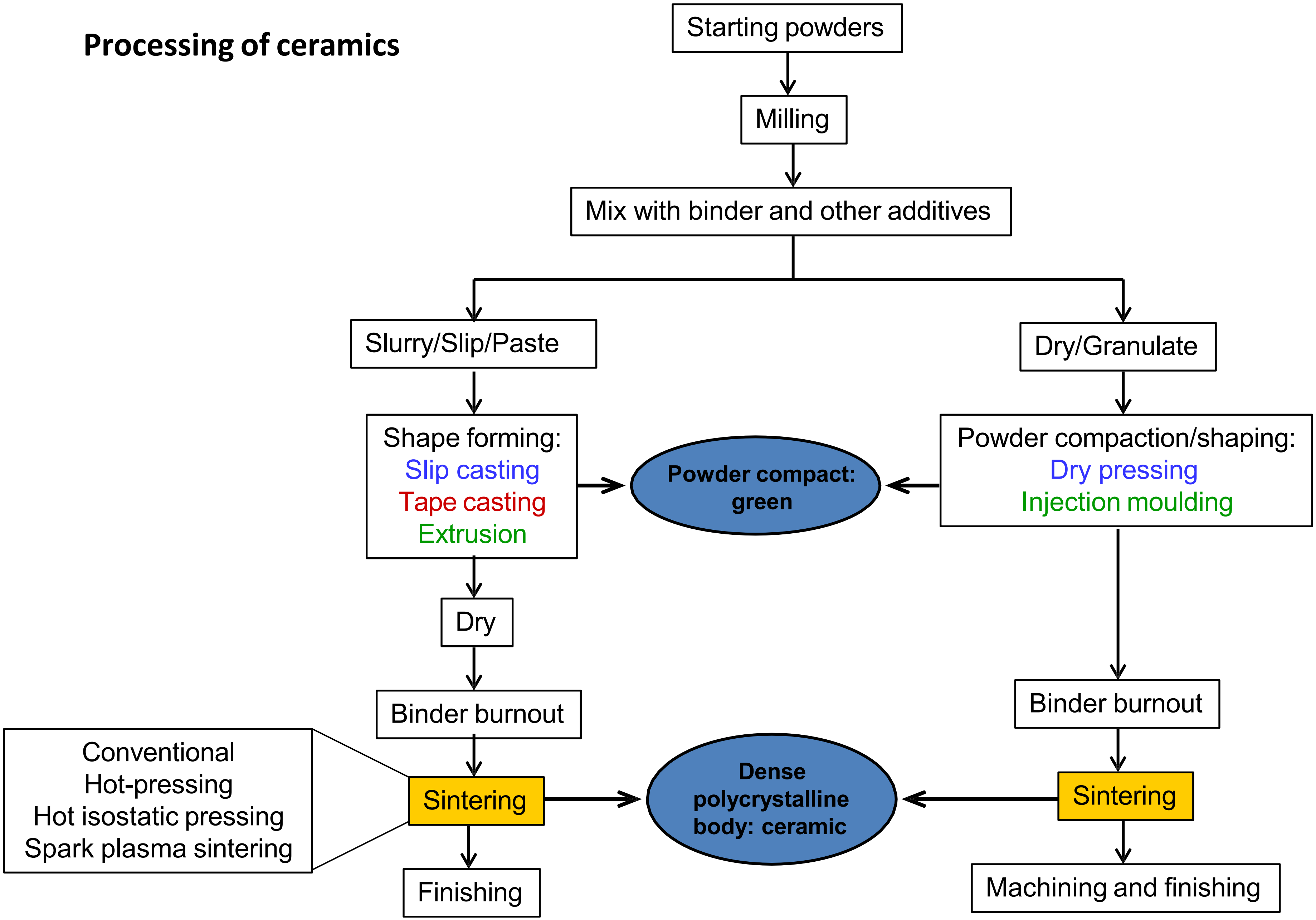
Processing of ceramics



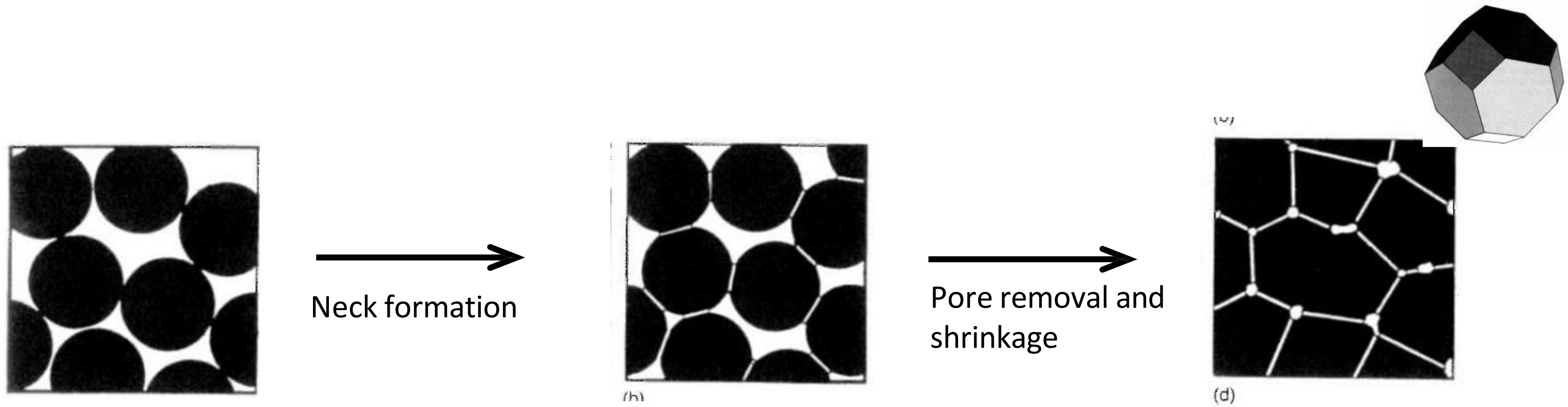
SINTERING OF CERAMICS

Sintering: In ceramic manufacturing, it is the process of subjecting powdered raw material (a compacted "green body") to high temperatures below its melting point.
Purpose: To reduce the porosity (voids) of the material, increase its density, mechanical strength, and hardness by forming atomic bonds between grain boundaries.
Result: Powder particles bond together, the material shrinks, and becomes a solid, cohesive mass.

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.

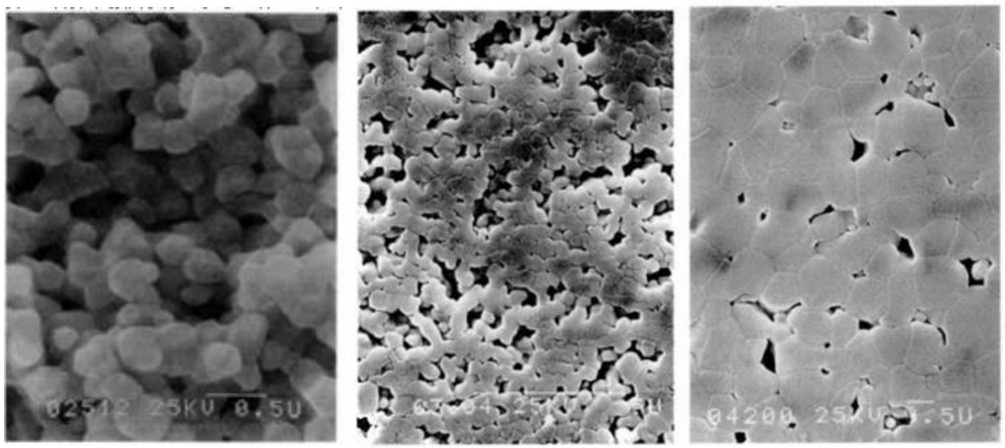
Types of Sintering

Type	Mechanism	Application
1. Solid-State Sintering	Diffusion of atoms within the solid phase at high temperature.	Pure oxide ceramics (Alumina, Zirconia) and powdered metal parts.
2. Liquid-Phase Sintering	A low-melting-point phase melts at high temperatures, surrounding particles and filling voids.	Ceramic-metal composites (cermets), cemented carbides.
3. Reaction Sintering	Bonding occurs through the formation of a new phase resulting from a chemical reaction between powder particles.	Complex ceramics such as Silicon Nitride (Si_3N_4).
4. Pressure-Assisted Sintering	Applying mechanical pressure externally along with high temperature.	Parts requiring very high density (close to theoretical density). (E.g.: Hot Pressing/HP, Spark Plasma Sintering/SPS)



Stages	Key Process	Structural Change
1. Initial Stage	Surface diffusion begins.	Necks start to form between contacting particles. Density increase is negligible.
2. Intermediate Stage	Volume diffusion and grain boundary diffusion accelerate.	Pores start to shrink and become isolated. Grain boundaries move. A significant increase in density is observed.
3. Final Stage	Remaining isolated pores become entrapped at grain boundaries and shrink.	The remaining isolated pores reduce in size and are eliminated. Density approaches its maximum.

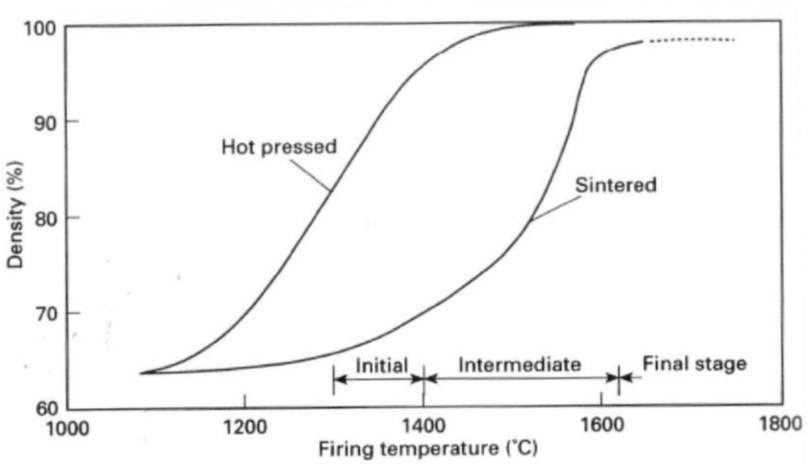
Effect of **particle size**: the smaller the particles, the higher the radius of curvature and the chemical potential → higher sintering rate.



Initial stage

Intermediate stage

Final stage



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

Parameter	Effect	Control Method
1. Temperature	Determines the diffusion rate and bonding strength.	Furnace temperature control system.
2. Time (Dwell)	The necessary duration for atomic bonding and reduction of porosity.	Furnace program.
3. Initial Powder Size	Smaller particles require less sintering temperature/time due to greater surface area.	Grinding and sieving processes.
4. Green Density	The initial density of the compacted part.	Pressing force and method (isostatic pressing, etc.).
5. Atmosphere	Influences oxidation/reduction reactions and grain growth.	Use of Air (Oxidizing), Vacuum, or Inert Gas (Neutral/Nitrogen, Argon).