Ceramic processing

• The higher performance of ceramics is the result of strict control of purity, composition, microstructure and processing.

• Because of their inherent brittleness, ceramics cannot be formed by rolling, extrusion, drawing etc…

• Their high melting temperatures also add restrictions on the use of casting techniques

• Processing of ceramics takes place through POWDER METALLURGY (PM) techniques.

Processing of ceramics generally takes place in four steps:

- Powder processing (raw materials)
- Forming
- Sintering (firing)
- Finishing: (painting, electroplating), densification & sizing, heat treatment (hardening and strengthening)

• Sintering has the greatest effect on the properties and is subject to the greatest amount of control.

1. Powder Processing/ materials preparation

• The characteristics and condition of the starting raw powders and the manner in which they are treated prior to sintering affect the final outcome of these techniques.

• Characteristics of powders include: particle size, shape, size distribution, degree of segregation and agglomeration

• Finer and homogeneous particles are preferred.

• Preparation of the starting powders include crushing and grinding to the desired size range and chemically treated to separate phases and compounds and to achieve specified purity.
2. Forming

- The powder is consolidated into a compact by shaping in a mould/die with the application of pressure (cold compaction) and/or heat (hot compaction).

- Water and/or plasticisers are added to allow the paste to be formed into the desired shape.

- Common forming methods include:
  - Pressing
  - Slip casting
  - Tape casting
  - Injection moulding

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**Slip Casting**

A slip is a suspension of clay and/or other nonplastic materials in water.

1. Preparation of a powdered ceramic material and a liquid (usually clay and water) into a stable suspension called a slip.
2. Pouring the slip into a porous mold usually made of plaster of paris and allowing the liquid portion of the slip to be partially absorbed by the mold. As the liquid is removed from the slip, a solid layer is formed against the mold surface.
3. When the sufficient wall thickness has been formed, the casting process is interrupted and the excess slip is poured out of the cavity (Drain casting).
4. The material in the mold is allowed to dry to provide adequate strength for handling and the subsequent removal of the part from the mold.
Advantages of slip casting:
- Produced uniform thickness for complex shapes
- Economic to develop parts with short production runs.

Tape Casting

- Thin sheets of a flexible tape are produced by casting. These sheets are prepared from slips. This slip contains a suspension of ceramics particles in an organic liquid that also contains binders and plasticizers to enhance strength and flexibility to cast.

Tape Casting

- Thin sheets of green ceramic cast as flexible tape
- Used for integrated circuits and capacitors
- Cast from liquid slip (ceramic + organic solvent)
Glass forming:
Glass is produced by heating the raw materials to an elevated temperature, above melting point.

Press-and-blow technique for glass bottle forming
1. A raw gob of glass, a parison or temporary shape is formed by mechanical pressing in a mold.
2. This piece is inserted into a finishing or blow mold and forced to conform to the mold contours by the pressure created from a blast of air.

Drying and Firing
• Drying: layer size and spacing decrease.
• Firing: liquid glass forms from clay and flows between SiO₂ particles. Flux melts at lower T.

Factors of green ceramic affecting the sintering process:
Composition of powders
Green density
Pore content (size, shape and distribution)
Particle size, shape and distribution
Extent of mixing (multi-component ceramics)

3. Powder Sintering
After forming, the “green” ceramic undergoes a sintering or firing process to produce a strong final product
• The driving force for sintering is the reduction in surface energy of the powder particles

Sintering: useful for both clay and non-clay compositions.
• Procedure: produce ceramic and/or glass particles by grinding
  -- place particles in mold
  -- press at elevated T to reduce pore size.
Aluminum oxide powder:
-- sintered at 1700 °C for 6 minutes.
The 3 stages in the sintering process

- Initial bonding
- Contact points grow into necks
- Grain boundary development

Microstructure development during sintering: (a) loose particles, (b) Initial stage, (c) Intermediate stage, (d) Final stage

CEMENTATION

- Produced in extremely large quantities.
- Portland cement:
  - mix clay and lime bearing materials
  - calcinate (heat to 1400°C)
  - primary constituents:
    - tri-calcium silicate, $3\text{CaO} \cdot \text{SiO}_2$
    - di-calcium silicate, $2\text{CaO} \cdot \text{SiO}_2$
- Adding water
  - produces a paste which hardens
  - hardening occurs due to hydration (chemical reactions with the water).
- Forming: done usually minutes after hydration begins.
**Heat Engines**

- **Advantages:**
  - Run at higher temperature
  - Excellent wear & corrosion resistance
  - Low frictional losses
  - Ability to operate without a cooling system
  - Low density
  - Possible parts – engine block, piston coatings, jet engines
    Ex: $\text{Si}_3\text{N}_4$, $\text{SiC}$, & $\text{ZrO}_2$

- **Disadvantages:**
  - Brittle
  - Too easy to have voids- weaken the engine
  - Difficult to machine

**Applications: Advanced Ceramics**

**Electronic Packaging**

- Chosen to securely hold microelectronics & provide heat transfer
- Must match the thermal expansion coefficient of the microelectronic chip & the electronic packaging material. Additional requirements include:
  - good heat transfer coefficient
  - poor electrical conductivity
  - Materials currently used include:
    - Boron nitride (BN)
    - Silicon Carbide (SiC)
    - Aluminum nitride (AlN)
  - Good materials include:
    - thermal conductivity 10x that for Alumina
    - Good expansion match with Si

**Summary**

- Basic categories of ceramics:
  - glasses
  - clay products
  - refractories
  - cements
  - advanced ceramics
- Fabrication Techniques:
  - Glass forming (impurities affect forming temp).
  - Particulate forming (needed if ductility is limited)
  - Cementation (large volume, room $T$ process)
- Heat treating: Used to
  - Alleviate residual stress from cooling.
  - Produce fracture resistant components by putting surface into compression.