BFF1113
Engineering Materials

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Course Guidelines:

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

1. Introduction to Engineering Materials
2. Bonding and Properties
3. Crystal Structures & Properties
4. Imperfection in Solids
5. Mechanical Properties of Materials
6. Physical Properties of Materials
7. Failure & Fundamental of Fracture
8. Metal Alloys
9. Phase Diagram
10. Phase Transformation – Heat Treatment
11. Processing and Application of Metals
12. <u>Ceramic Materials</u>
13. Polymer Materials
14. Composite Materials
15. Corrosion & Degradation of Materials
16. Environment and Sustainability

Ceramic

Chapter Outline

1. **Introduction**
2. **Types of Ceramics**
   a) **Oxide Ceramic**
   b) **Silicate Ceramic (Silica Glass)**
   c) **Carbon-based Ceramic**
   d) **Carbide Ceramic**
   e) **Nitride Ceramic**
3. **Properties & Application of Ceramics**
4. **Ceramic Fabrication Method**

1.0: Introduction

Ceramics:

- Keramikos - burnt stuff in Greek -> desirable properties of ceramics are normally achieved through a high-temperature heat treatment process (firing).
- Usually a compound between metallic and non-metallic elements.
- Always composed of more than one element (e.g.,Al_2O_3, NaCl, SiC, SiO_2)
- Interaction bond either totally ionic or having some covalent character

General Properties:

- Generally hard and brittle
- Generally electrical and thermal **insulators** (exceptions: graphite, diamond, AlN… and others)
- Can be optically opaque, semi-transparent, or transparent
- High chemical stability and high melting temperature.

Ceramic

- Divided into 2 categories:

Traditional ceramics:
- primary raw materials is clay.
- example: porcelain, bricks, tiles, glasses.




Industrial / Engineering ceramics:
- new generation of ceramic.
- example: oxygen sensor, electro-ceramic, high
ceramic, advance cer



Oxide Ceramics

- 2 major types of oxide ceramics: alumina and zirconia

Alumina

- Also known as Aluminium oxide (Al_2O_3), most widely used *oxide ceramic.*
- High hardness and moderate strength
- Used for electrical and thermal insulation and in cutting tools and abrasives

Zirconia **(zirconium oxide, Zr_2O)**

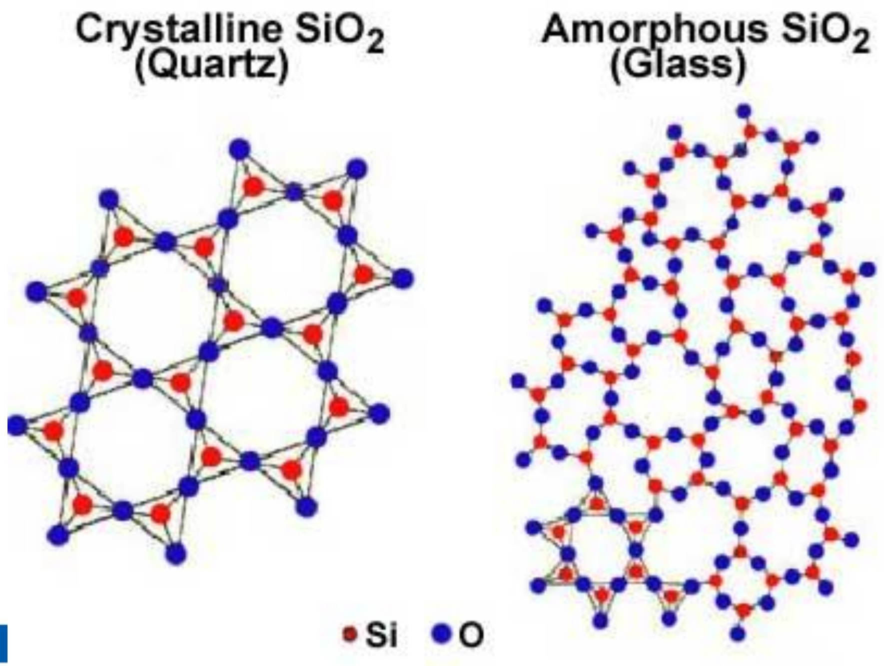
- Has good toughness, good resistance to thermal shock, wear, and corrosion, low thermal conductivity and a low friction coefficient
- Used for dies for the hot extrusion of metals and zirconia beads

Silicate Ceramics

- **Silicates** primarily composed of Si & O ; two most abundant elements in the earth's crust.
- The bulk of soils, rocks, clays, and sand come under the silicate classification.
- The most simple silicate material is Silicon Dioxide, or known as **Silica (SiO_2)**

GLASS

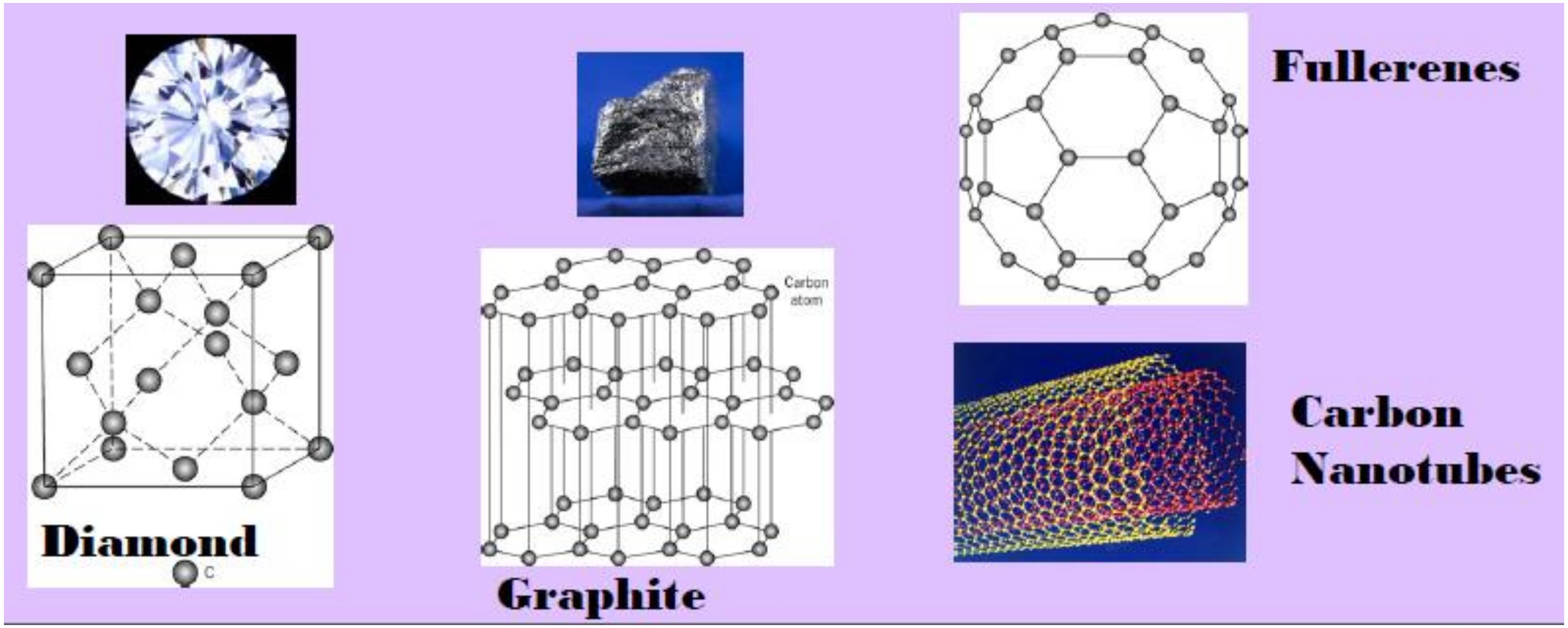
- **Glass** is a solid substance, with an amorphous (non-crystalline) structure, contain at least 50% silica.
- Physically hard, brittle, has resistance to electricity and heat transmission as ceramics, but usually transparent.
- Glass has a smooth, non-porous surface which is resistant to chemical attack.



The color in the glass can be obtained by adding small amounts of oxide and chromium (green), cobalt (blue), nickel (purple or brown) and selenium (red). The amber color is obtained with iron, sulfides and carbon.

Carbon-based Ceramics

Diamond
Graphite
Carbon nanotubes



Diamond

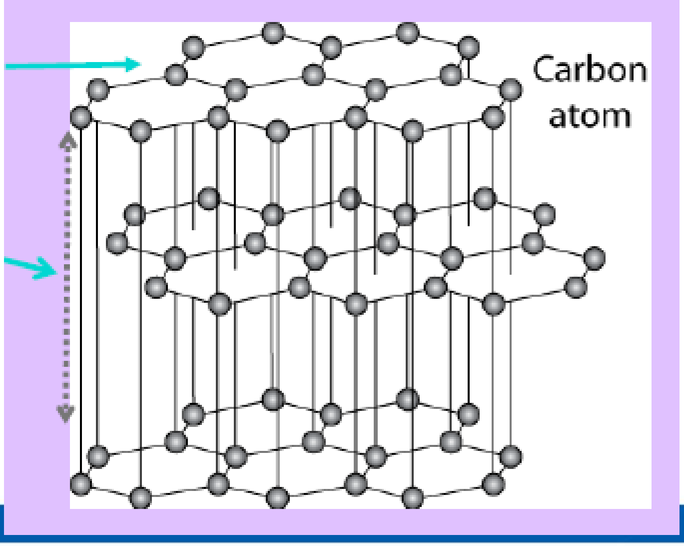
- **Diamond** is a principal form of carbon with a covalently bonded structure
- Extremely hard, low electrical conductivity, high thermal conductivity.
- Transparent to visible light
- Has numerous important applications:
  1. Cutting-tool materials
  2. Abrasives in grinding wheels
  3. Dressing of grinding wheels
  4. Dies for drawing wire
  5. Coatings for cutting tools and dies

Graphite

- *Graphite* is a crystalline form of carbon having a *layered structure* with close-packed carbon atoms
- More stable than diamond at ambient temperature and pressure
- It is weak when sheared along the layers
- It is brittle, has high electrical and thermal conductivity and good resistance to thermal shock

Strong covalent bond of carbon with three coplanar neighbors

weak van derWaal's forces between layers



Graphite

Properties:

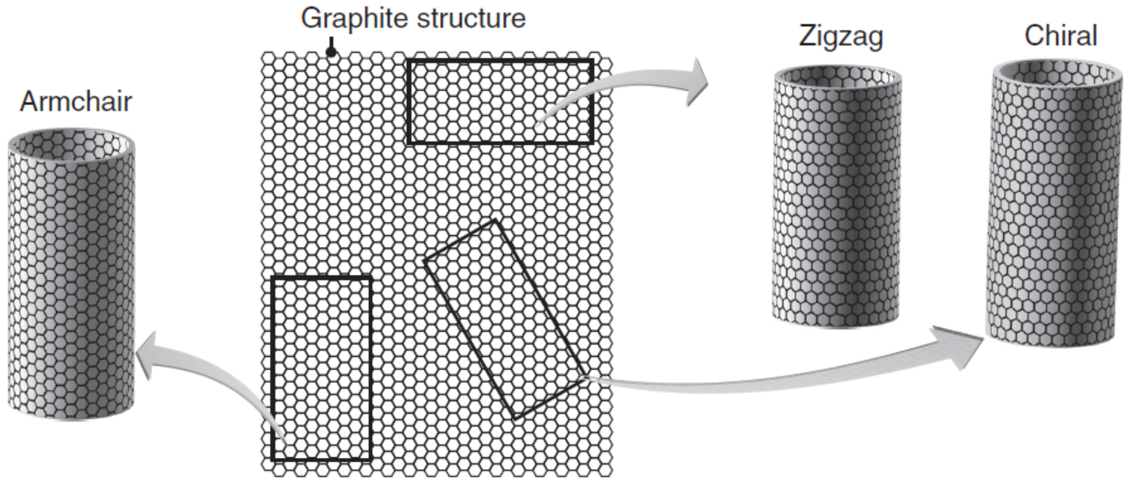
- Good electrical conductivity parallel to the hexagonal sheets
- High strength
- good chemical stability at high temperature and in non-oxidising atmosphere
- high melting point
- high thermal conductivity
- High resistance to thermal shock
- High absorption of gasses
- Good machinibality

Applications:

- Heating element for electrical furnaces
- Electrodes for arch welding
- Crucibles in metallurgical processes
- High temperature refectories
- Insulation and rocket nozzles
- Brushes and resistors
- Electrodes in batteries

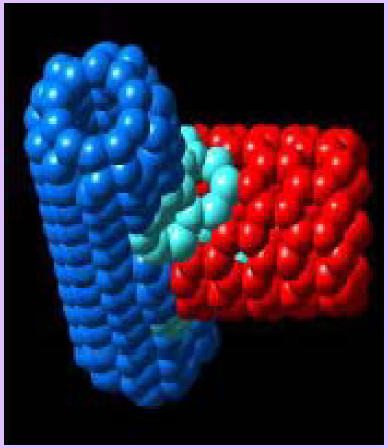
Carbon Nanotubes

- Carbon nanotubes is tubular forms of graphite to implement in nanoscale devices
- Have high strength, to make into a reinforcing fiber for composite materials
- They have very high electrical current carrying capability, which can be made as semiconductors or conductors

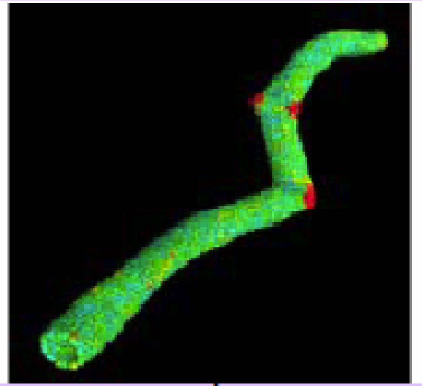


Carbon Nanotubes

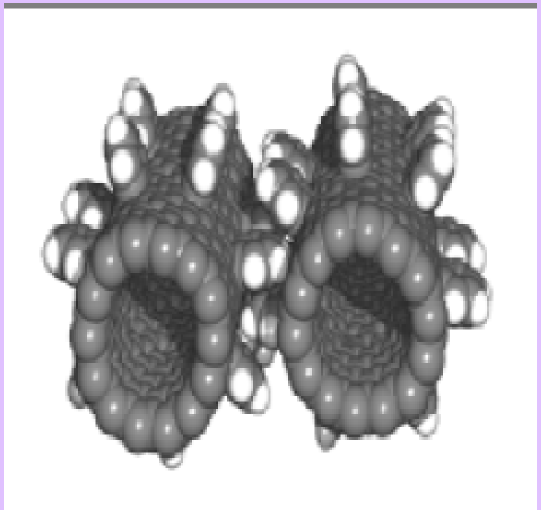
carbon nanotubes are expected to play an important role in future ***nanotechnology*** applications (nanoscale materials, sensors, machines, and computers)



Carbon nanotube T-junction



C nanotube as reinforcing fibre in nanocomposite



carbon nanotube gear

Properties:

- Have tensile strength 20 times than that of the strongest steel
- High elastic modulus
- Low density, conduct electricity, high heat conductivity

Carbide Ceramics

- Made of tungsten, titanium and silicon
- Examples of carbides:
  1. Tungsten carbide (WC)
  2. Titanium carbide (TiC)
  3. Silicon carbide (SiC)

Nitride Ceramics

1. Cubic boron nitride (cBN)
2. Titanium nitride (TiN)
3. Silicon nitride (SiN)

3.0: General Properties and Applications of Ceramics

- Ceramics is brittle, has high strength and hardness at elevated temperatures, but low thermal and electrical conductivity
- They are sensitive to flaws, defects, and surface or internal cracks - Crack growth through grains
- Failed by brittle fracture - without the formation of necking or any plastic deformation
- The process of brittle fracture consist of the formation and propagation of cracks through the cross section of material in a direction perpendicular to the applied load.

Mechanical Properties

- Table shows mechanical properties of engineering ceramics

Properties of Various Ceramics at Room Temperature

Material	Symbol	Transverse rupture strength (MPa)	Compressive strength (MPa)	Elastic modulus (GPa)	Hardness (HK)	Poisson's ratio, ν	Density (kg/m^3)
Aluminum oxide	Al_2O_3	140–240	1000–2900	310–410	2000–3000	0.26	4000–4500
Cubic boron nitride	cBN	725	7000	850	4000–5000	—	3480
Diamond	—	1400	7000	830–1000	7000–8000	—	3500
Silica, fused	SiO_2	—	1300	70	550	0.25	—
Silicon carbide	SiC	100–750	700–3500	240–480	2100–3000	0.14	3100
Silicon nitride	Si_3N_4	480–600	—	300–310	2000–2500	0.24	3300
Titanium carbide	TiC	1400–1900	3100–3850	310–410	1800–3200	—	5500–5800
Tungsten carbide	WC	1030–2600	4100–5900	520–700	1800–2400	—	10,000–15,000
Partially stabilized zirconia	PSZ	620	—	200	1100	0.30	5800

Note: These properties vary widely depending on the condition of the material.

Applications of Ceramics:

EXAMPLE 1

Ceramic Gun Barrels

- Wear resistance and low density of ceramics
- Zirconia chosen due to high toughness, flexural strength, specific heat, operating temperature, and very low thermal conductivity
- Barrel is wrapped with a carbon fiber / polymer-matrix composite to improve tensile stresses developed during firing

EXAMPLE 2

Ceramic Knives

- Made of zirconium oxide
- Advantages ceramic knives:

1. High hardness and wear resistance
2. Chemically inert, do not stain
3. Lightweight and are easier to use

EXAMPLE 3

Ceramic Ball and Roller Bearings

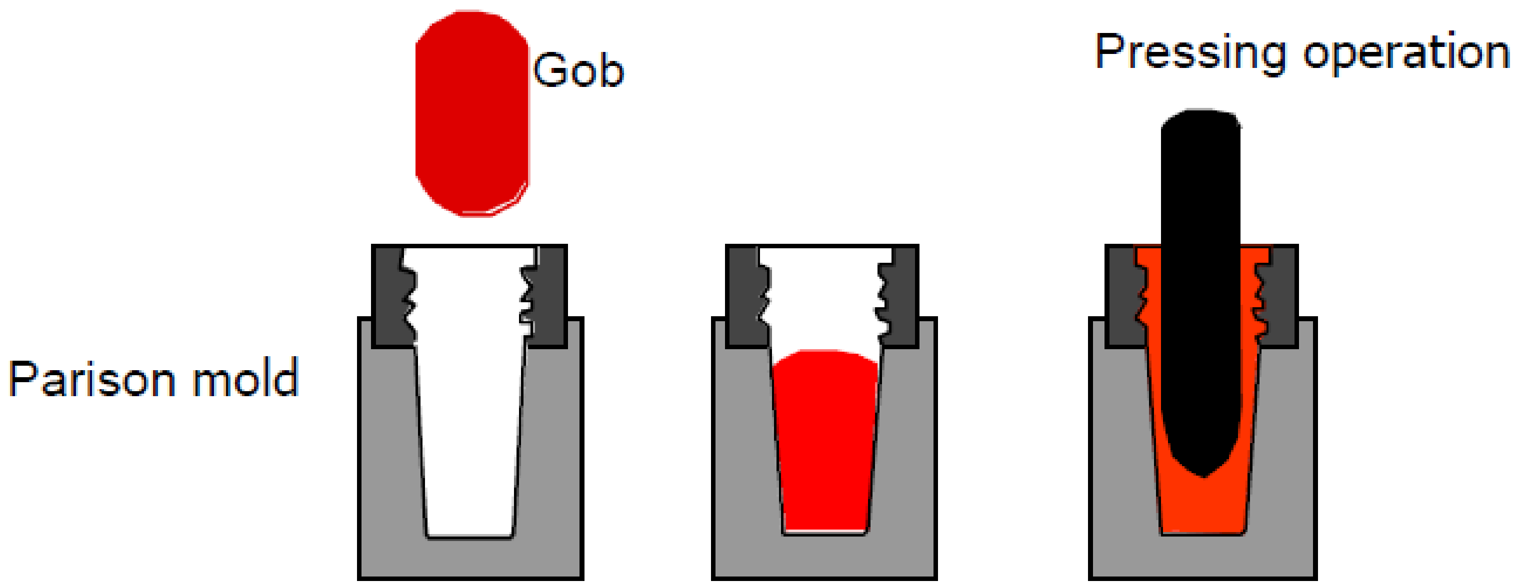
- Used when high temperature, high speed, or marginally lubricated conditions occur

4.0: FABRICATION METHOD

Ceramic Fabrication Methods-I

- GLASS FORMING
  - pressing
  - blowing
  - drawing
  - Sheet glass forming
- PARTICULATE FORMING
- CEMENTATION

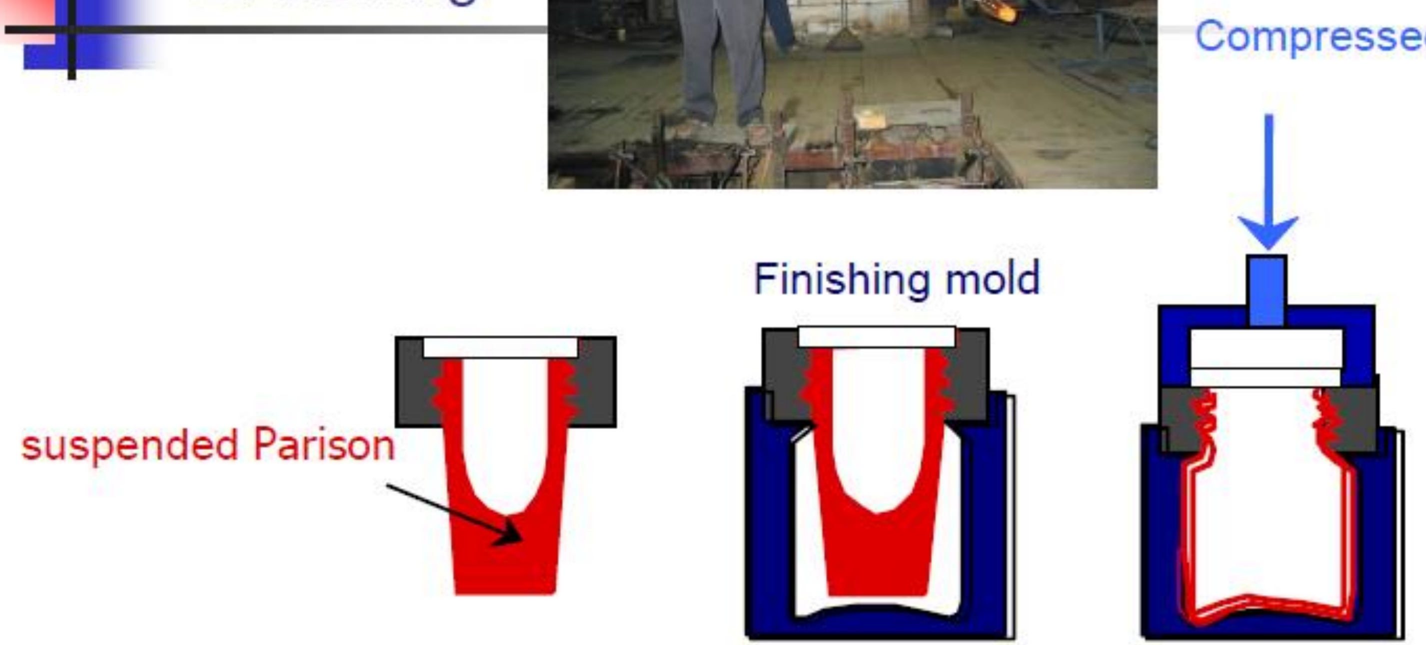
1. Pressing:



From a raw gob of glass, a parison (temporary shape) is formed by mechanical pressing in a mold.

2. Blowing:

Traditional blowing process

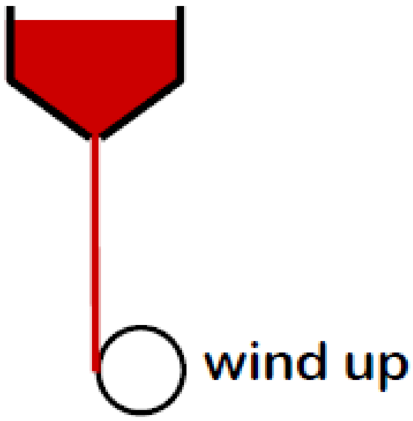


[Video glass blowing]

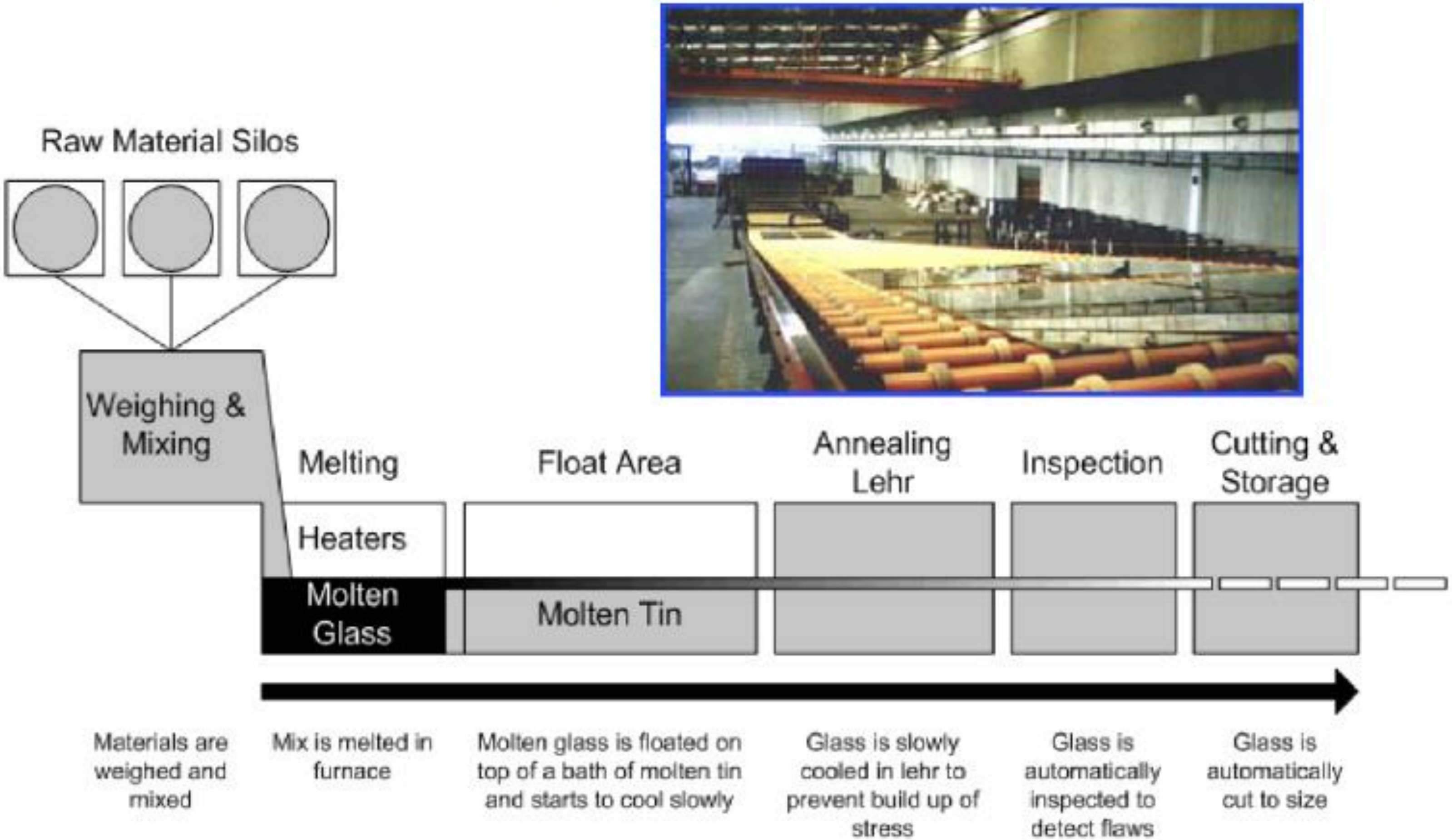
The piece is inserted into a finishing mold and forced to conform to the mold contours by the pressure created from a blast of air

3. Fiber drawing:

Drawing is used to form long glass piece such as sheet, rod, tubing, fiber which have a constant cross section



4. Sheet Glass/Float glass Forming



[Video – how to make a glass window]

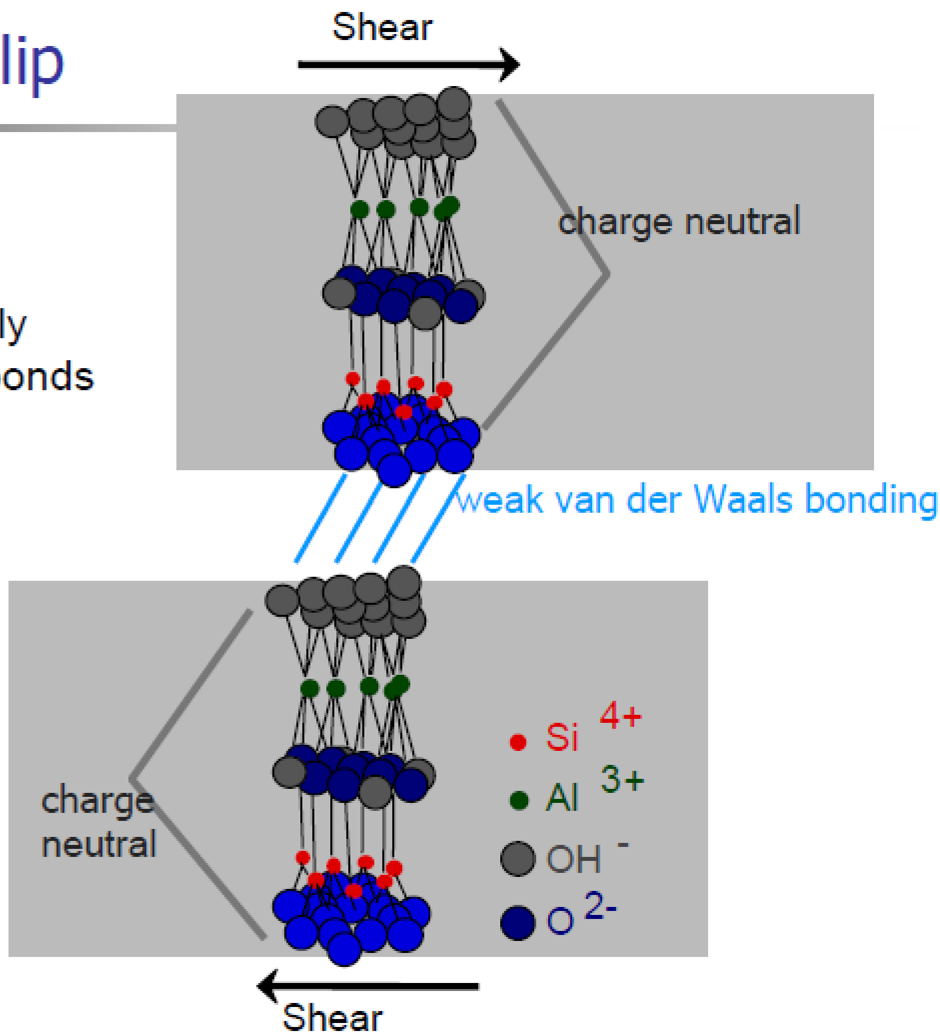
Ceramic Fabrication Methods-II

- GLASS FORMING
- PARTICULATE FORMING
  - Powder pressing
  - hydroplastic forming
  - Slip casting
  - Tape casting
- CEMENTATION

Features of a Slip

- Clay is inexpensive
- Adding water to clay
  -- allows material to shear easily
     along weak van der Waals bonds
  -- enables extrusion
  -- enables slip casting

- Structure of Kaolinite Clay:



Clay Composition

A mixture of components used

(50%) 1. Clay

(25%) 2. Filler – e.g. quartz (finely ground)

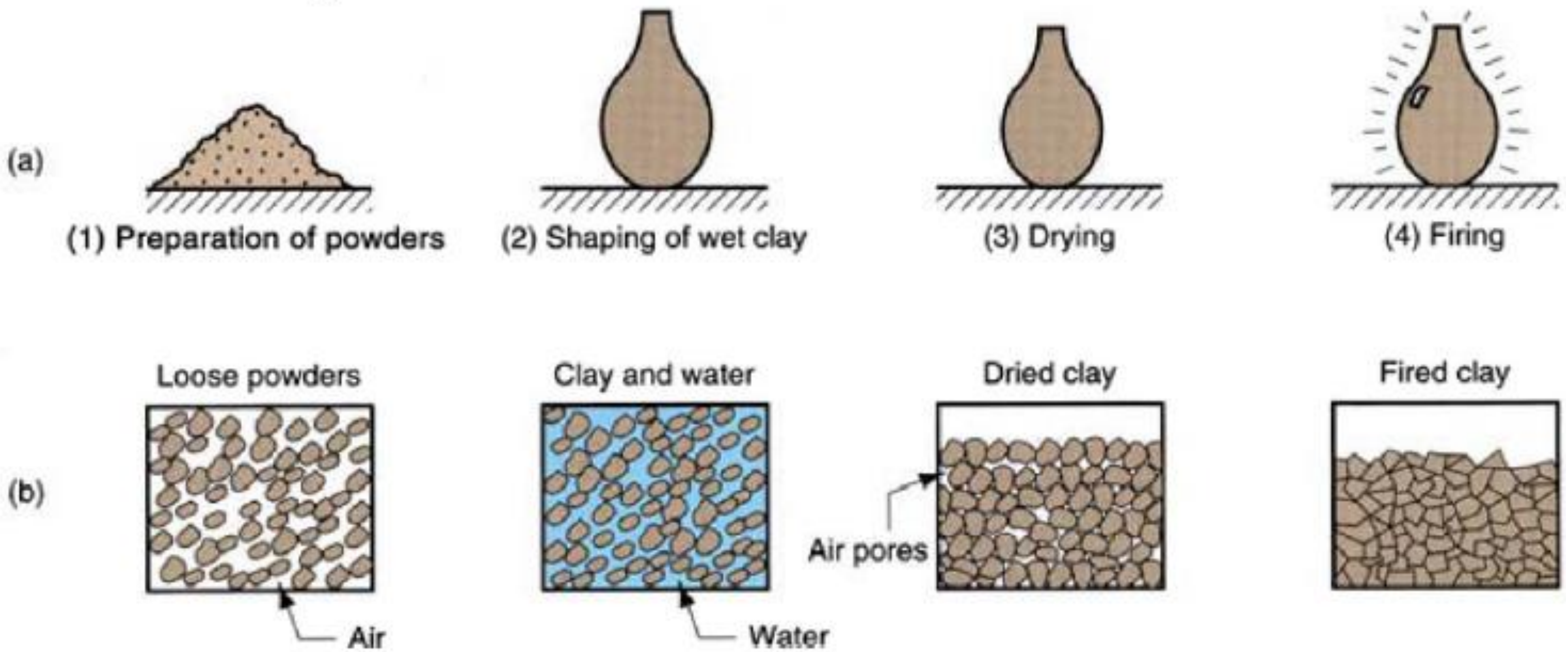
(25%) 3. Fluxing agent (Feldspar)

binds it together

aluminosilicates + K^+, Na^+, Ca^+

Traditional Ceramic Processing

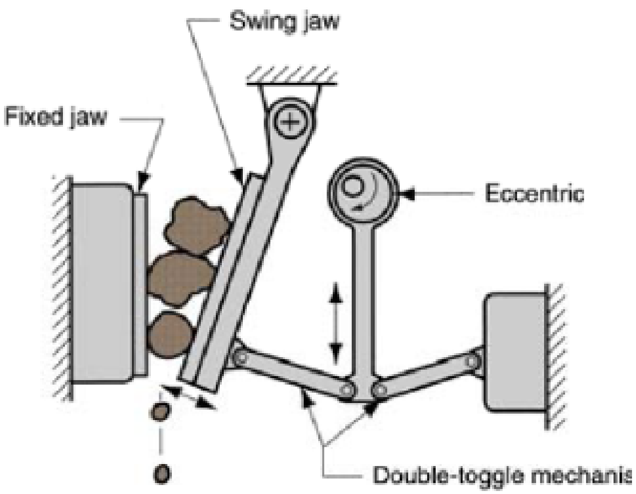
Processing sequence
- Preparing powders
- Shaping of wet clay
- Drying
- Firing



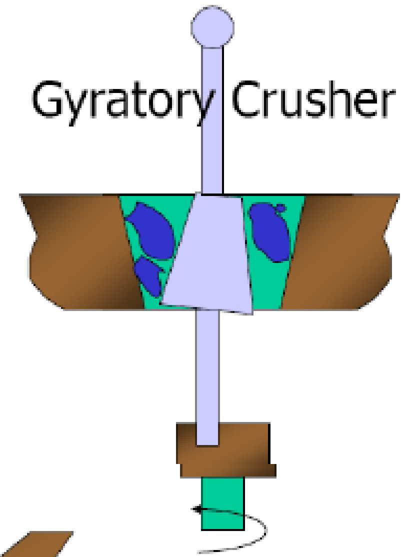
Preparation of Raw Materials – Comminution: Crushing and Grinding

Crushing

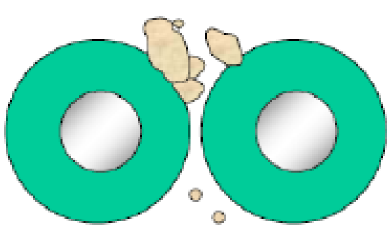
Jaw Crusher



Gyratory Crusher

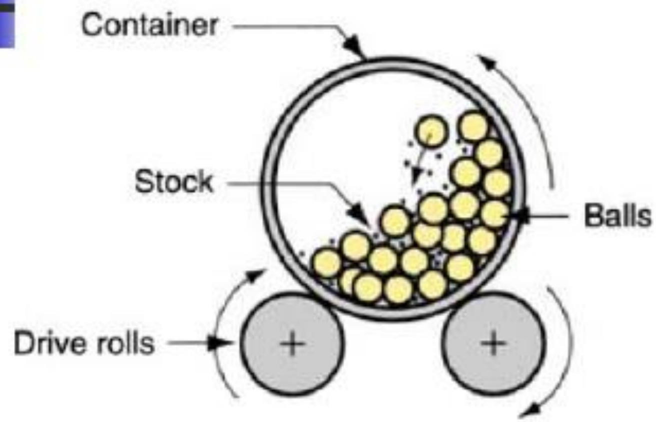


Hammer Mill

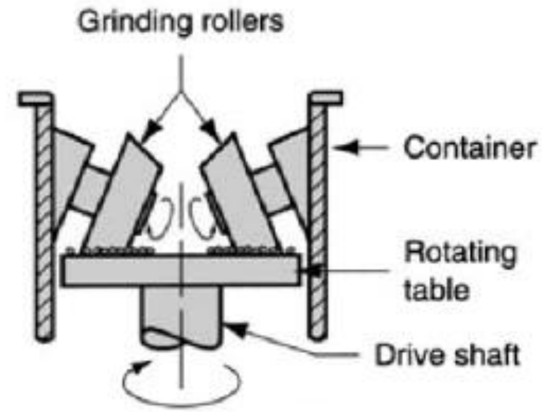


Roll Crusher

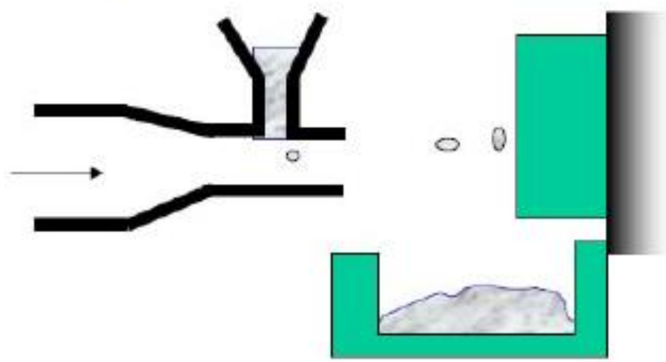
Grinding



Ball Milling



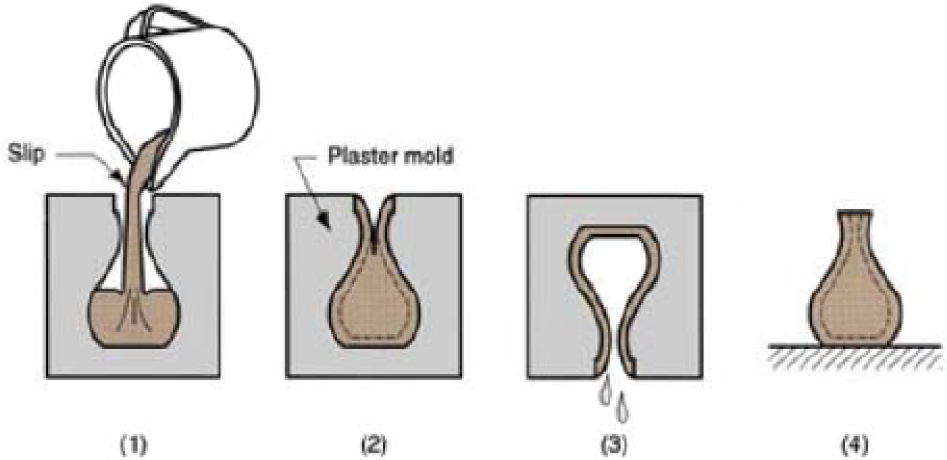
Roller Milling



Impact Grinding

Shaping

1. Slip Casting



A suspension of ceramic powders in water, called a *slip*, is poured into a porous plaster of paris mold so that water from the mix is absorbed into the plaster to form a firm layer of clay at the mold surface

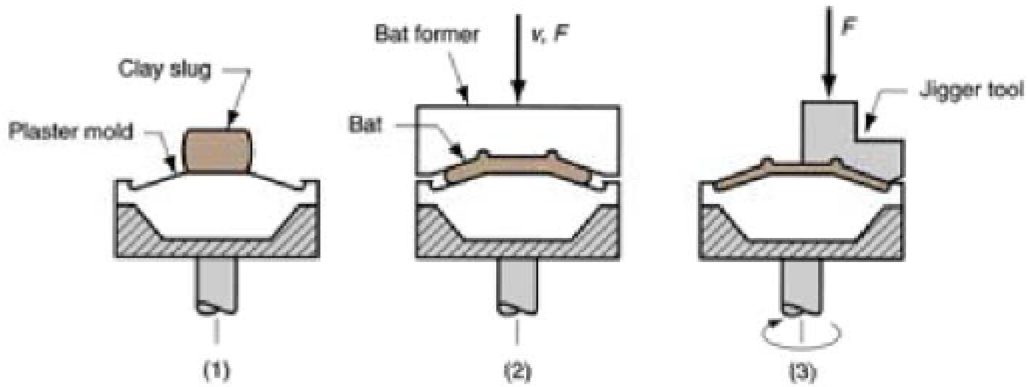
The slip composition is 25% to 40% water

Two principal variations:
Drain casting - the mold is inverted to drain excess slip after a semi-solid layer has been formed, thus producing a hollow product

Solid casting - to produce solid products, adequate time is allowed for entire body to become firm

Shaping

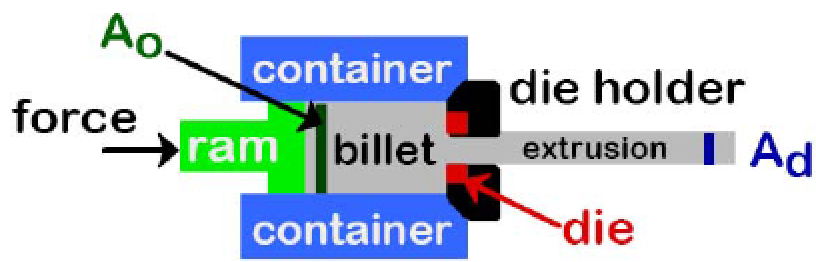
2. Hydroplastic Forming



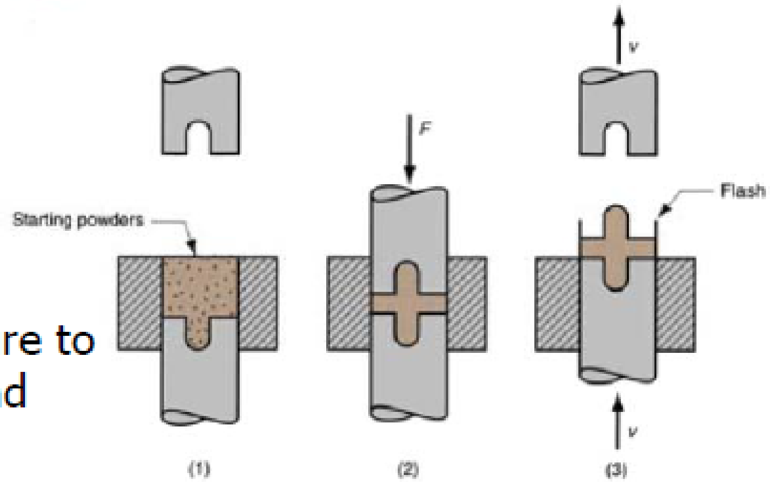
The starting mixture must have a plastic consistency, with 15% to 25% water

Variety of manual and mechanized methods
– Manual methods use clay with more **water** because it is more easily formed (*More water means greater shrinkage in drying*)
• Hand modeling (manual method)

– Mechanized methods generally use a mixture with less water so starting clay is stiffer
• Jiggering (mechanized)
• Plastic pressing (mechanized)
• Extrusion (mechanized)



Pressing Processes



Semi-dry Pressing: Uses high pressure to overcome the clay's low plasticity and force it into a die cavity

- Dry Pressing: process sequence is similar to semi-dry pressing - the main distinction is that the water content of the starting mix is < 5%

- Dies must be made of hardened tool steel or cemented carbide to reduce wear since dry clay is very hard

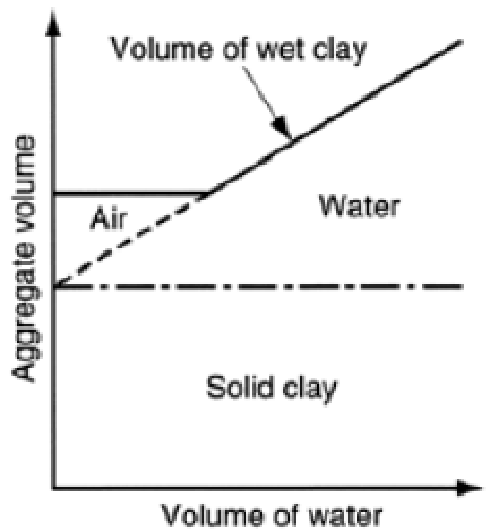
- No drying shrinkage occurs, **so drying time is eliminated** and **good dimensional accuracy** is achieved in the final product

- Typical products: bathroom tile, electrical insulators, refractory brick, and other simple geometries

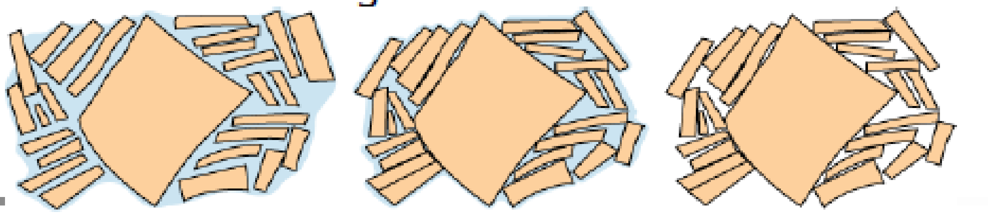
Drying

Water must be removed from the clay piece *before firing*

Shrinkage is a problem during drying because water contributes volume to the piece, and the volume is reduced when it is removed

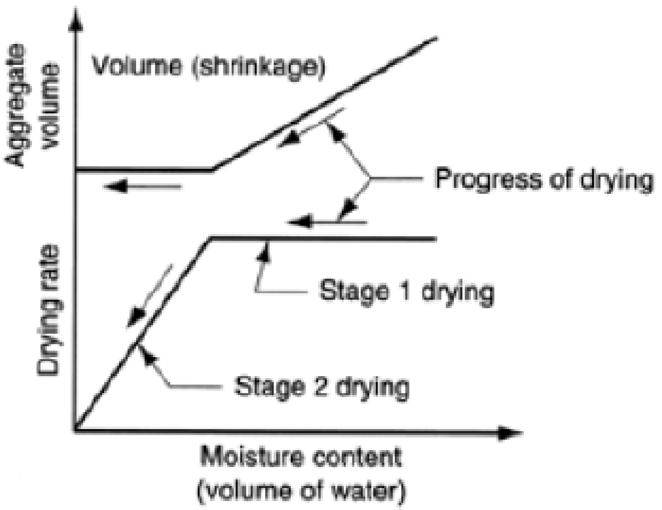


The drying process occurs in two stages:



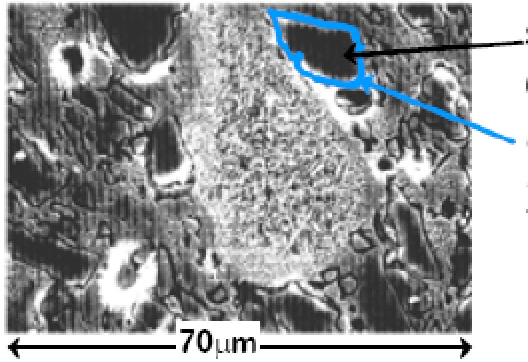
Stage 1: drying rate is rapid and constant as water evaporates from the surface into the surrounding air and water from the interior migrates by capillary action to the surface to replace it. (*This is when shrinkage occurs, with the risk of warping and cracking*)

Stage 2: the moisture content has been reduced to where the ceramic grains are in contact
- ***Little or no further shrinkage occurs***



Firing and Glazing

micrograph of porcelain



Firing: Heat treatment process that *sinters* the ceramic material performed in a furnace called a *kiln*

• Bonds are developed between the ceramic grains which leads to densification and reduction of porosity. Hence additional **shrinkage** occurs.

• In the firing of traditional ceramics, a glassy phase forms among the crystals which acts as a binder

•vitrification: liquid glass forms from clay and flows between SiO_2 particles. Flux melts at lower *T*.

• **Glazing:** Application of a ceramic surface coating to make the piece more impervious to water and enhance its appearance

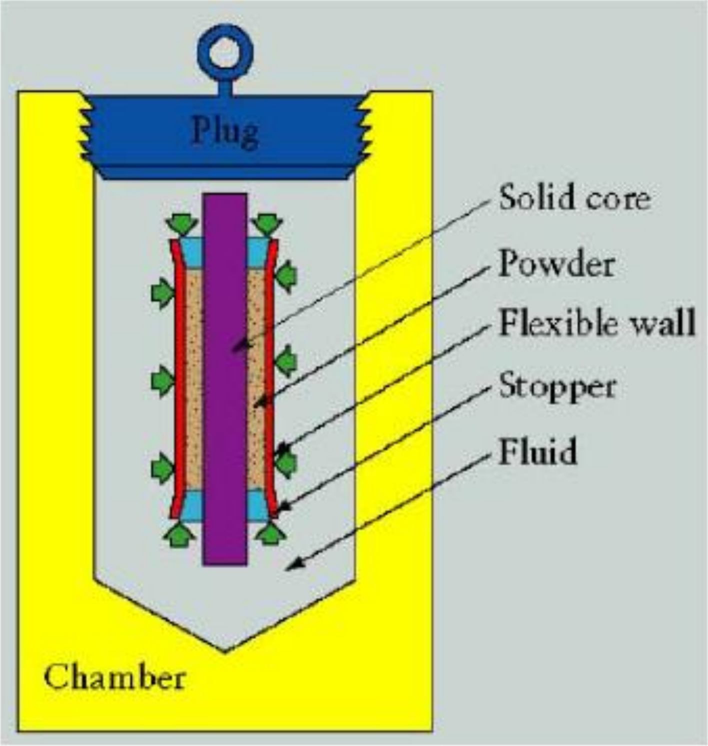
• The usual processing sequence with glazed ware is:

1. Fire the piece once before glazing to harden the body of the piece
2. Apply the glaze
3. Fire the piece a second time to harden the glaze

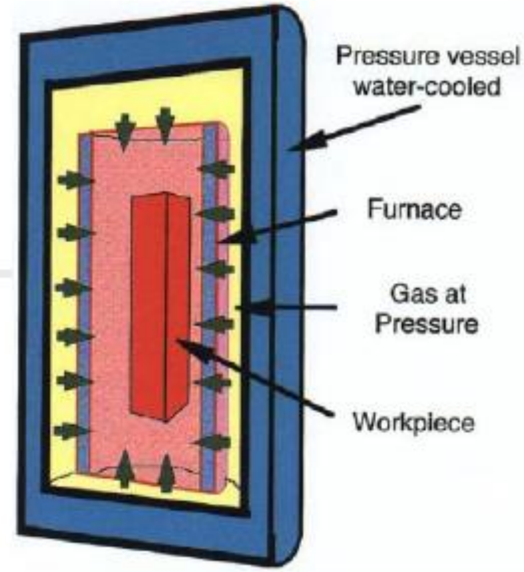
Alternative Pressing Techniques

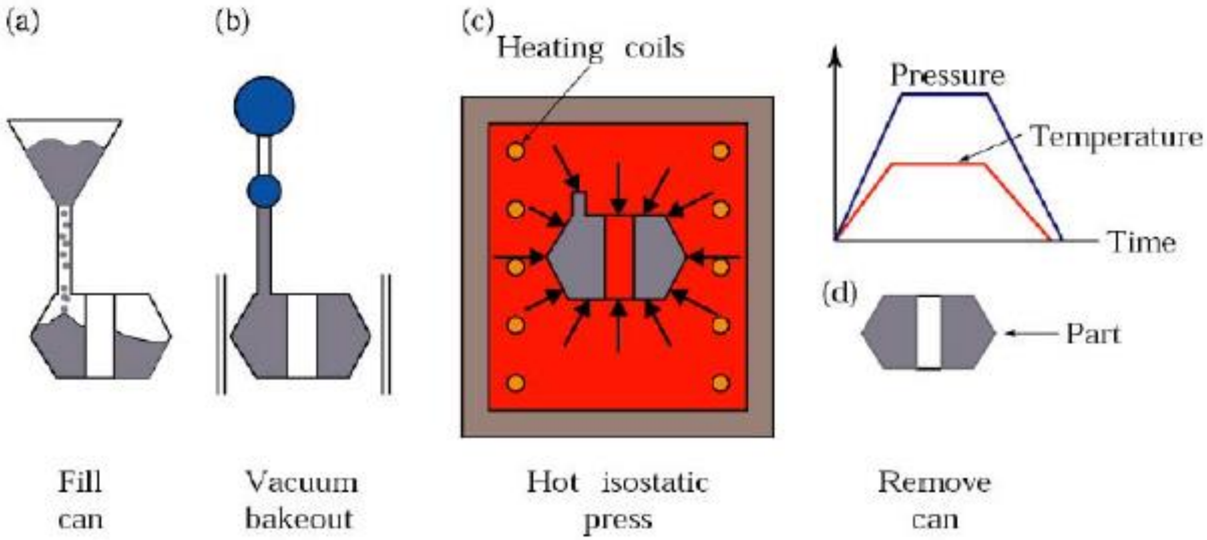
Isostatic Pressing

1. Cold Isostatic Pressing (CIP)

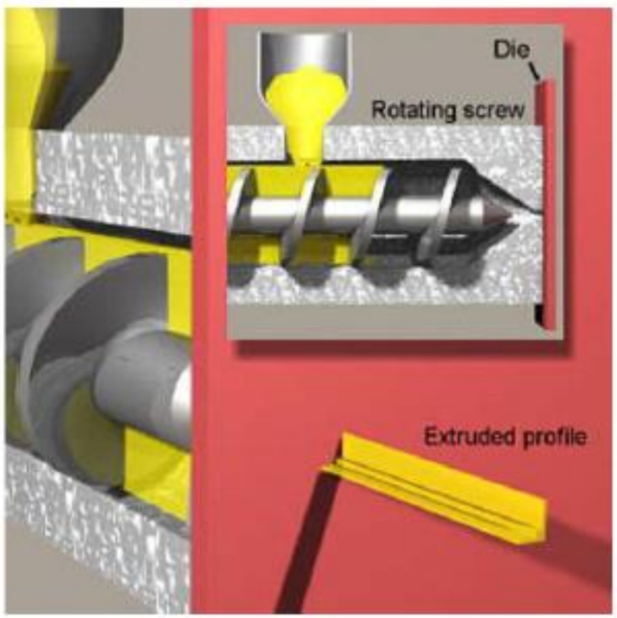


2. Hot Isostatic Pressing (HIP)

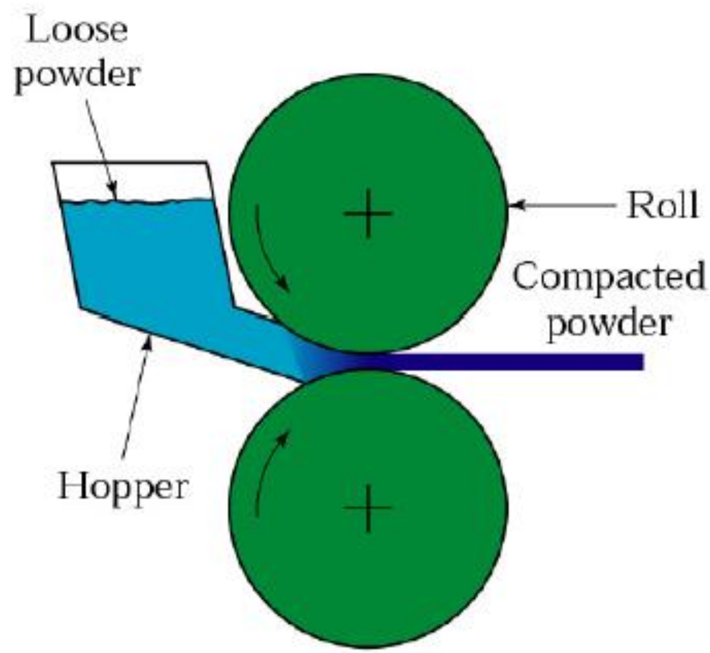




Powder Extrusion

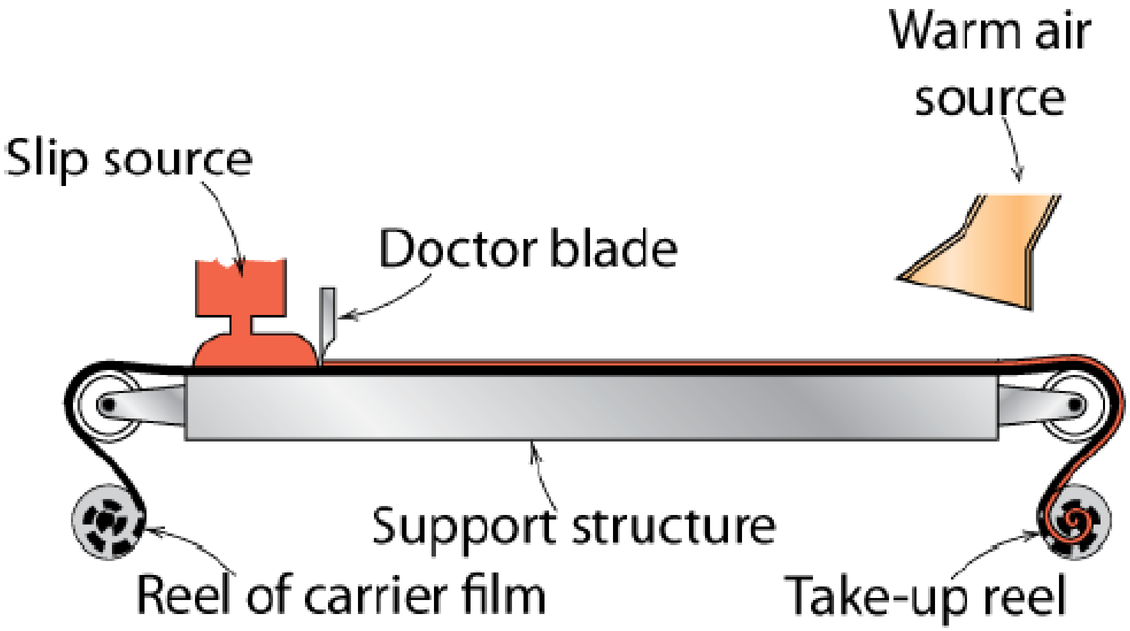


Powder Rolling



Tape Casting

- thin sheets of green ceramic cast as flexible tape
- used for integrated circuits and capacitors
- cast from liquid slip (ceramic + organic solvent)



Ceramic Fabrication Methods-III

- GLASS FORMING
- PARTICULATE FORMING
- CEMENTATION

Cements

Portland cement:

❖Produced by grinding and mixing clay and lime bearing materials
❖And then heat mixture to 1400°C in rotary kiln to produce physical and chemical changes in raw materials
❖The resulting clinker is then ground to fine powder to which gypsum is`added. (to retard the setting process)

Primary constituents:
 tri-calcium silicate
 di-calcium silicate

When mixed with water, forms a paste which harden as a results of complex hydration reactions