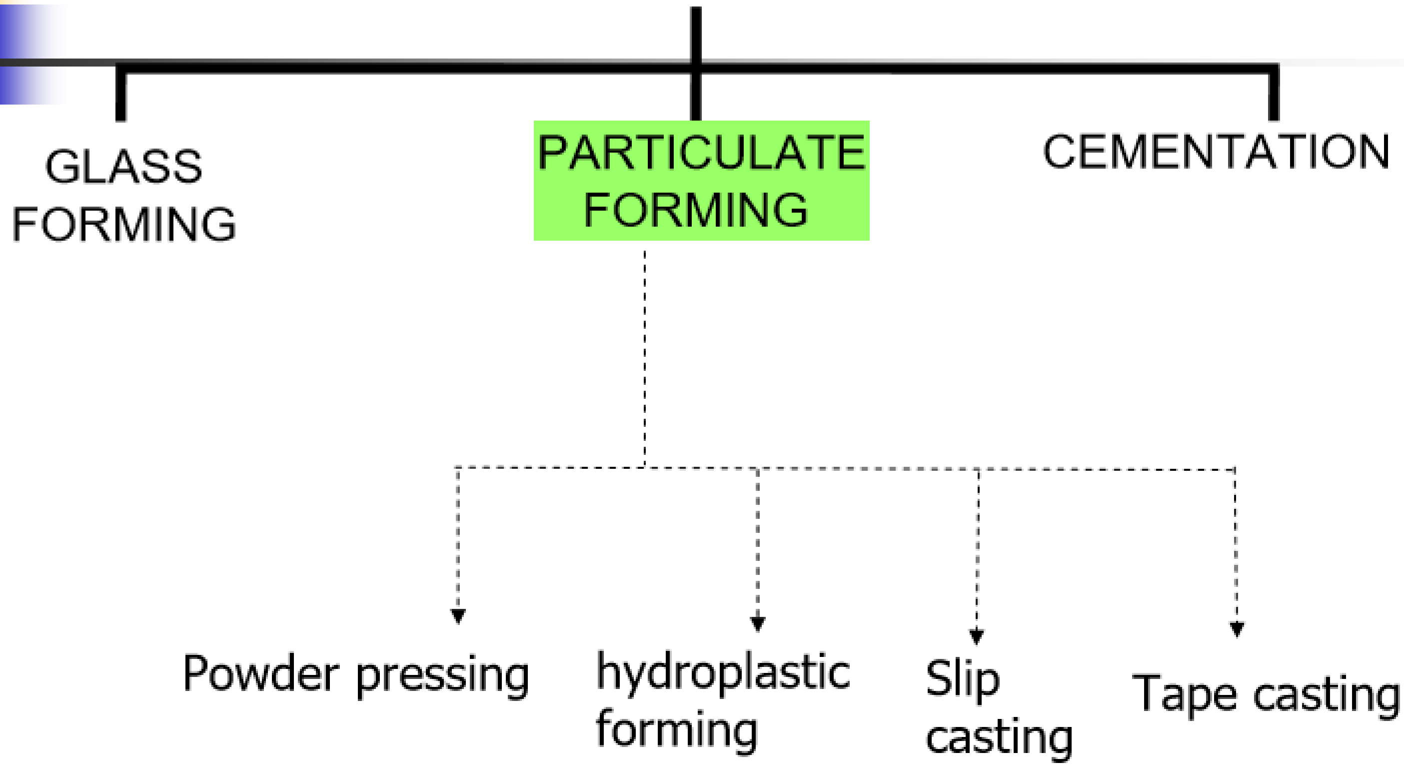
Ceramics Materials Processing

Part 1

Ceramic Fabrication Methods-II



Types of Ceramics and Their Processing

- Ceramic materials divide into three categories:

1. Traditional ceramics – particulate processing
2. New ceramics – particulate processing
3. Glasses – solidification processing

Ceramics Processing Overview

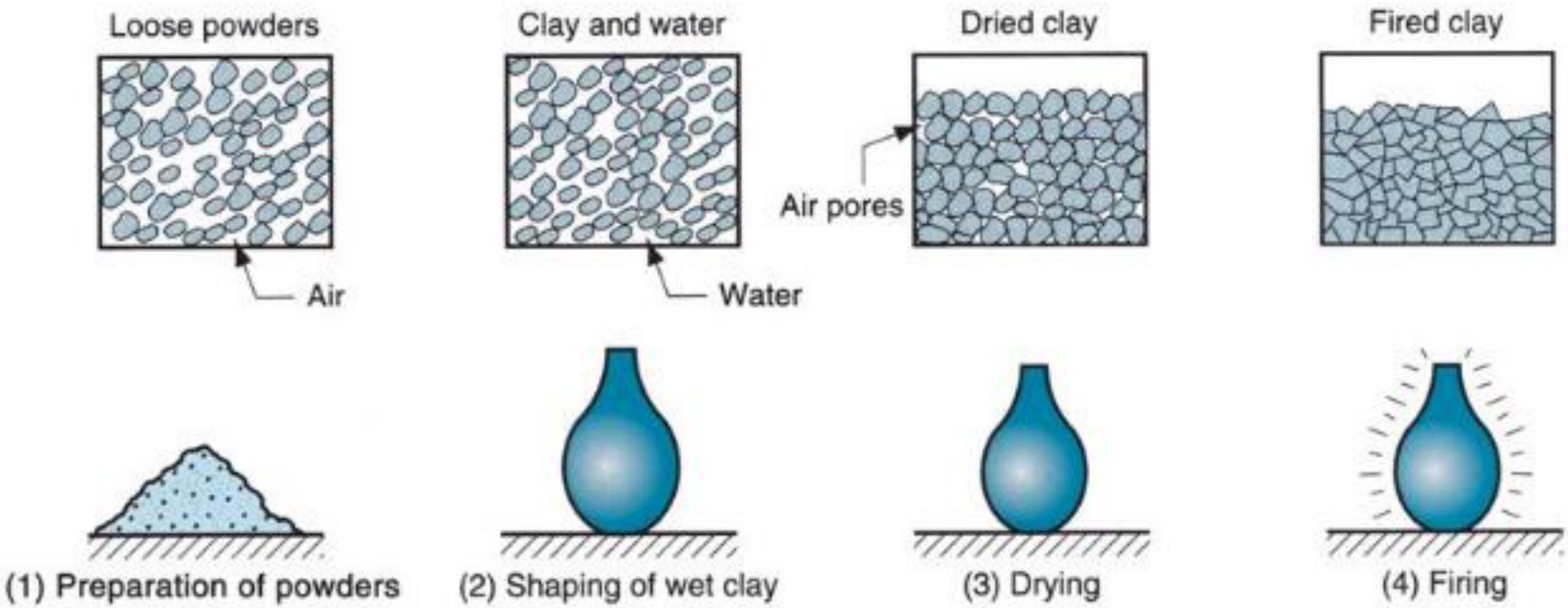
- Traditional ceramics are made from minerals occurring in nature
  - Products: pottery, porcelain, bricks, and cement
- New ceramics are made from synthetically produced raw materials, i.e. Alumina (Al2O3), Carbon Boron Nitride (CBN), Titanium Carbide (TiC), Tungsten Carbide (WC)
  - Products: cutting tools, artificial bones, nuclear fuels, substrates for electronic circuits
- Starting material for these products is powder

Ceramics Processing Overview

- For traditional ceramics
  - Powders are mixed with water to bind them together and achieve proper consistency for shaping
- For new ceramics
  - Substances other than water are used as binders during shaping
- After shaping, green part is *fired* (sintered)
  - Function is the same as in PM - to effect a solid state reaction that bonds the particles into a hard mass

Processing Overview for Traditional Ceramics

- Condition of powders and part during (1) preparation of raw materials, (2) shaping, (3) drying, and (4) firing



Preparation of Raw Materials in Traditional Ceramics Processing

- Most shaping processes for traditional ceramics require the starting material to be a plastic paste
  - This paste is comprised of fine ceramic powders mixed with water
- The starting raw ceramic material usually occurs in nature as rocky lumps
  - Purpose of the preparation step is to reduce the rocky lumps to powder

Comminution

Reducing particle size in ceramics processing by using mechanical energy in various forms such as impact, compression, and attrition

- Comminution techniques are most effective on brittle materials such as cement and metallic ores
- Two general types of comminution operations:
  1. Crushing
  2. Grinding

Crushing

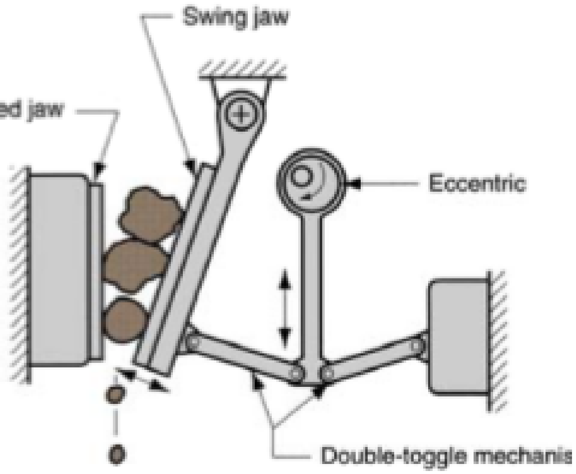
Reduction of large lumps from the mine to smaller sizes for subsequent further reduction

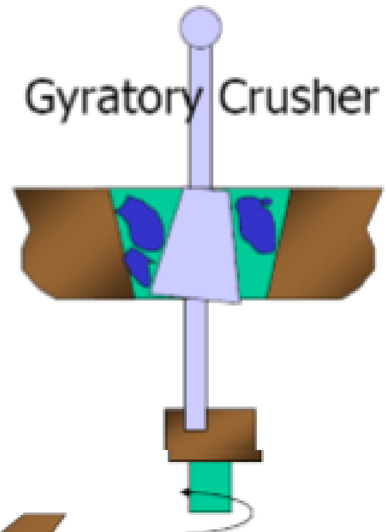
- Several stages may be required (e.g., primary crushing, secondary crushing)
  - Reduction ratio in each stage in the range 3 to 6
- Crushing of minerals is accomplished by
  - Compression against rigid surfaces or
  - Impact against surfaces

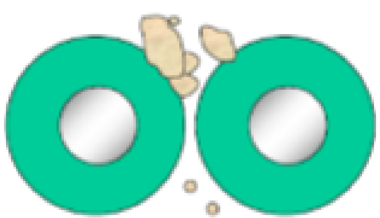
Preparation of Raw Materials
– Comminution: Crushing and Grinding

Crushing

Jaw Crusher





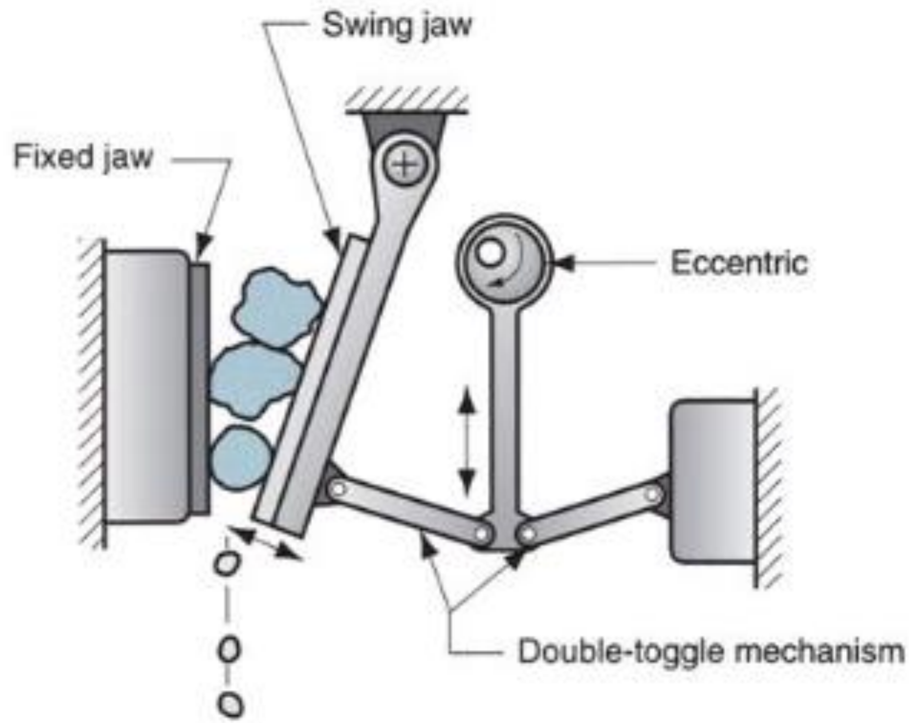


Roll Crusher

Hammer Mill

Jaw Crusher

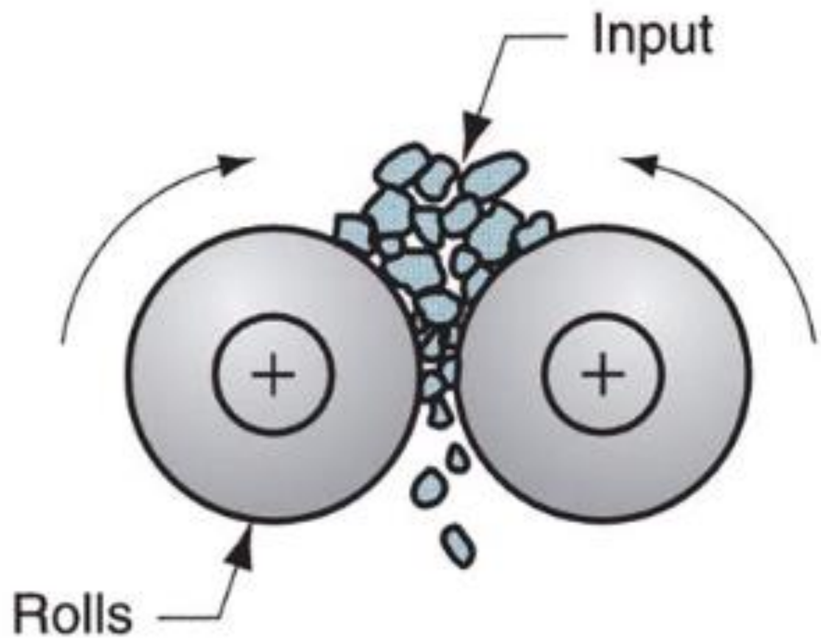
- Large jaw toggles back and forth to crush lumps against a hard, rigid surface



(a)

Roll Crusher

- Ceramic lumps are squeezed between rotating rolls



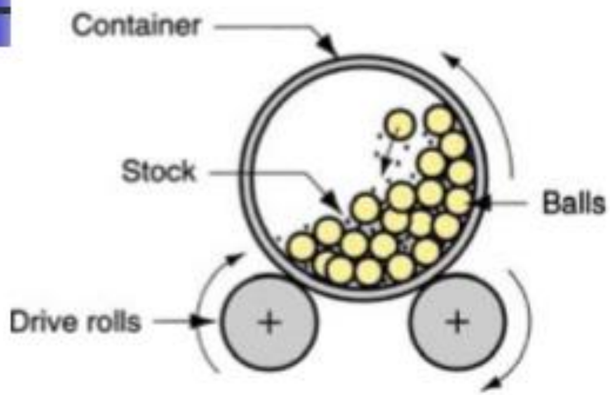
(c)

Grinding

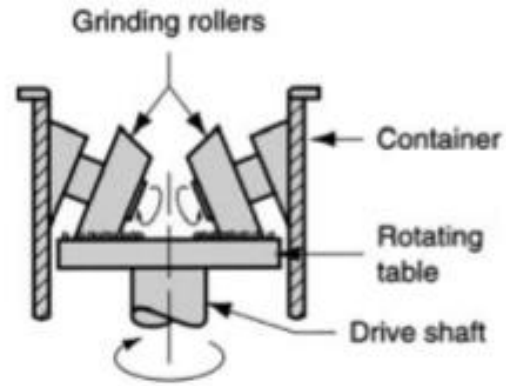
In the context of comminution, grinding refers to the reduction of small pieces after crushing to fine powder

- Accomplished by abrasion, impact, and/or compaction by hard media such as balls or rolls
- Examples of grinding include:
  - Ball mill
  - Roller mill
  - Impact grinding

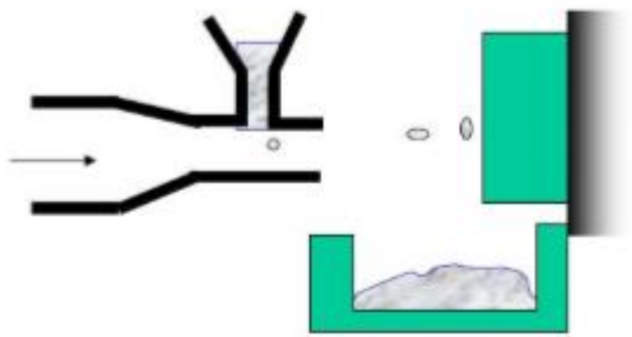
Grinding



Ball Milling



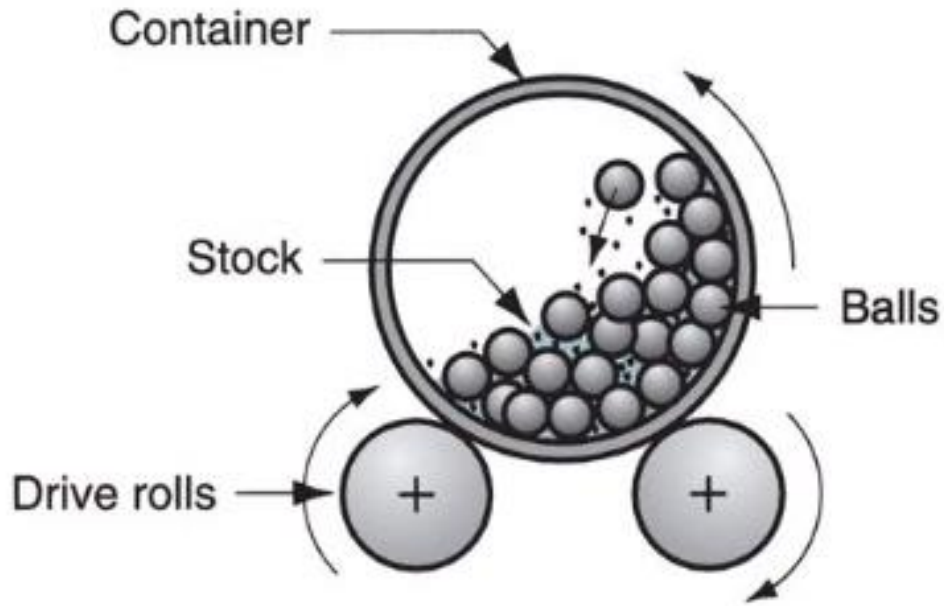
Roller Milling



Impact Grinding

Ball Mill

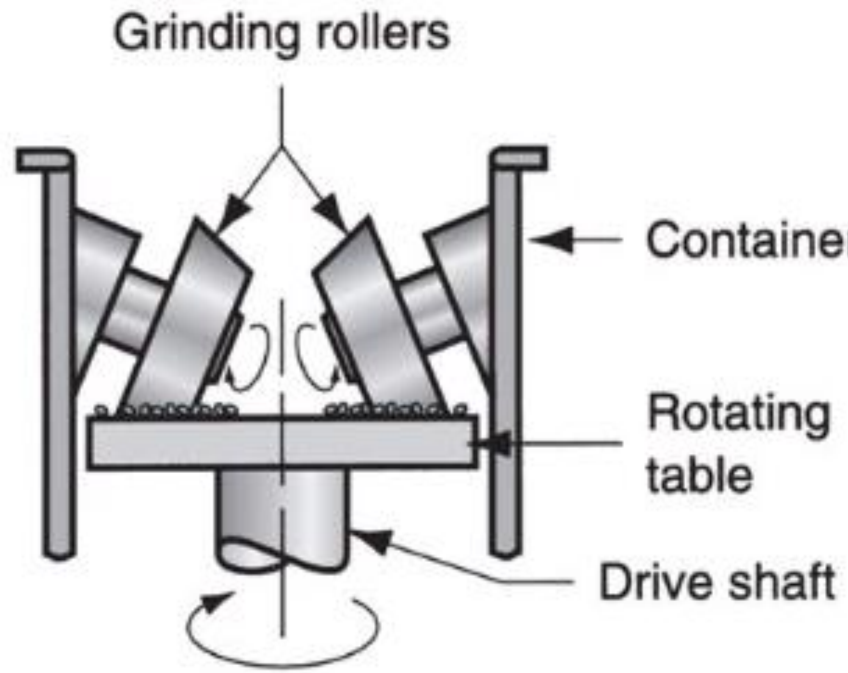
- Hard spheres mixed with stock are rotated inside large cylindrical container
- Mixture is carried upwards in container as it rotates, then dropped by gravity to accomplish grinding action



(a)

Roller Mill

- Stock is compressed against flat horizontal table by rollers riding on the table surface



(b)

Main Ingredients of Ceramic Paste

1. Clay
   - Chemistry = hydrous aluminum silicates
   - Usually the main ingredient because of ideal forming characteristics when mixed with water
2. Water
   - Creates clay-water mixture with good plasticity for shaping

Additional Ingredients of Ceramic Paste

3. Non-plastic raw materials
   - Such as alumina and silica
   - Purpose is to reduce shrinkage in drying and firing but also reduces plasticity during forming
4. Other ingredients
   - Such as fluxes that melt (vitrify) during firing and promote sintering
   - Wetting agents to improve mixing of ingredients

Clay Composition

A mixture of components used

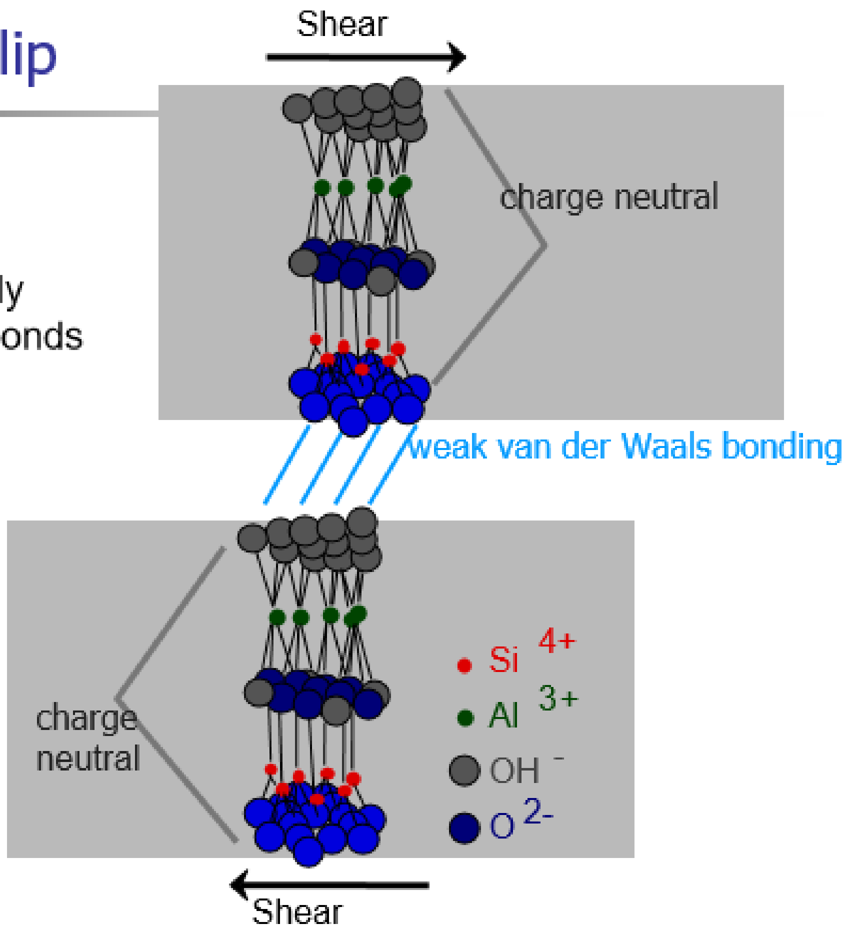
(50%) 1. Clay
(25%) 2. Filler – e.g. quartz (finely ground)
(25%) 3. Fluxing agent (Feldspar)
binds it together

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

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

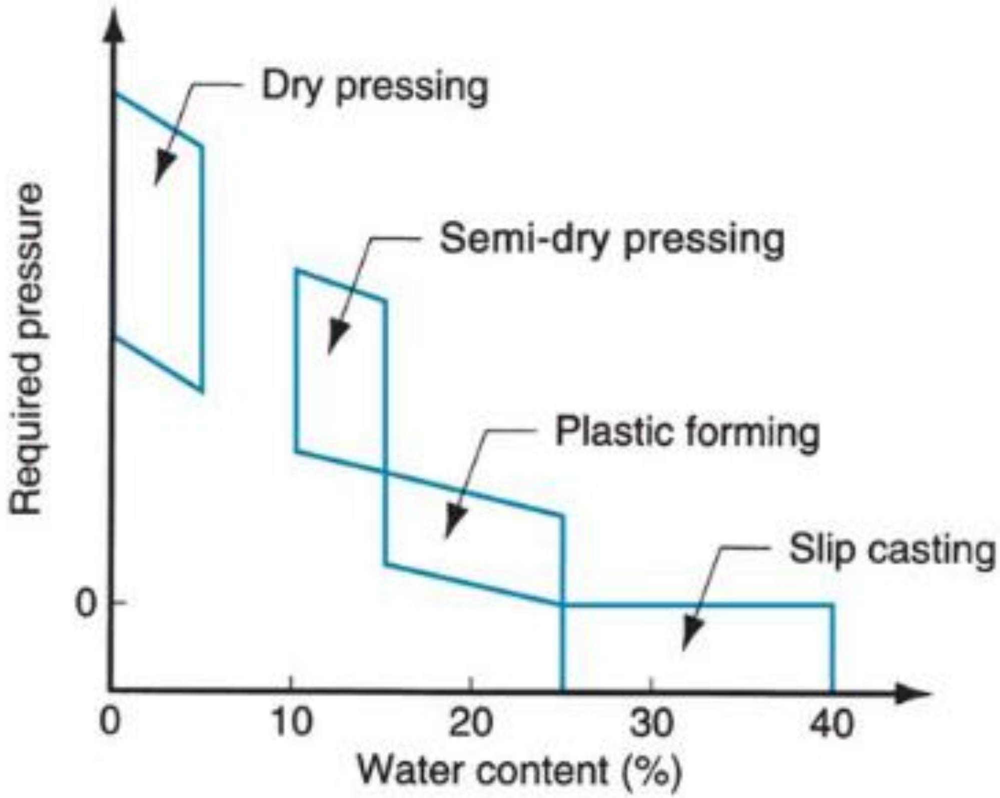
- Structure of Kaolinite Clay:



Shaping Processes

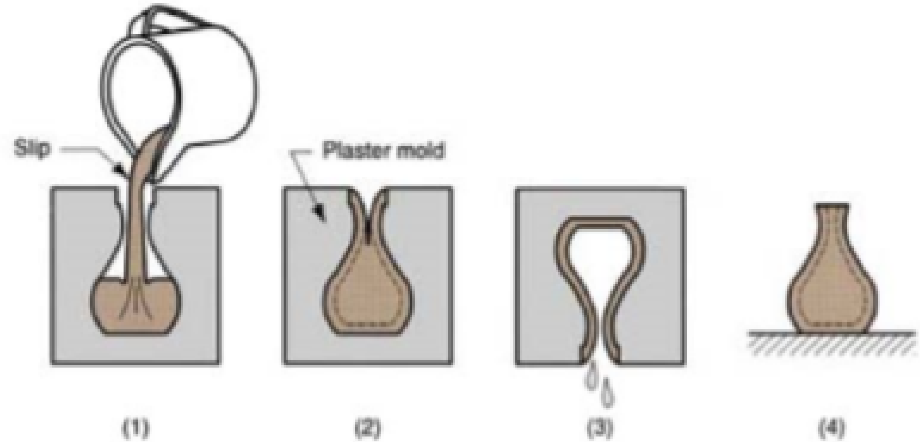
- Slip casting
  - The clay-water mixture is a slurry
- Plastic forming methods
  - The clay is plastic
- Semi-dry pressing
  - The clay is moist but has low plasticity
- Dry pressing
  - The clay is basically dry (less than 5% water) and has no plasticity

Effect of Water Content in Shaping Processes



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

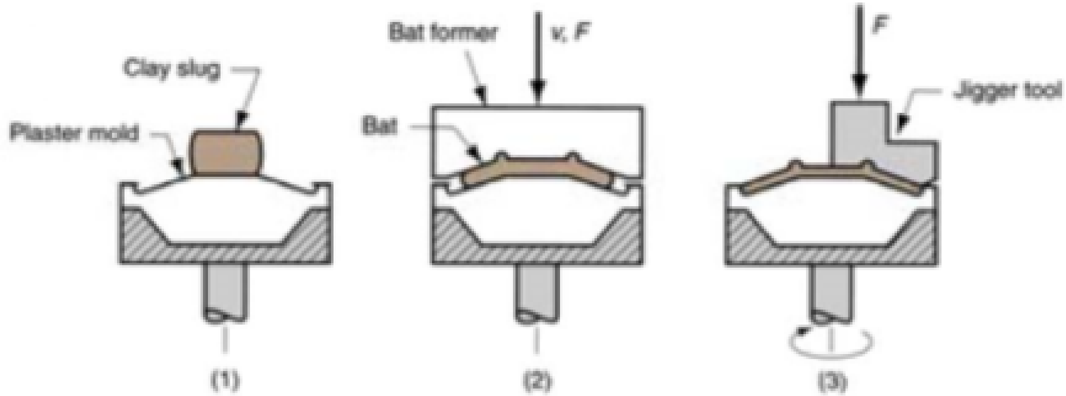
The slip composition is 25% to 40% water

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

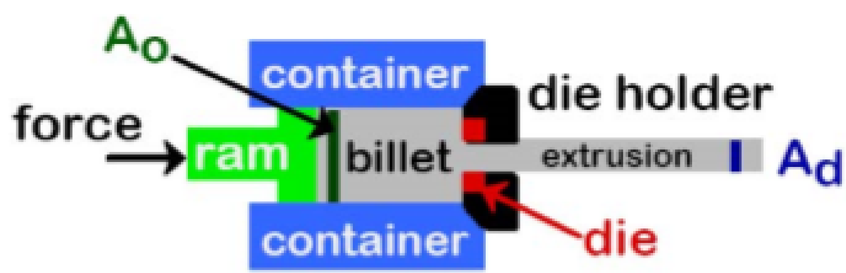
2. Hydroplastic Forming



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)



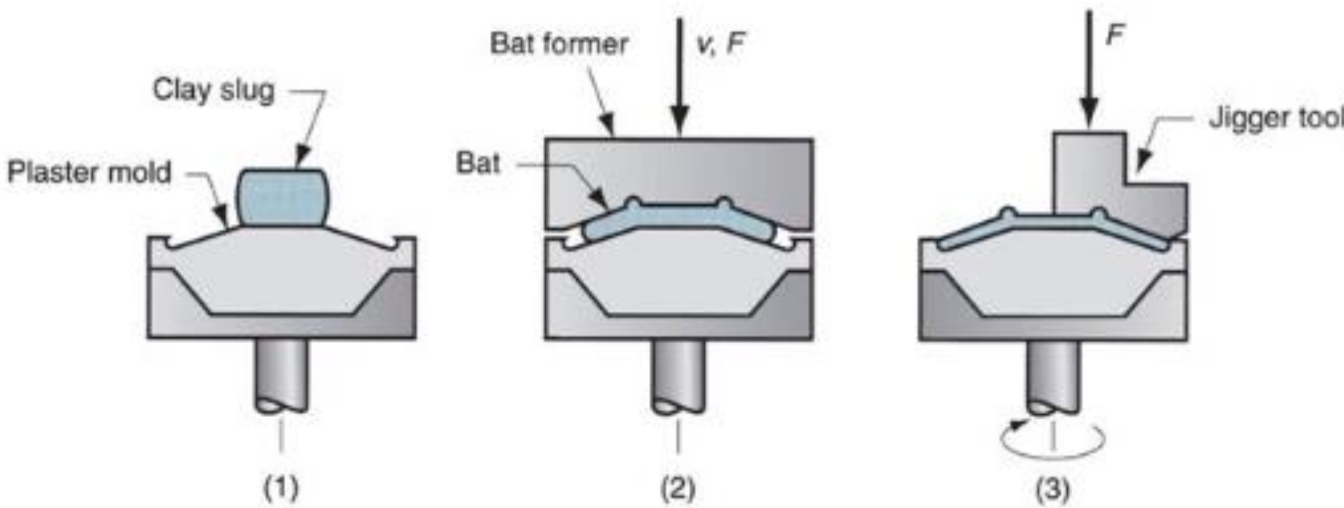
Hand Modeling

Fabrication of ceramic product by manipulating plastic clay into desired geometry

- Hand molding - a mold or form is used to define portions of the part geometry
- Hand throwing on a potter's wheel
  - Potter's wheel - a round table that rotates on a vertical spindle
  - Products of circular cross section can be formed by throwing and shaping the clay, sometimes using a mold to provide the internal shape

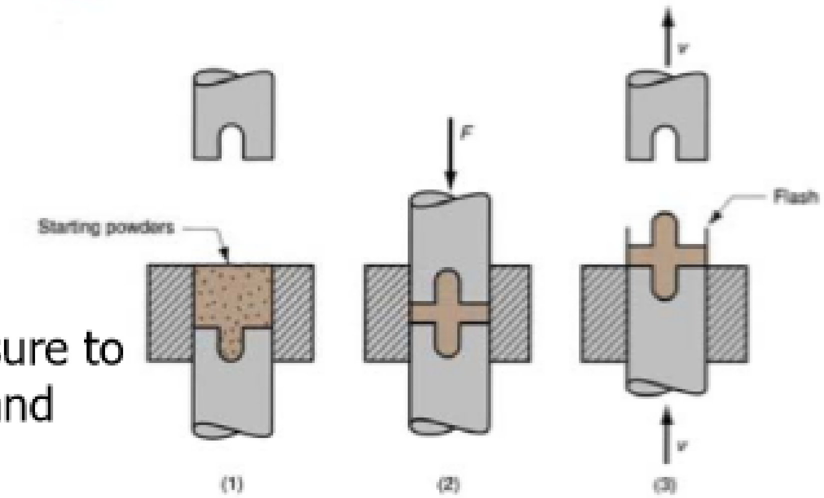
Jiggering

- (1) Wet clay slug is placed on a convex mold; (2) batting; and (3) a jigger tool imparts the final product shape



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

Semi-dry Pressing

Uses high pressure to overcome the clay's low plasticity and force it into a die cavity

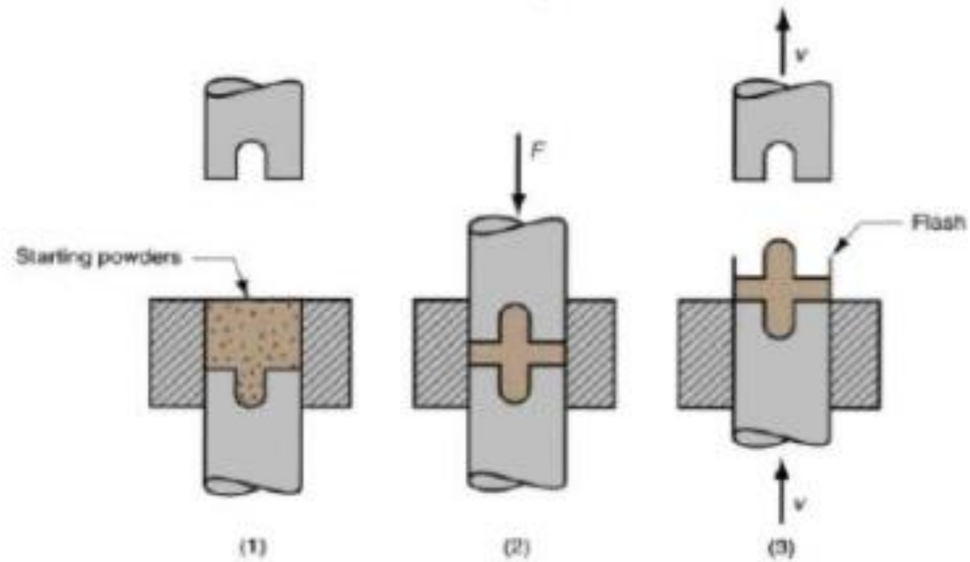


Figure 17.7 - Semi-dry pressing: (1) depositing moist powder into die cavity, (2) pressing, and (3) opening the die sections and ejection

Dry Pressing

Process sequence is similar to semi-dry pressing - the main distinction is that the water content of the starting mix is typically below 5%

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

Clay Volume vs. Water Content

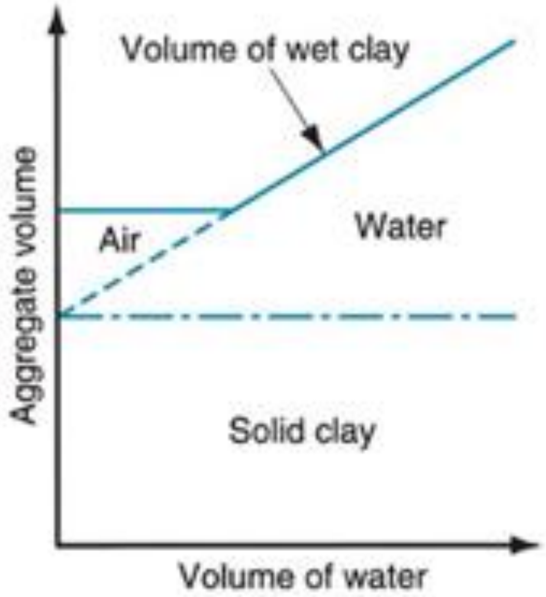
- Water plays an important role in most of the traditional ceramics shaping processes
  - Thereafter, it has no purpose and must be removed from the clay piece before firing
- Shrinkage is a problem during drying because water contributes volume to the piece, and the volume is reduced when it is removed

Drying

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

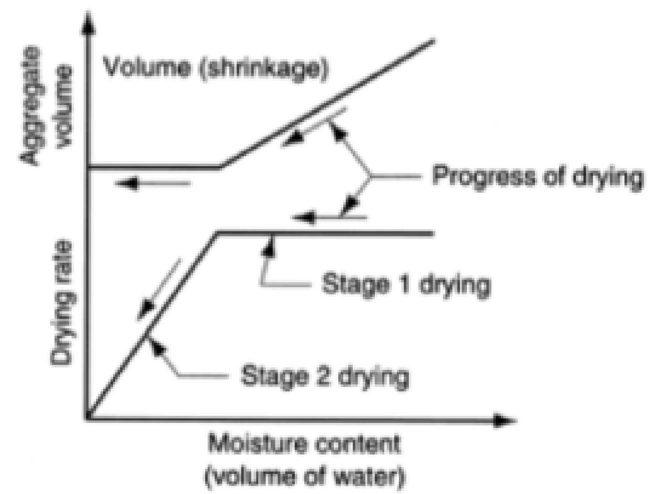
Shrinkage is a problem during drying because water contributes volume to the piece, and the volume is reduced when it is removed

- Volume of clay as a function of water content
  - Relationship shown here is typical
    - It varies for different clay compositions



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*)

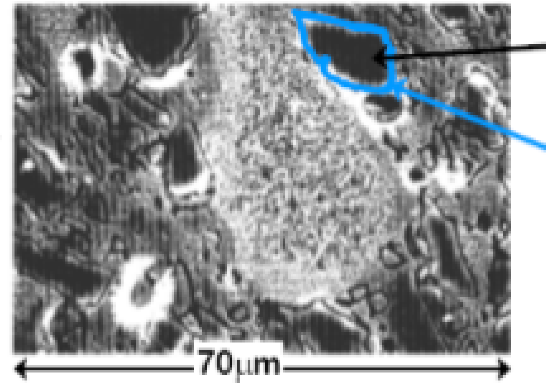


Stage 2: the moisture content has been reduced to where the ceramic grains are in contact

- ***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

Processing of New Ceramics

- The manufacturing sequence for the new ceramics can be summarized in the following steps:
  1. Preparation of starting materials
  2. Shaping
  3. Sintering
  4. Finishing
- While the sequence is nearly the same as for the traditional ceramics, the details are often quite different

Preparation of Starting Materials

- Strength requirements are usually much greater for new ceramics than for traditional ceramics
- Therefore, the starting powders must be smaller and more uniform in size and composition, since the strength of the resulting ceramic product is inversely related to grain size
- Greater control of the starting powders is required
- Powder preparation includes mechanical and chemical methods

Shaping of New Ceramics

- Many of the shaping processes for new ceramics are borrowed from powder metallurgy (PM) and traditional ceramics
  - PM press and sinter methods have been adapted to the new ceramic materials
- And some of the traditional ceramics forming techniques are used to shape the new ceramics, such as: slip casting, extrusion, and dry pressing
- The processes described here are not normally associated with the forming of traditional ceramics, although several are associated with PM

Hot Pressing

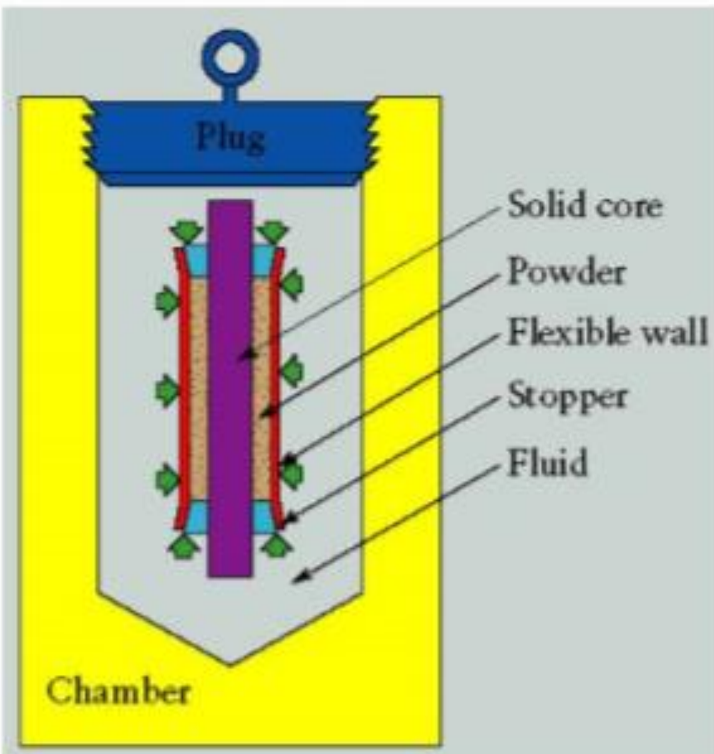
Similar to *dry pressing* except it is carried out at elevated temperatures so sintering of the product is accomplished simultaneously with pressing

- This eliminates the need for a separate firing step
- Higher densities and finer grain size are obtained, but die life is reduced by the hot abrasive particles against the die surfaces

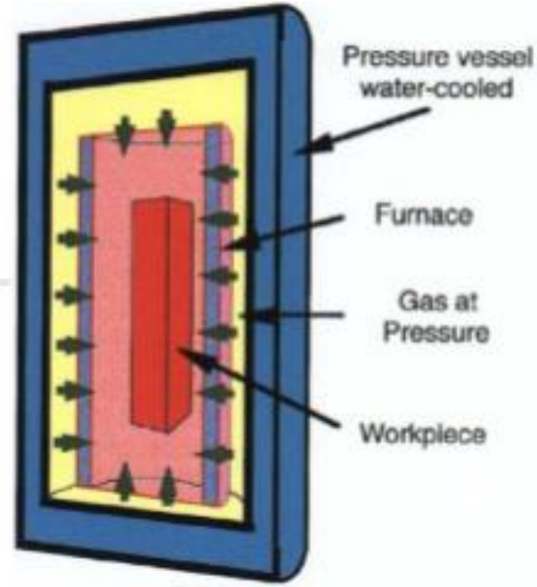
Alternative Pressing Techniques

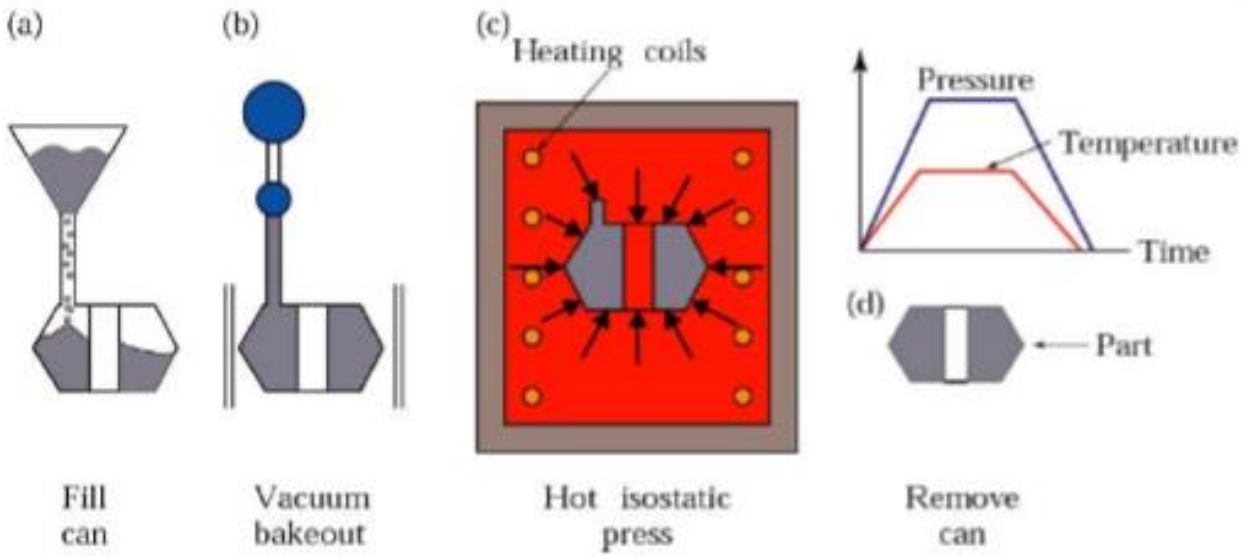
Isostatic Pressing

1. Cold Isostatic Pressing (CIP)



2. Hot Isostatic Pressing (HIP)





Isostatic Pressing

Uses hydrostatic pressure to compact the ceramic powders from all directions

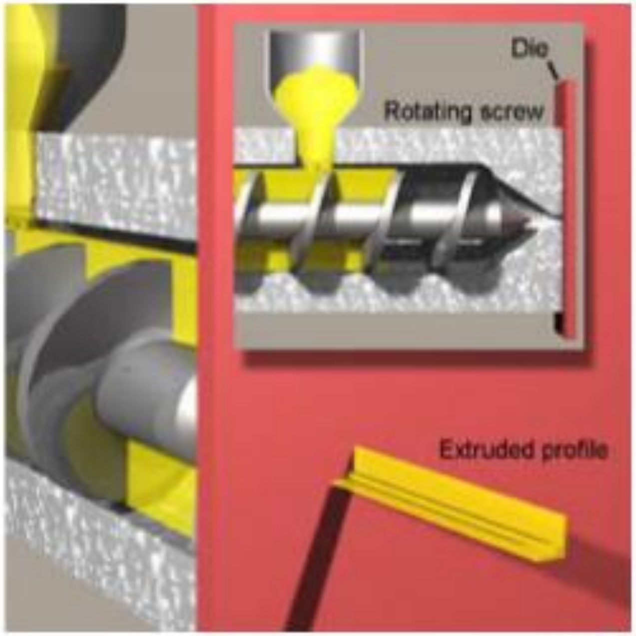
- Avoids the problem of nonuniform density in the final product that is often observed in conventional uniaxial pressing
- Same process used in powder metallurgy

Powder Injection Molding (PIM)

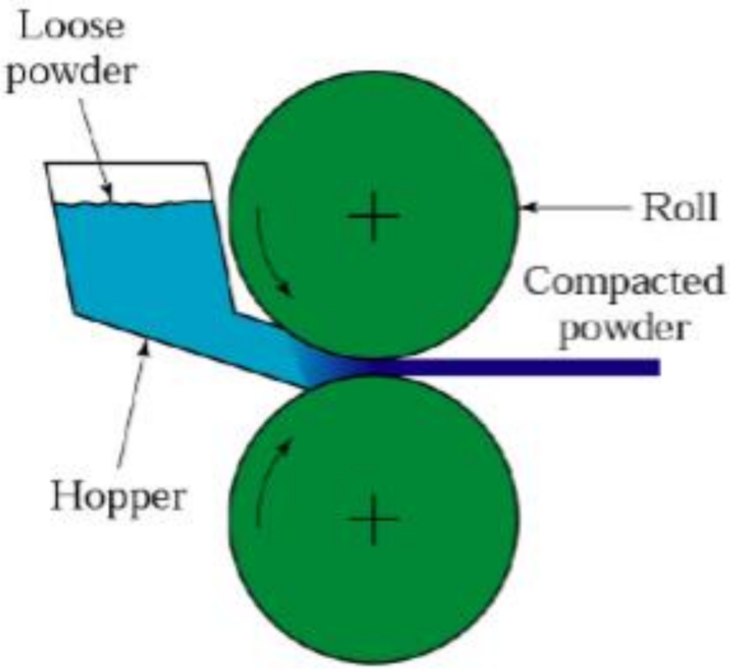
Ceramic particles are mixed with a thermoplastic polymer, then heated and injected into a mold cavity

- The polymer acts as a carrier and provides flow characteristics for molding
- Upon cooling which hardens the polymer, the mold is opened and the part is removed
- Because temperatures needed to plasticize the carrier are much lower than those required for sintering the ceramic, the piece is green after molding
- The plastic binder is removed and the remaining ceramic part is sintered

Powder Extrusion

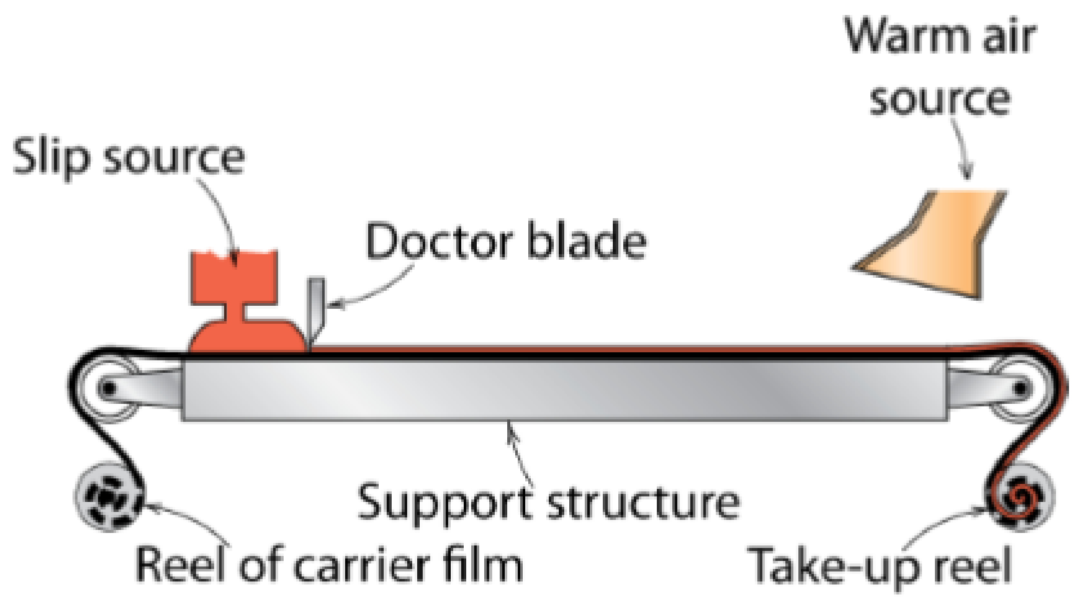


Powder Rolling



Tape Casting

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

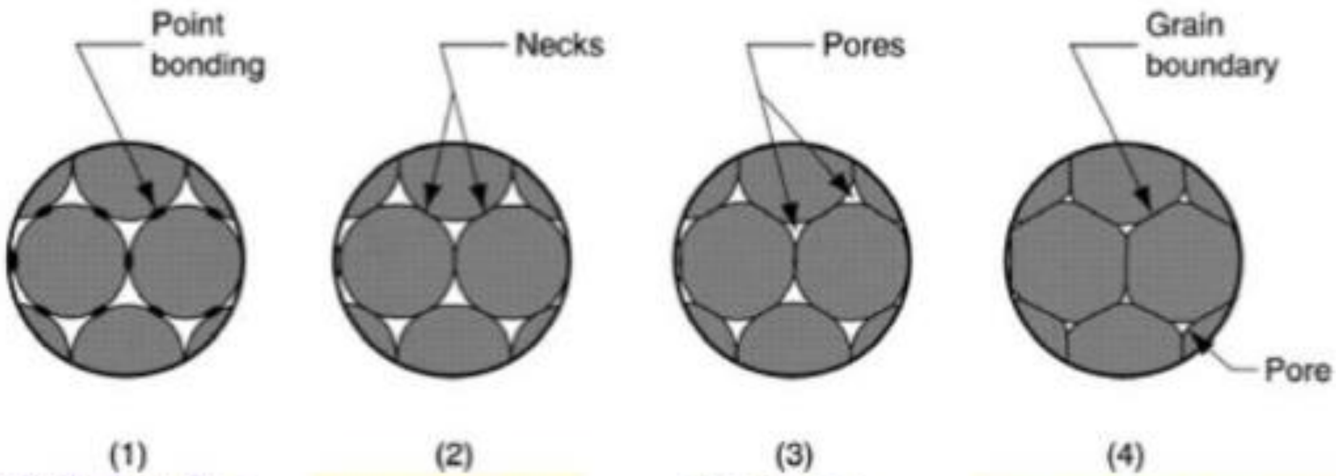


Sintering of New Ceramics

- Since the plasticity needed to shape the new ceramics is not normally based on water, the drying step required for traditional green ceramics can be omitted for most new ceramic products
- The sintering step is still very much required
- Functions of sintering are the same as before:
  1. Bond individual grains into a solid mass
  2. Increase density
  3. Reduce or eliminate porosity

Sintering

Solid state sintering



particle bonding is initiated at contact points

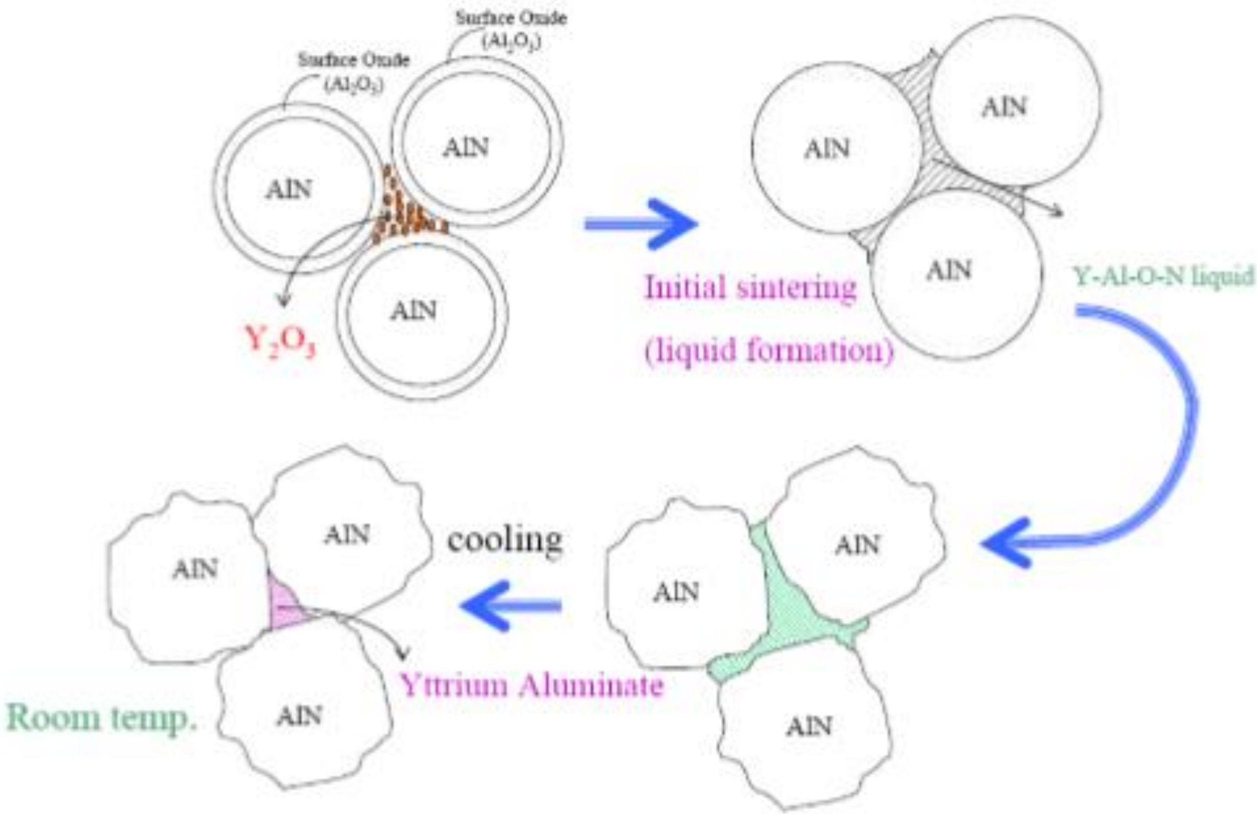
contact points grow into "necks";

the pores are reduced in size

grain boundaries develop in place of the necked regions

Sintering

Liquid state sintering



Finishing Operations for New Ceramics

- Parts made of new ceramics sometimes require finishing, which has one or more of the following purposes:
  1. Increase dimensional accuracy
  2. Improve surface finish
  3. Make minor changes in part geometry
- Finishing usually involves abrasive processes
  - Diamond abrasives must be used to cut the hardened ceramic materials