Sintering and postprocessing

Calcination: Heating with decomposition
Annealing: Heating, usually homogenization or defect reduction
Sintering: heating with microstructure changes, densification, crystal growth

Driving force: reducing surface free energy

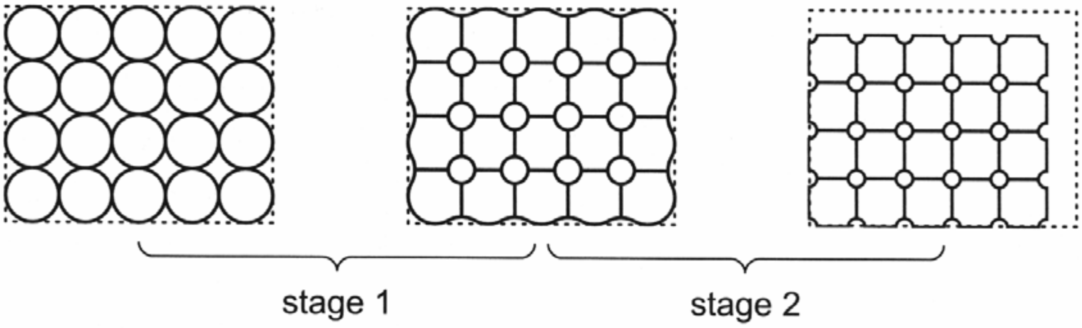


Figure 2-14. A two-dimensional sphere model illustrating the first two stages during sintering.

Sintering

Densification of a polycrystalline object close to, but below the melting point
(Molten phases may be present during the process.)

Shrinkage makes it difficult to prepare objects with a predefined shape and size.

If liquids are present they should be in minor amounts
The vitrification range is the temperature interval between liquid formation and "slumping" due to excess liquid. Should be as large as possible to avoid large shape changes.

Phase diagrams are important.

Avoid eutectics

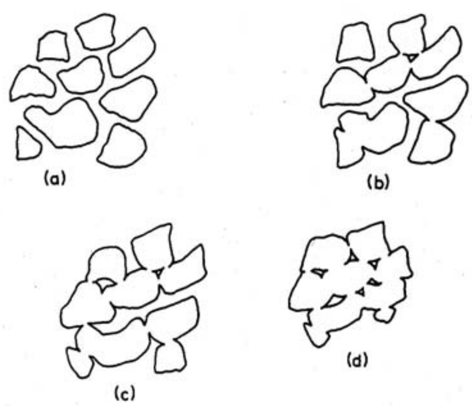


Fig. 20.1 Progressive stages of sintering, starting from (a) a loosely compacted powder to (b) the onset of contact between grains to (c) formation of a porous three-dimensional network of linked particles to (d) formation of a solid, non-porous piece with isolated pores. In the final stages (not shown), the isolated pores may be 'swept out' to the surface by grain growth

Sintering routes

•Reduce excess surface free energy
•A chemical potential difference between surfaces of different curvature.
•Mass transport from convex to concave surfaces. Grain growth

1)Evaporation-condensation (higher vapour pressure over a convex surface compared to a concave)
2)Diffusion (differences in vacancy concentration) Surface diffusion(a), grain boundary diffusion(b), volume diffusion(c)
3) Flow (pressure induced)
4) Dissolution-precipitation (liquid phase wetting the surface)

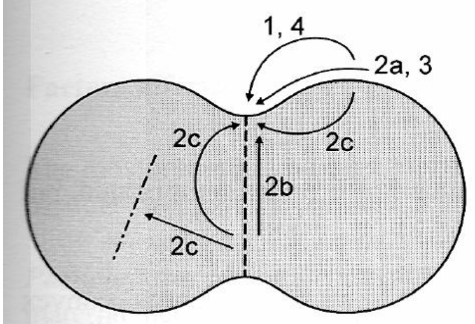


Figure 2-14. Diffusion paths during sintering. The numbers correspond to the numbers in the following paragraph.

Sintering

Surface properties:
Surface tension properties of crystals and liquids are important for sintering kinetics and slag attack.

Small grains: fast sintering (high surface area)

$$dD/dt = k/D$$

D: grain diameter, k: rate constant

Low dihedral angle:
Small amount of grain-grain contact
Large amount of liquid penetration between grains
Rapid grain growth, large crystals
Large dihedral angle:
Strong solid-solid contacts
Good hot strength
Resists slag attack

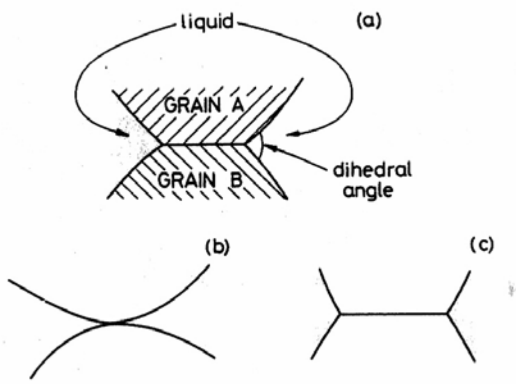
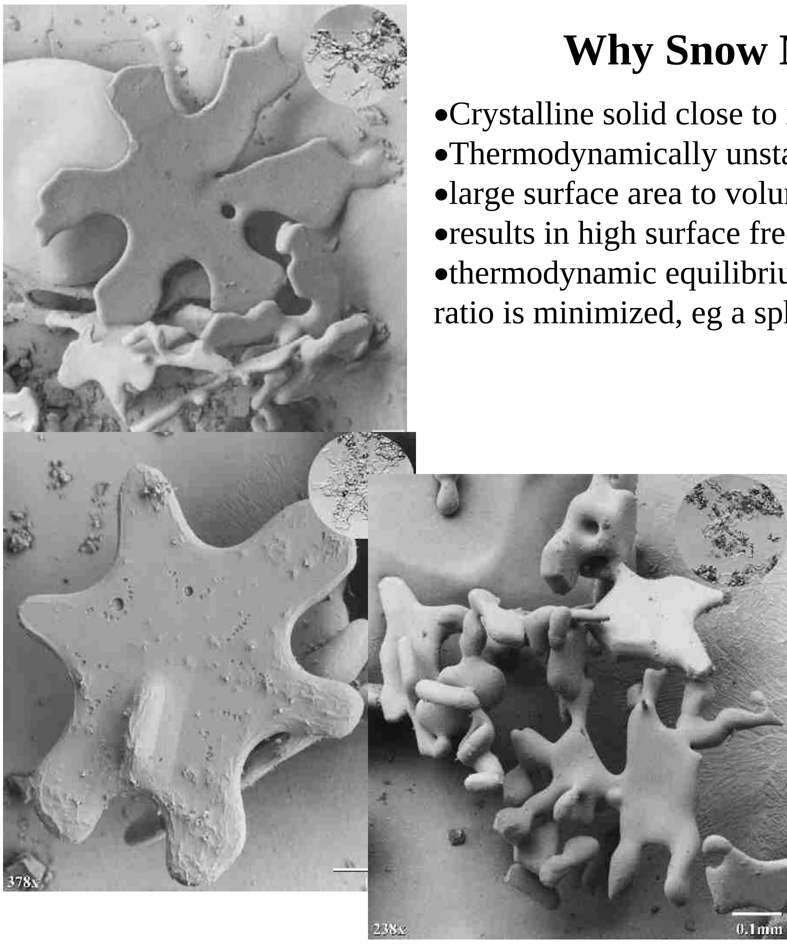


Fig. 20.2 The dihedral angle and its effect on the amount of grain-to-grain contact



Why Snow Metamorphsim Occurs

- Crystalline solid close to its melting temperature
- Thermodynamically unstable
- large surface area to volume ratio
- results in high surface free energy
- thermodynamic equilibrium occurs when surface to volume ratio is minimized, eg a sphere or rounded grain

Effects:
- **avalanche stability**
- **avalanche release**
- **melt-water runoff**
- **radiant-energy penetration into the snowpack**
- **release of solutes from the snowpack**

Sintering stages

Initial stage: Transport from high energy convex particle surfaces to concave surfaces, necks. Fusing, increased contact area. Pore volume and density remains almost constant (4-5% shrinkage, relative density 0.5-0.6)
Intermediate stage: Interparticle neck growth, grain boundary area increase, interparticle grain boundary flattens, pore diameters decrease. (5-20% shrinkage, relative density up to 0.95)
Final stage: isolated pores may remain at triple points or inside grain matrix. These pores may be gradually eliminated. (relative density > 0.95)

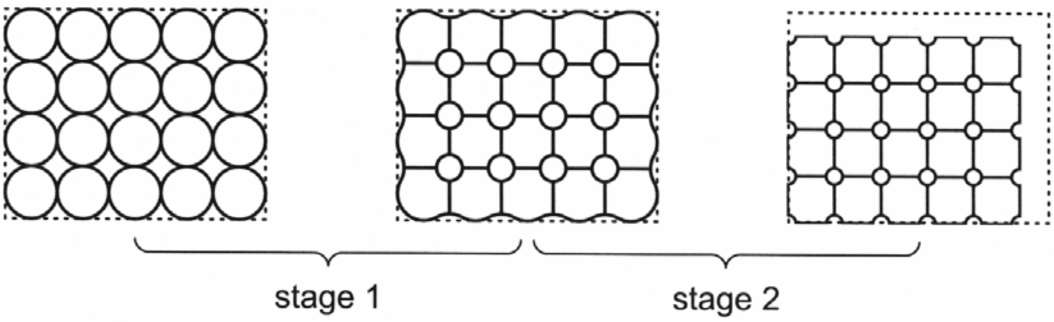


Figure 2-14. A two-dimensional sphere model illustrating the first two stages during sintering.

Factors influencing sintering

Particle size: Materials transport over smaller distances, higher surface energies. Larger grains grow at the expense of smaller ones. Coarsening of the grains.

Particle packing: Improves the number of ontact points between particles. Relative density increased. Faster densification, less volume shrinkage.

Particle shape: Irregular shaped particles with higher surface area/volume ratio, have a higher driving force for sintering. Particles that pack poorly sinter poorly

Ceramics processing

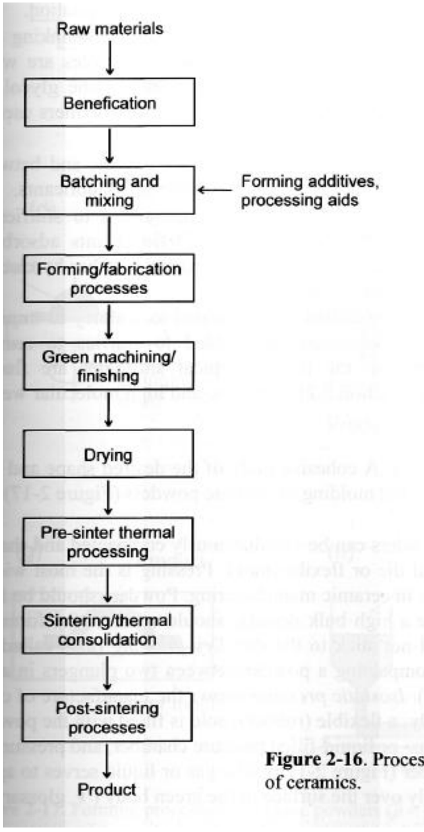


Figure 2-16. Processing steps in the fabrication of ceramics.

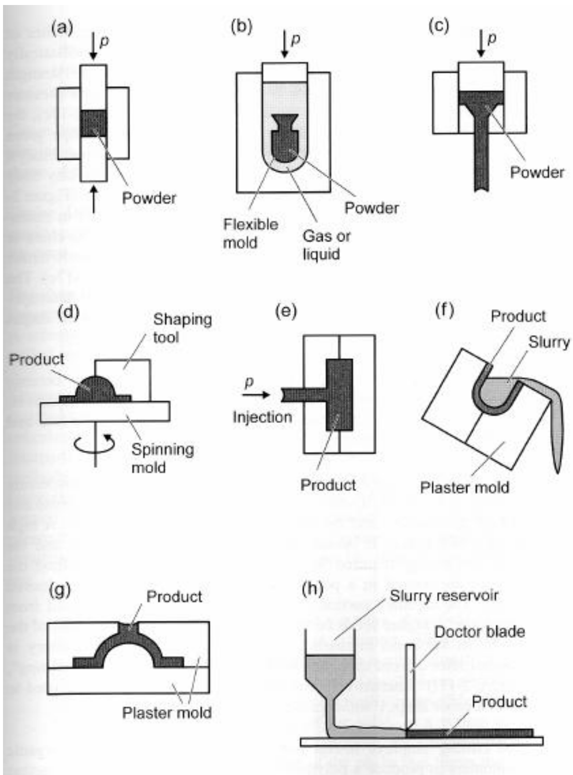


Figure 2-17. Forming processes of ceramic powders (p = pressure). (a) Dry pressing; (b) isostatic pressing; (c) extrusion; (d) jiggering; (e) injection molding; (f) drain casting; (g) solid casting; and (h) tape casting.