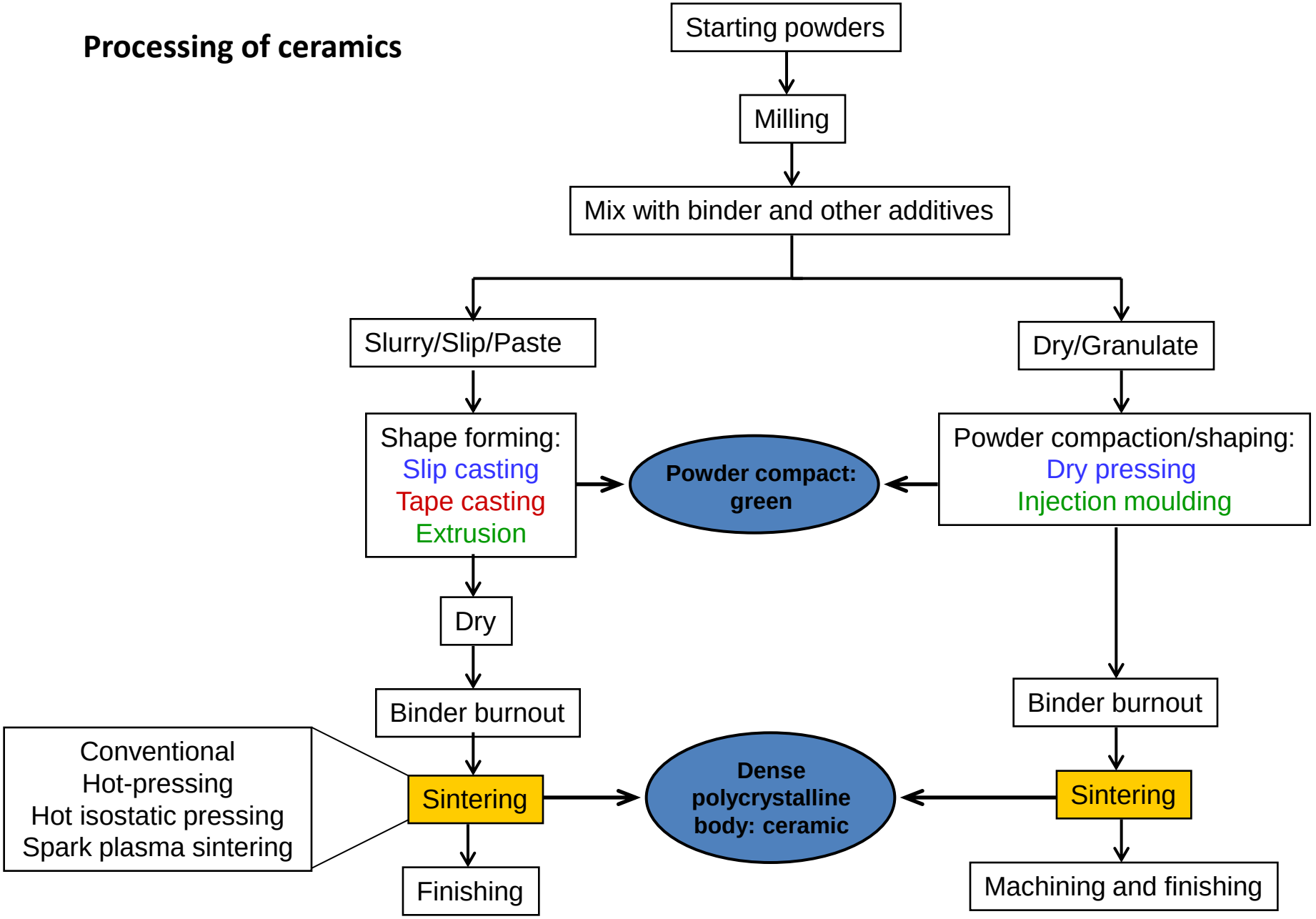
Processing of ceramics



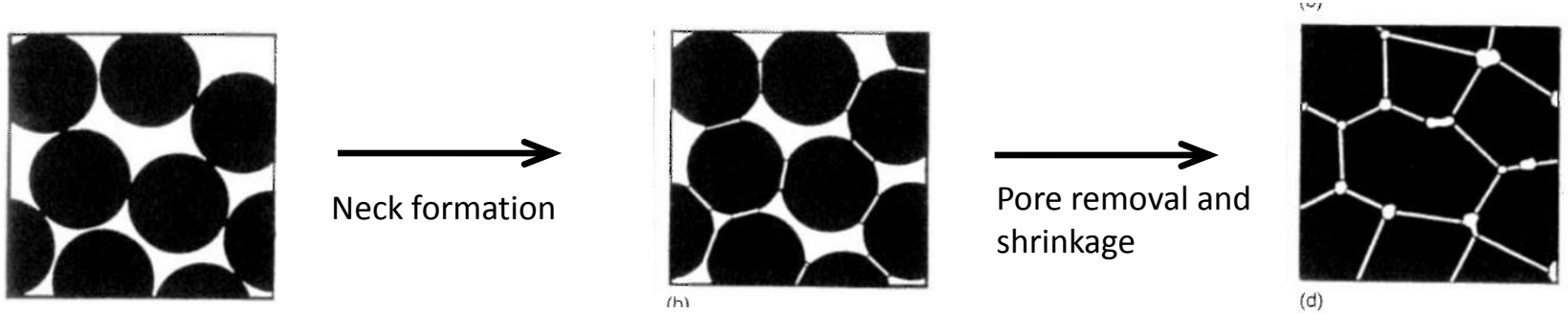
Sintering and grain growth

Sintering: removal of pores between particles accompanied by shrinkage (densification) and grain growth.

Types of sintering

Solid-state sintering (SSS)
only in high-purity compounds
Liquid phase sintering (LPS)
<20% liquid; impurities or specific additives
Viscous glass sintering or viscous flow (VGS)
Densification of glass powders
Viscous composite sintering or vitrification (VCS)
>20% liquid: whitewares, porcelains

Driving force for sintering: reduction of surface area and lowering of surface energy. High energy solid-gas surfaces are replaced by low energy solid-solid interfaces (grain boundaries). At microscopic level, the driving force is related to the difference in surface curvature and consequently of partial pressure and chemical potential between different parts of the system.

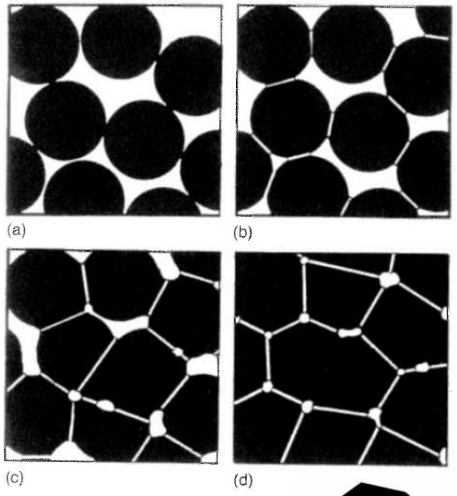


Effect of **particle size**: the smaller the particles, the higher the radius of curvature and the chemical potential → higher sintering rate.

Sintering and grain growth

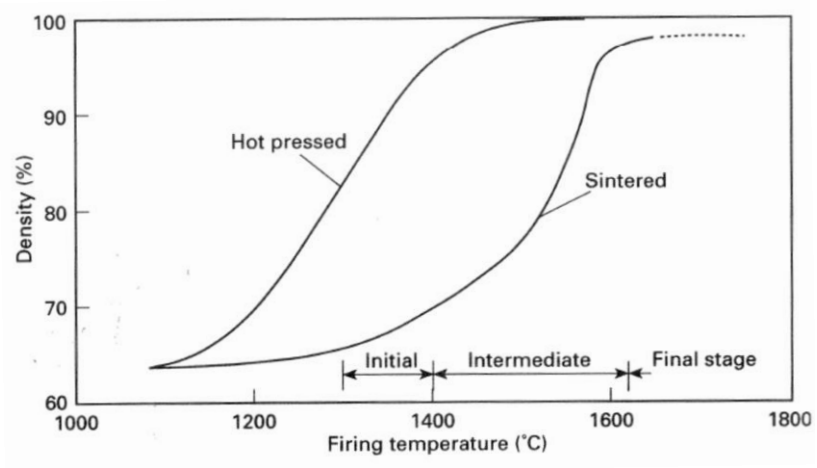
Stages of sintering

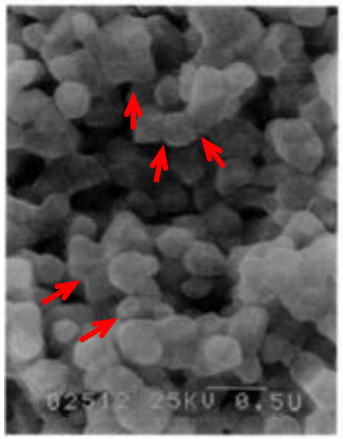
(a, b) Initial stage sintering. Formation of strong bonds and necks between particles at the contact points. Moderate decrease of porosity (initial 40-50%) from particle rearrangement.
(c) Intermediate stage sintering. The size of the necks increases and the amount of porosity decreases. The sample shrinks (the centers of the grains move towards each other. The grains transforms from spheres to truncated octahedra (tetrakaidecahedra). This stage continues until pores are closed (r.d. 90%).
(d) Final stage sintering. Pores are slowly eliminated and major grain growth can occur.



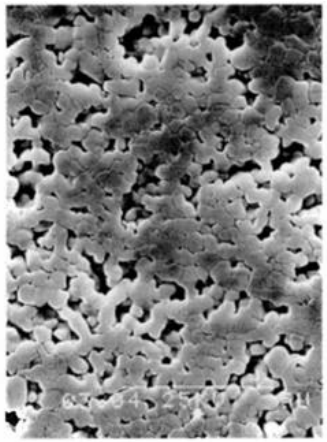
tetrakaidecahedron
6s+8h faces

In hot-pressing and hot isostatic pressing an additional driving force is provided by the external stress/pressure.

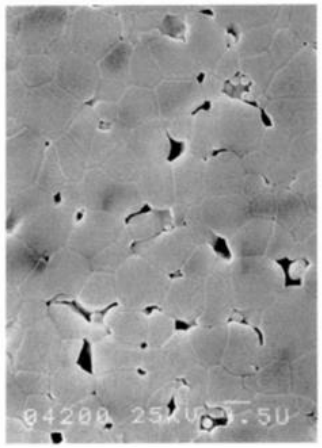




Initial stage



Intermediate stage



Final stage

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