder-metallurgy-process/

Pressure-assisted sintering

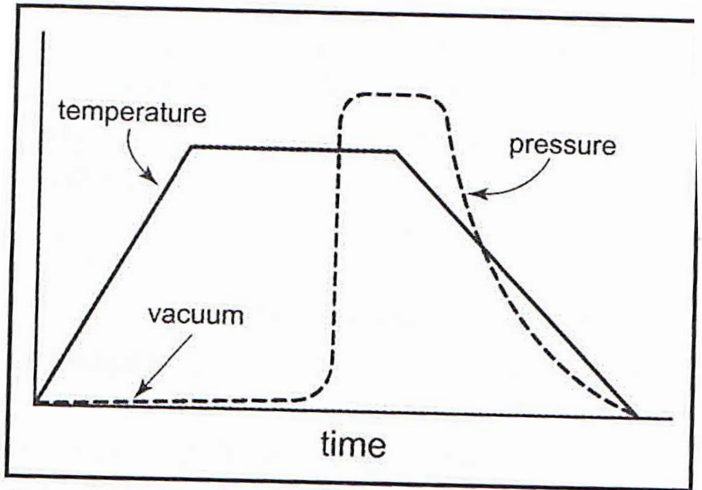


Figure 10.22. Pressure-assisted sintering uses an initial vacuum sintering cycle to reach the closed pore condition, such that subsequent pressurization pushes the evacuated pores closed.

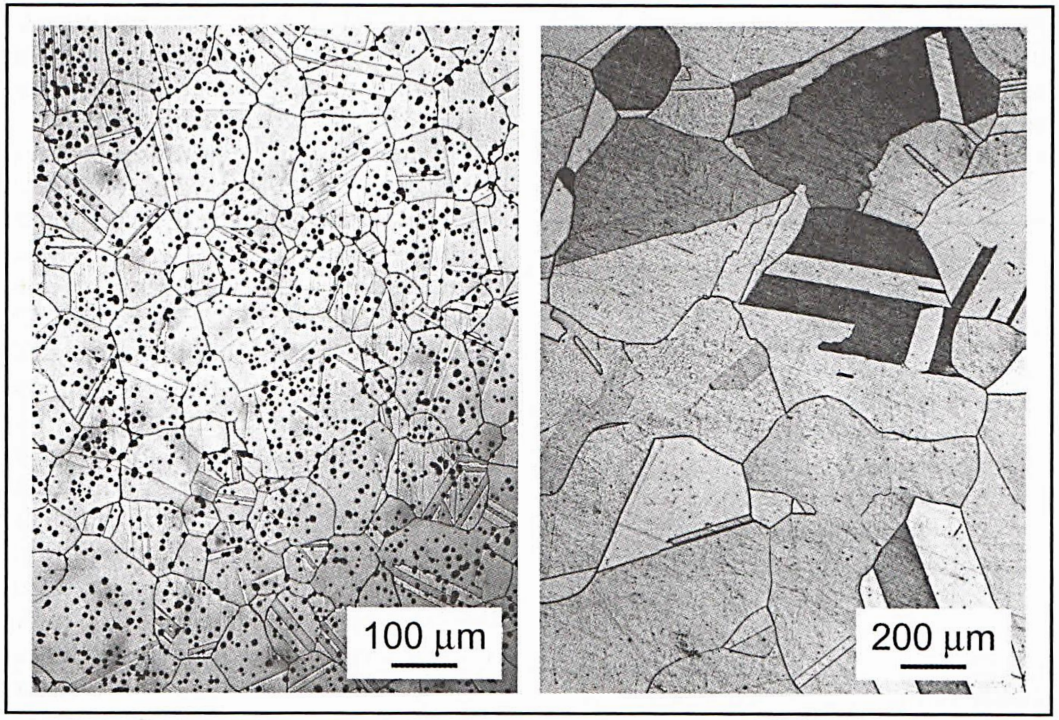
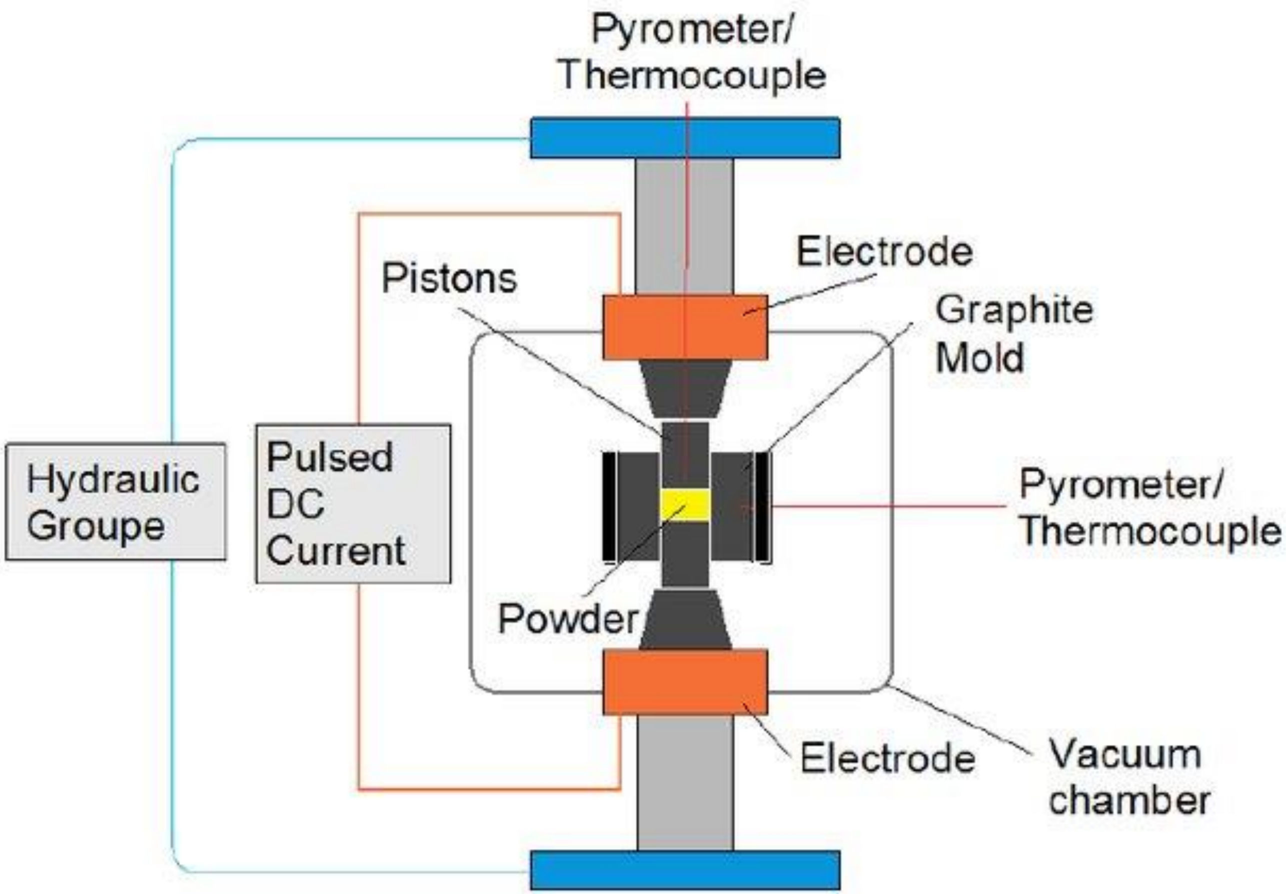


Figure 10.23. A nickel-iron powder compact sintered at 1410°C (2570°F) for 1 h to a closed pore condition at 95% density and then further densified by containerless hot isostatic pressing at 103 MPa (15 ksi) and 1200°C (2200°F) for 30 min with elimination of the pores and growth of the grains (micrographs courtesy of A. Bose and G. Camus).

Randall M. German - Powder Metallurgy & Particulate Materials Processing-Metal Powder Industry (2005)

Spark Plasma Sintering



Field and Pressure Assisted Sintering Technique

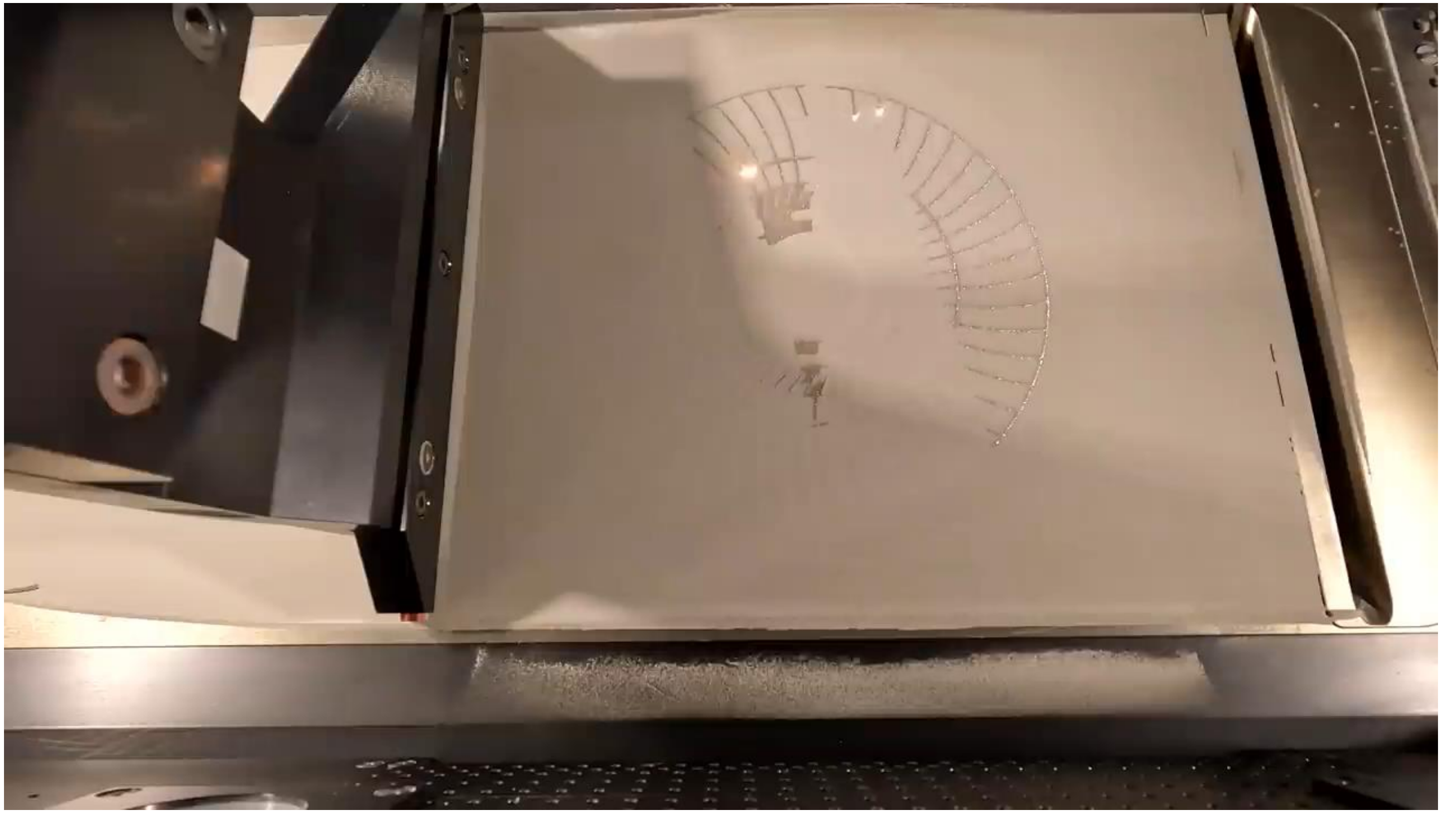
•DOI: [10.4028/www.scientific.net/MSF.834.41](https://doi.org/10.4028/www.scientific.net/MSF.834.41)

Powder Metallurgy

- Design principles to consider
  - Shape of the compact must be simple and uniform
  - Bulk production must be met
  - Provision must be made for the ejection of the part
  - Wide tolerances should be used whenever possible

- Limitations
  - High cost of equipment
  - Tooling cost for short production runs
  - Limitations on part size and shape
  - Mechanical properties of the part
    - Strength
    - Ductility

Freeform Fabrication: 3-D printing



https://www.youtube.com/watch?v=xM36RpcgcQc