MATERIALS SCIENCE

SSP 2412

PROCESSING OF SEMICONDUCTORS AND CERAMICS

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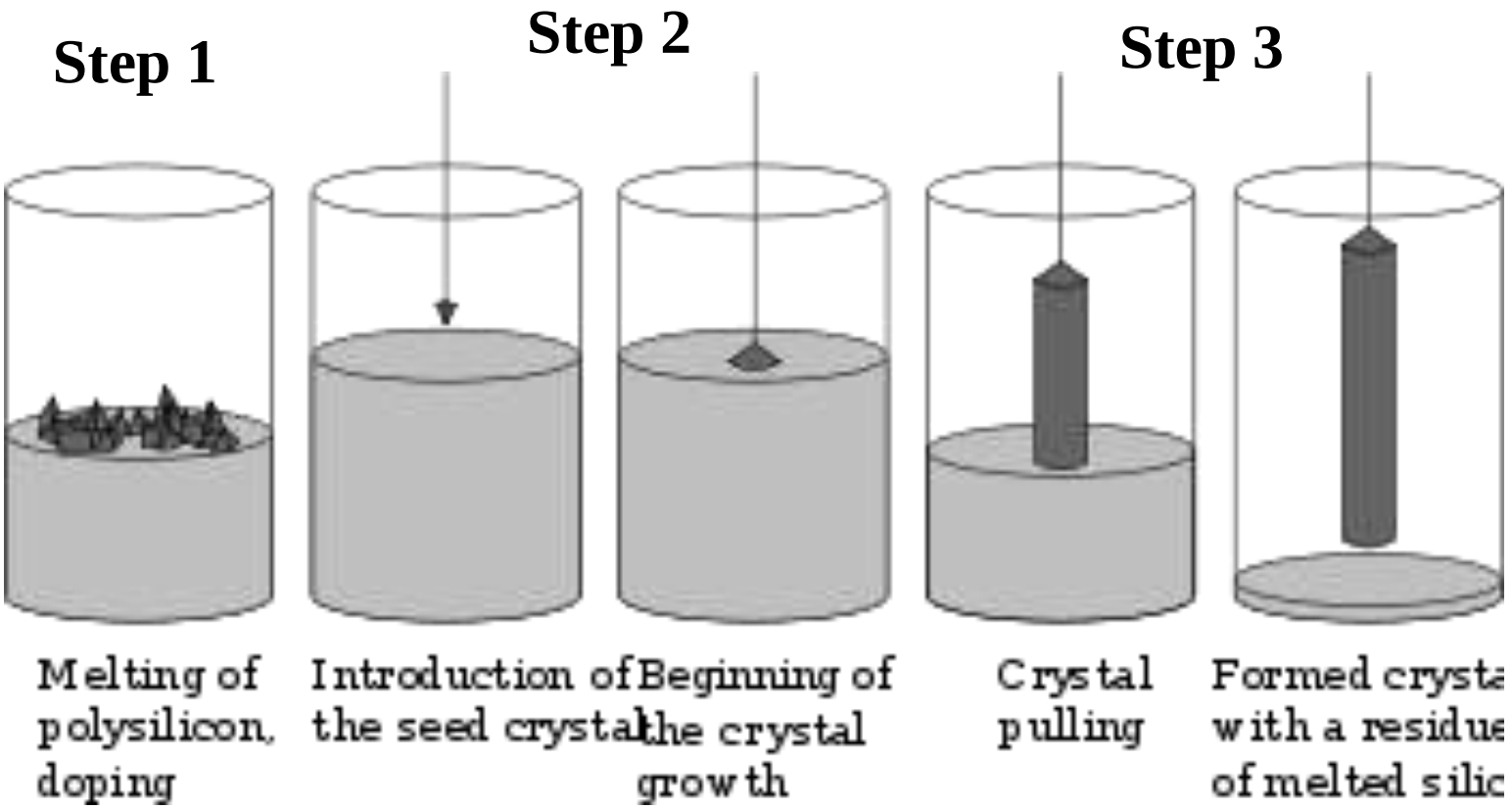
FABRICATING SILICON

- Quartz, or Silica, Consists of Silicon Dioxide
- Sand Contains Many Tiny Grains of Quartz
- Silicon Can be Artificially Produced by Combining Silica and Carbon in Electric Furnice
- Gives Polycrystalline Silicon (multitude of crystals)
- Practical Integrated Circuits Can Only be Fabricated from Single-Crystal Material

CRYSTAL GROWTH

- **CZOCHRALSKI PROCESS is a Technique in Making Single-Crystal Silicon**
- **A Solid Seed Crystal is Rotated and Slowly Extracted from a Pool of Molten Si**
- **Requires Careful Control to Give Crystals Desired Purity and Dimensions**

The **Czochralski process** is a method of crystal growth used to obtain single crystals of semiconductors (Si, Ge), metals (Pd, Pt, Ag, Au), salts and many oxide crystals (LaAlO3, YAG, etc.)



Ingots

Step 1: High-purity, semiconductor-grade silicon (only a few parts per million of impurities) is melted down in a crucible , which is usually made of Quartz/iridium. Dopant impurity atoms such as boron or phosphorus can be added to the molten intrinsic silicon in precise amounts in order to dope the silicon, thus changing it into n-type or p-type extrinsic silicon. This influences the electrical conductivity of the silicon. A control system is used to maintain the temperature of the melt just a few degrees above the 2050 C of the alumia. In this case the atmosphere is mostly nitrogen to keep the quartzform oxidizing and reacting with the melt.

Step 2: A *seed crystal*, mounted on a rod, is dipped into the molten silicon. The seed crystal is lowered into the melt and just touches the top of the liquid. The melt goes into equilibrium with the seed crystals exterior and the seed is slowly withdrawn. If the temperature is too high, the seed melts and another must be added. If the temperature is too low, then the seed initiates the total crystallization of the melt. Temperature control is critical in this process.

Step 3: The seed crystal's rod is pulled upwards and rotated at the same time. By precisely controlling the temperature gradients, rate of pulling and speed of rotation, it is possible to extract a large, single-crystal, cylindrical ingot from the melt. This process is normally performed in an inert atmosphere, such as argon, and in an inert chamber, such as quartz. Crystals as large as 4-5 inches in diameter can be produced with lengths over 1 to 2 feet.

As the seed crystal is withdrawn (and rotated- about 30 rpm) the newly formed crystal grows downward with the natural pull of gravity. The pull rate is about 25mm per hour. To create nearly perfect crystals the process is computer controlled using secondary measurements to maintain nearly perfect pulling speed and rotation. The secondary measurements may involve weighing the crucible during the process and continually calculating the weight loss of reactant. Or measuring spot temperatures near the crystal liquid contact point and adjusting the pull accordingly.

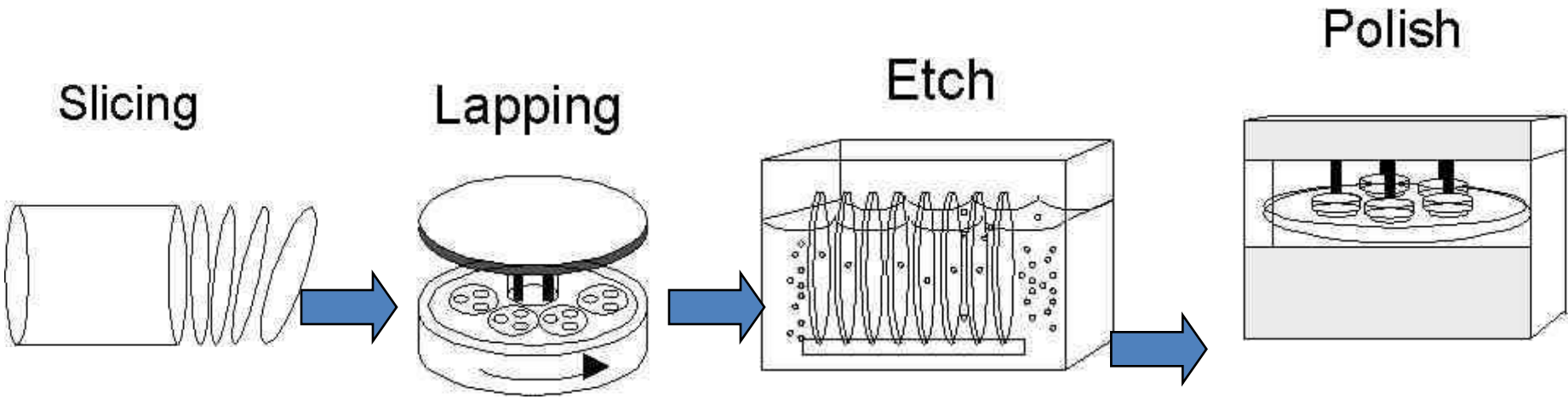
The electrical characteristics of the silicon are controlled by adding stuff like phosphorus or boron to the silicon before it is melted. The stuff added is called dopant and the process is called doping. This method is also used with semiconductor materials other than silicon, such as gallium arsenide. As a necessary step in the production of large-scale integrated circuit chips, the Czochralski method is a basic technique in the making of computers, TVs, cell phones and the advanced electronic equipment of all kinds that shape modern life as we know it at the beginning of the 21st Century.

CYLINDER OF MONOCRYSTALLINE

- The Silicon Cylinder is Known as an Ingot
- Typical Ingot is About 1 or 2 Meters in Length
- Can be Sliced into Hundreds of Smaller Circular Pieces Called Wafers
- Each Wafer Yields Hundreds or Thousands of Integrated Circuits

WAFER MANUFACTURING

- The Silicon Crystal is Sliced by Using a Diamond-Tipped Saw into Thin Wafers
- Sorted by Thickness
- Damaged Wafers Removed During Lapping
- Etch Wafers in Chemical to Remove any Remaining Crystal Damage
- Polishing Smoothes Uneven Surface Left by Sawing Process



Further Silicon Processing

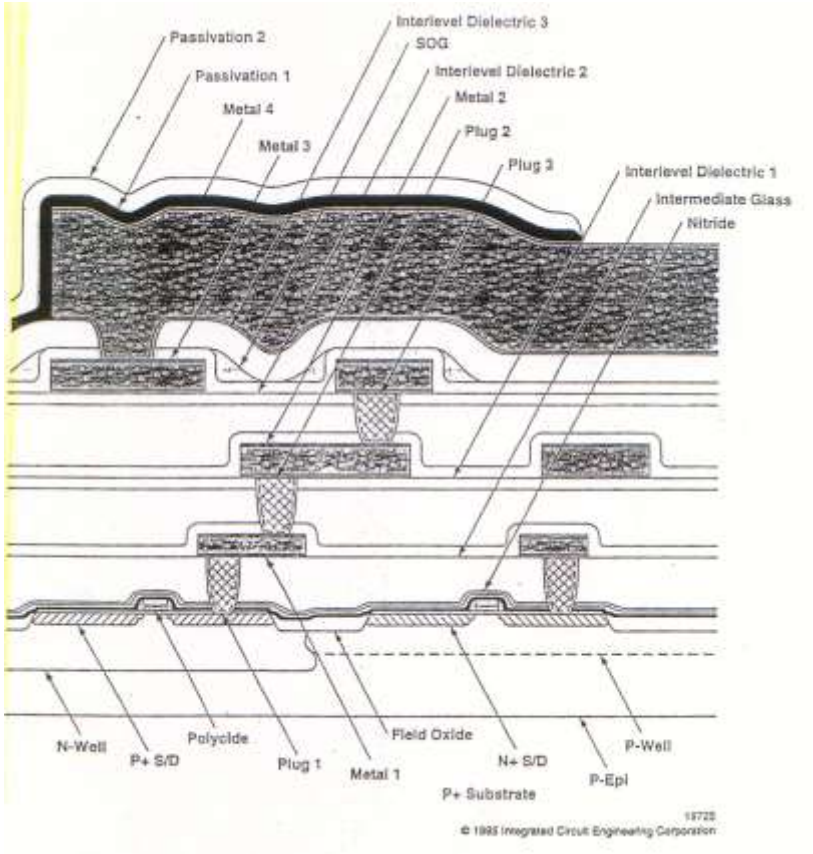
Photolithography

Oxidation of silicon

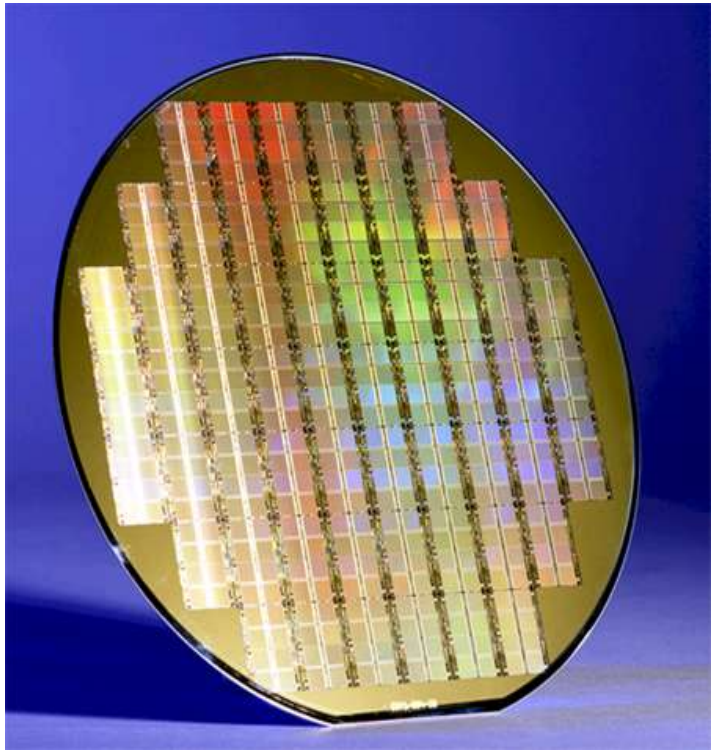
Diffusion & ion implantation

Device Manufacturing

0.5µ CMOS Process Flow



Fab



PROCESSING OF CERAMICS

Processing of Traditional Ceramics

Processing of Ceramics

- Generally procedure involves:
  - Crushing/grinding (Comminution) material into very fine particles
  - Mixing with additives to impart certain characteristics
  - Shaping
  - Drying
  - Firing

Ceramics Particulate Processing - continued

- For traditional ceramics, the powders are usually mixed with water to temporarily bind the particles together and achieve the proper consistency for shaping
- For new ceramics, substances other than water are used as binders during shaping
- After shaping, the green parts are fired (sintered), whose function is the same as in powder metallurgy:
  - To effect a solid state reaction which bonds the material into a hard solid mass

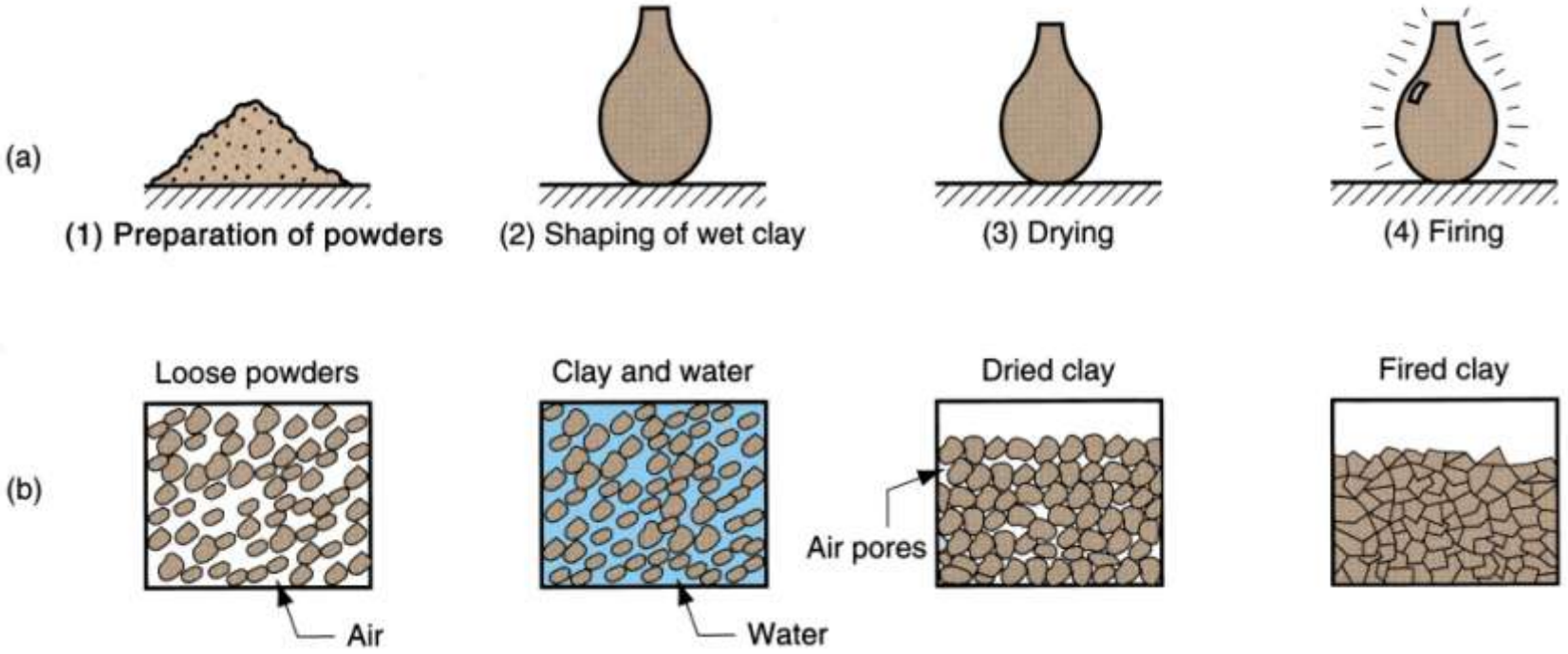


Figure 17.1 - Usual steps in traditional ceramics processing: (1) preparation of raw materials, (2) shaping, (3) drying, and (4) firing

Part (a) shows the workpart during the sequence, while (b) shows the condition of the powders

Preparation of the Raw Material for Traditional Ceramics

- 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 raw ceramic material usually occurs in nature as rocky lumps, and reduction to powder is the purpose of the preparation step in ceramics processing

Comminution- reducing particle size

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

- Comminution techniques are most effective on brittle materials such as cement, metallic ores, and brittle metals
- 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), the reduction ratio in each stage being in the range 3 to 6
- Crushing of minerals is accomplished by compression against rigid surfaces or by impact against surfaces in a rigid constrained motion

Jaw Crusher

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

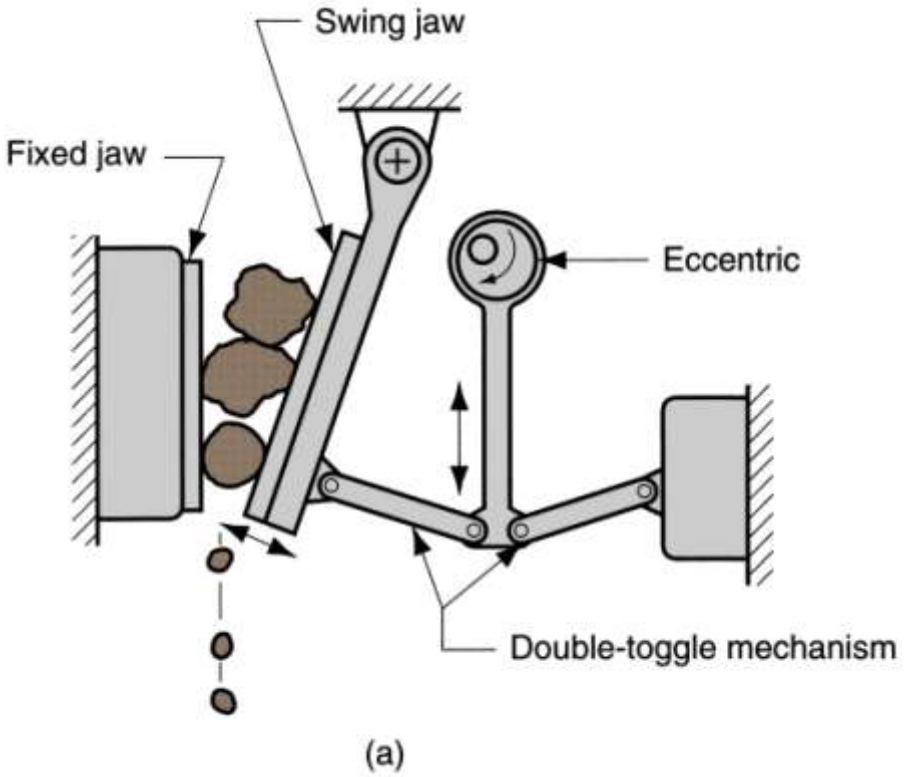


Figure 17.2 -

Crushing operations:
(a) jaw crusher

Roll Crusher

Ceramic lumps are squeezed between rotating rolls

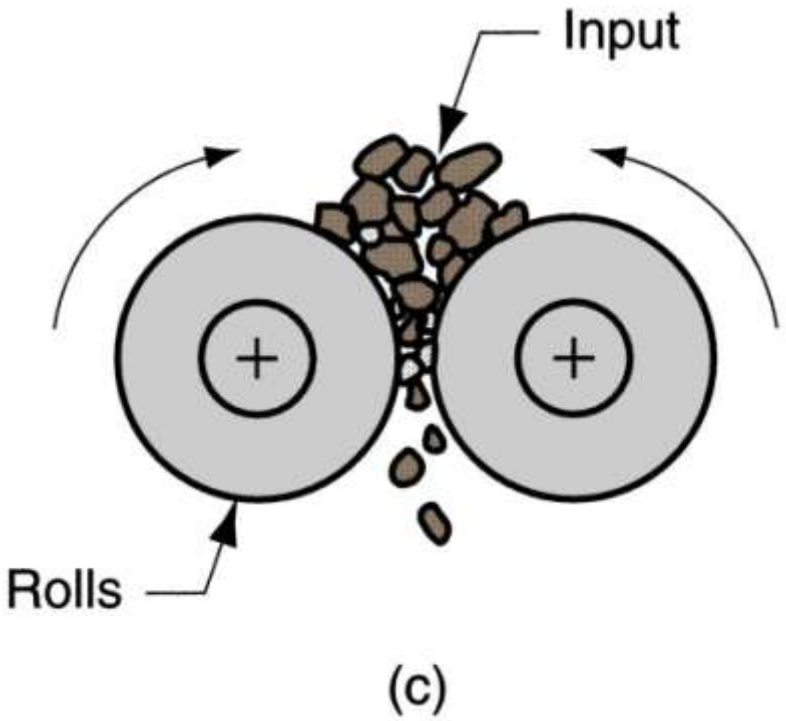


Figure 17.2 - Crushing operations: (c) roll crusher

Grinding

In the context of comminution, grinding refers to the operation of reducing the small pieces after crushing to a fine powder

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

Ball Mill

Hard spheres mixed with stock are rotated inside a large cylindrical container; the mixture is carried up the container wall as it rotates, and then pulled back down by gravity for grinding action

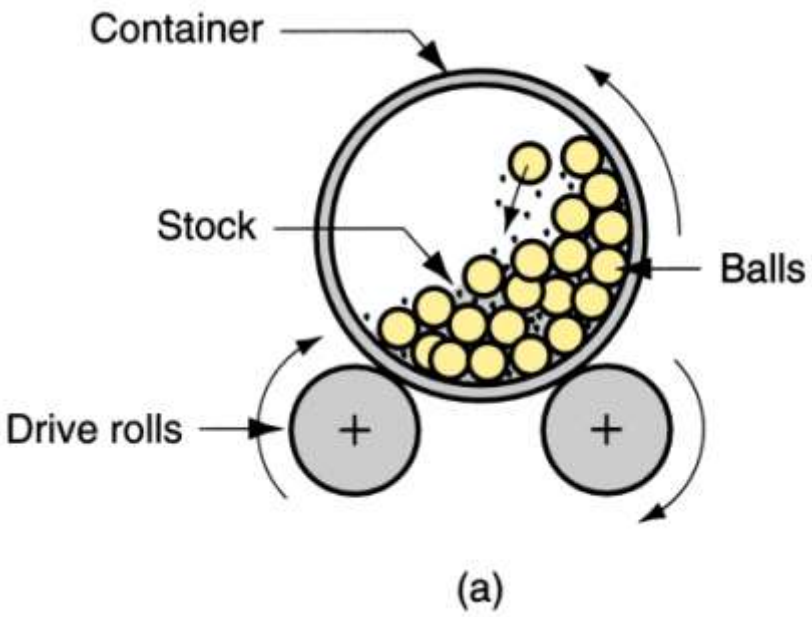


Figure 17.3 - Mechanical methods of producing ceramic powders: (a) ball mill

Roller Mill

Stock is compressed against a flat horizontal grinding table by rollers riding over the table surface

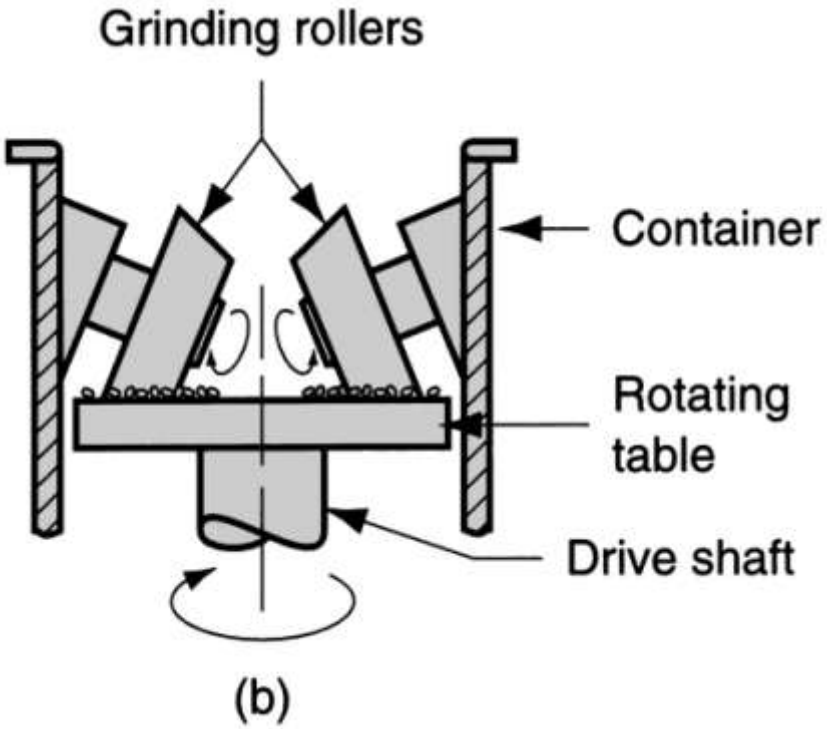


Figure 17.3 -

Mechanical methods of producing ceramic powders: (b) roller mill

Ingredients of Ceramic Paste for Shaping

1. *Clay* (hydrous aluminum silicates) - usually the main ingredient because of ideal forming characteristics when mixed with water
2. *Water* – creates clay-water mixture with suitable plasticity for shaping
3. Non-plastic raw materials, such as *alumina* and *silica* - reduce shrinkage in drying and firing but also reduce plasticity of the mixture during forming
4. Other ingredients, such as *fluxes* that melt (vitrify) during firing and promote sintering, and *wetting agents* to improve mixing of ingredients

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

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

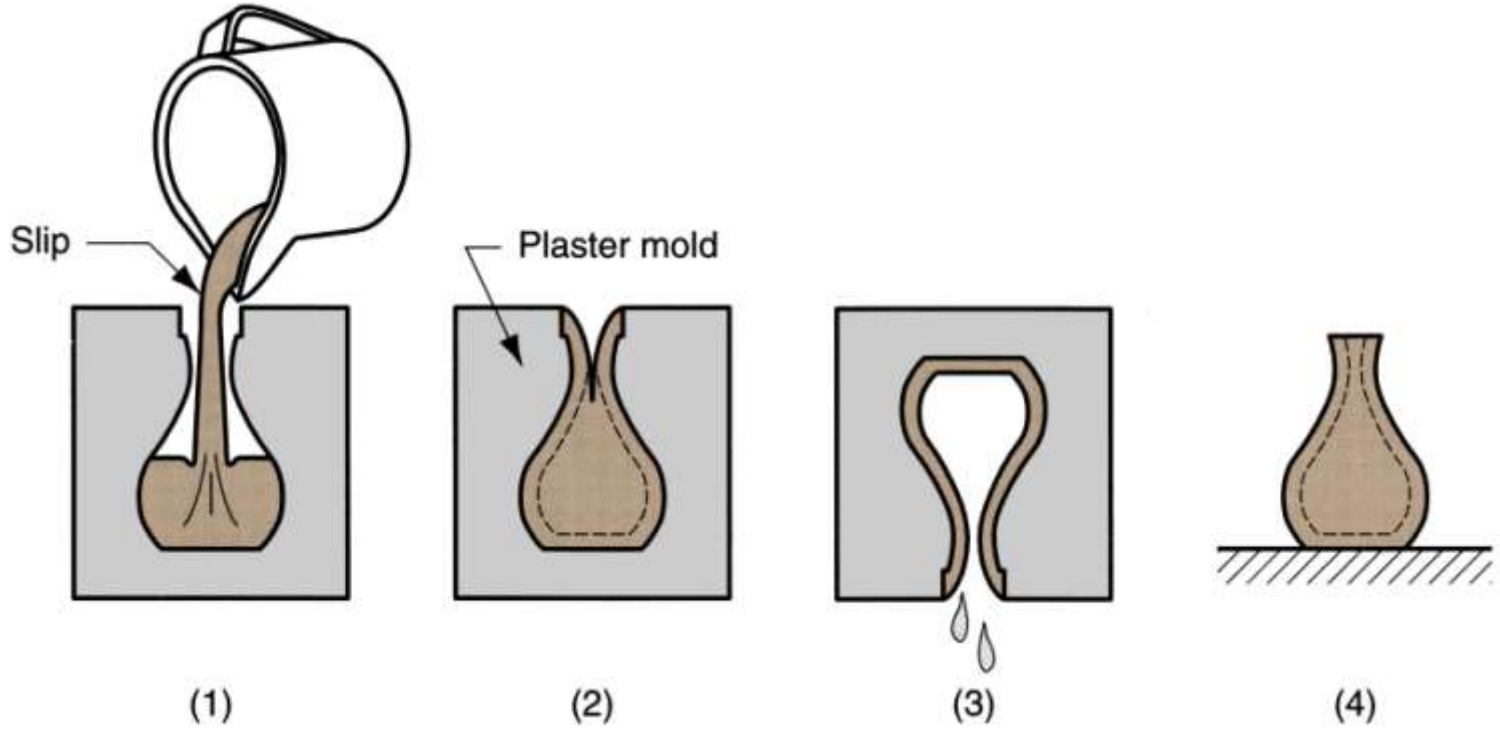


Figure 17.5 - Sequence of steps in drain casting, a form of slip casting: (1) slip is poured into mold cavity, (2) water is absorbed into plaster mold to form a firm layer, (3) excess slip is poured out, and (4) part is removed from mold and trimmed

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

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 of Traditional Ceramics

Heat treatment process that *sinters* the ceramic material

- Performed in a furnace called a *kiln*
- Bonds are developed between the ceramic grains, and this is accompanied by densification and reduction of porosity
- Therefore, additional shrinkage occurs in the polycrystalline material in addition to that which has already occurred in drying
- In the firing of traditional ceramics, a glassy phase forms among the crystals which acts as a binder

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
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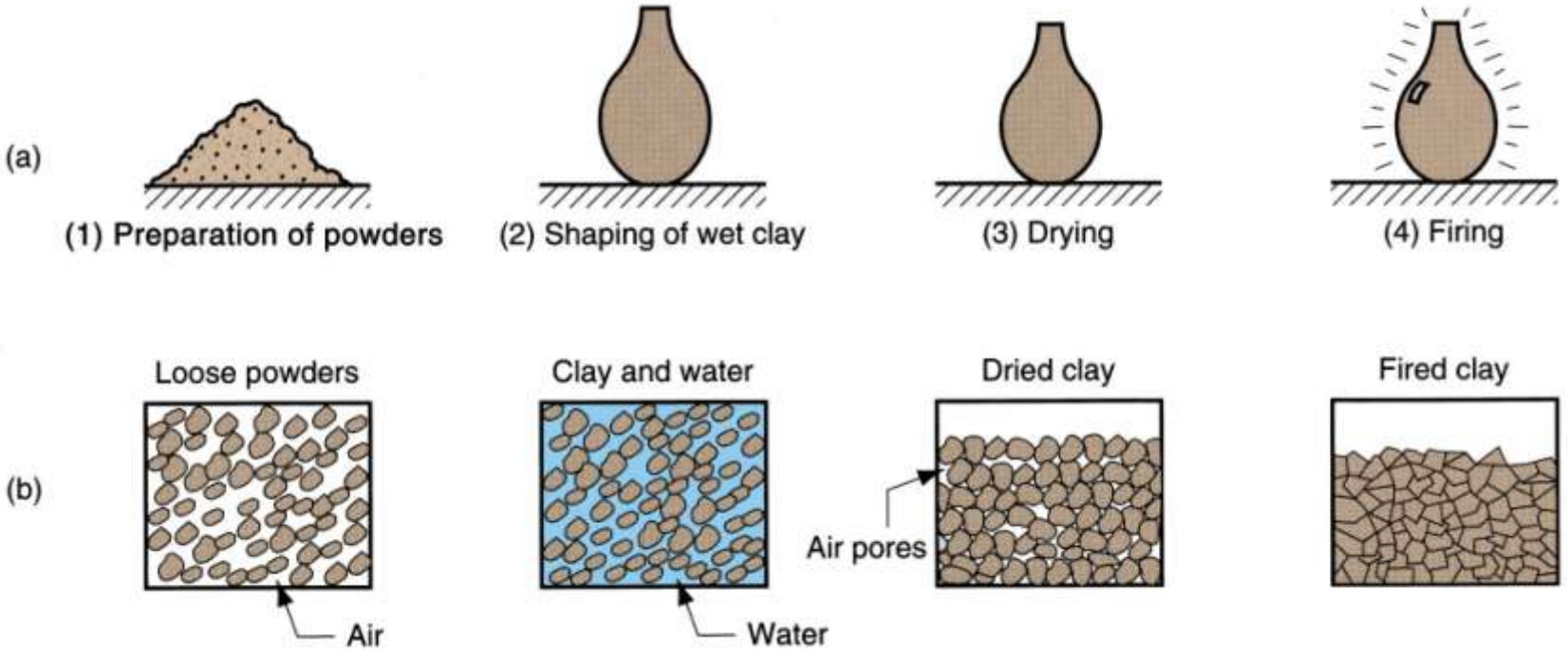

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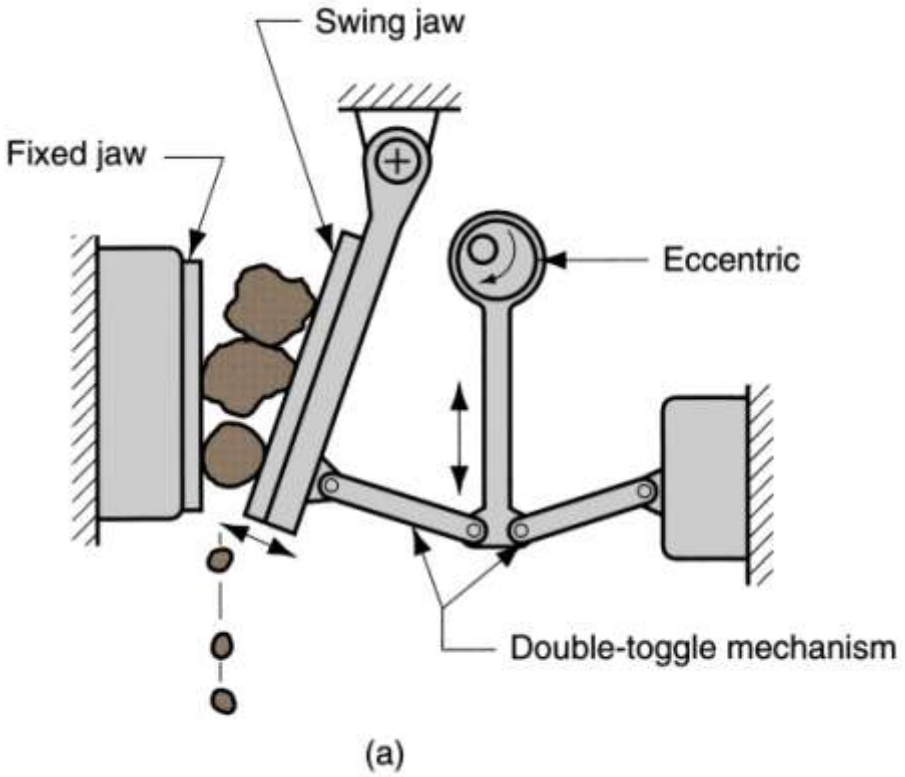

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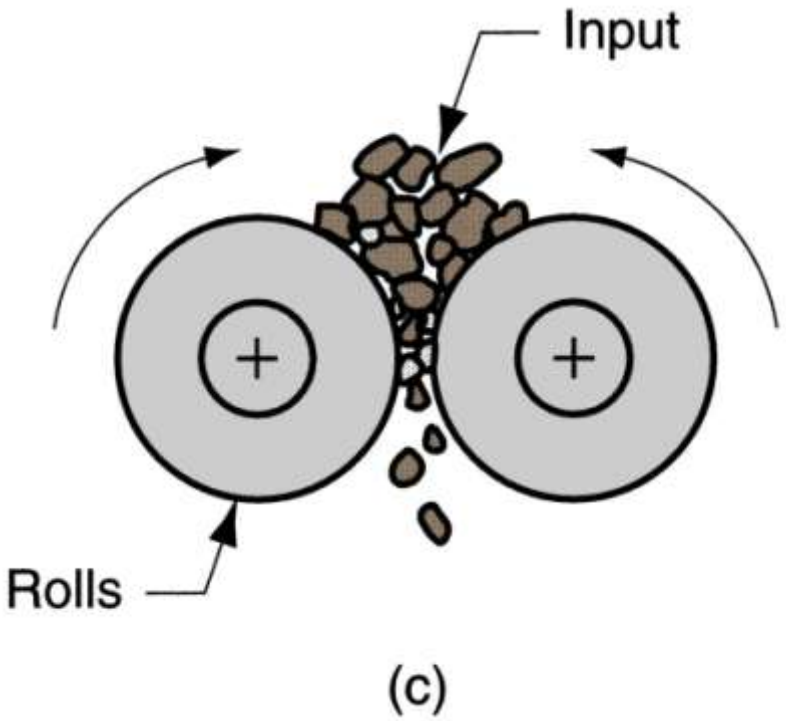

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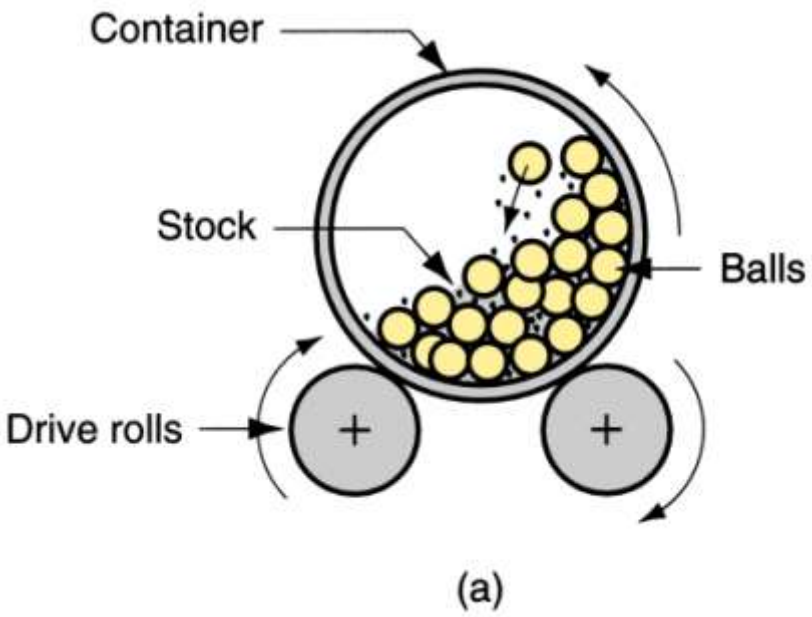

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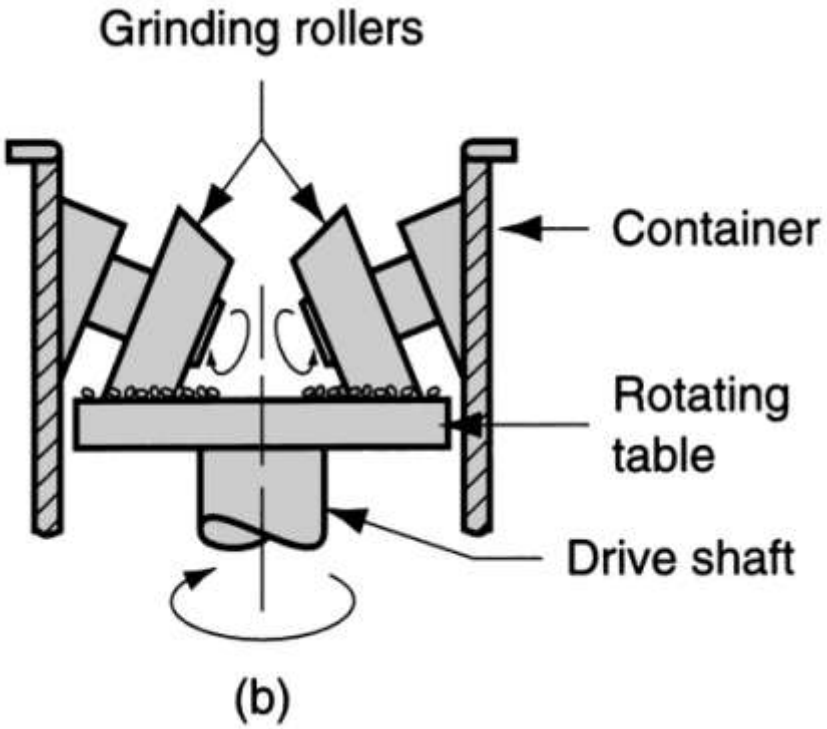

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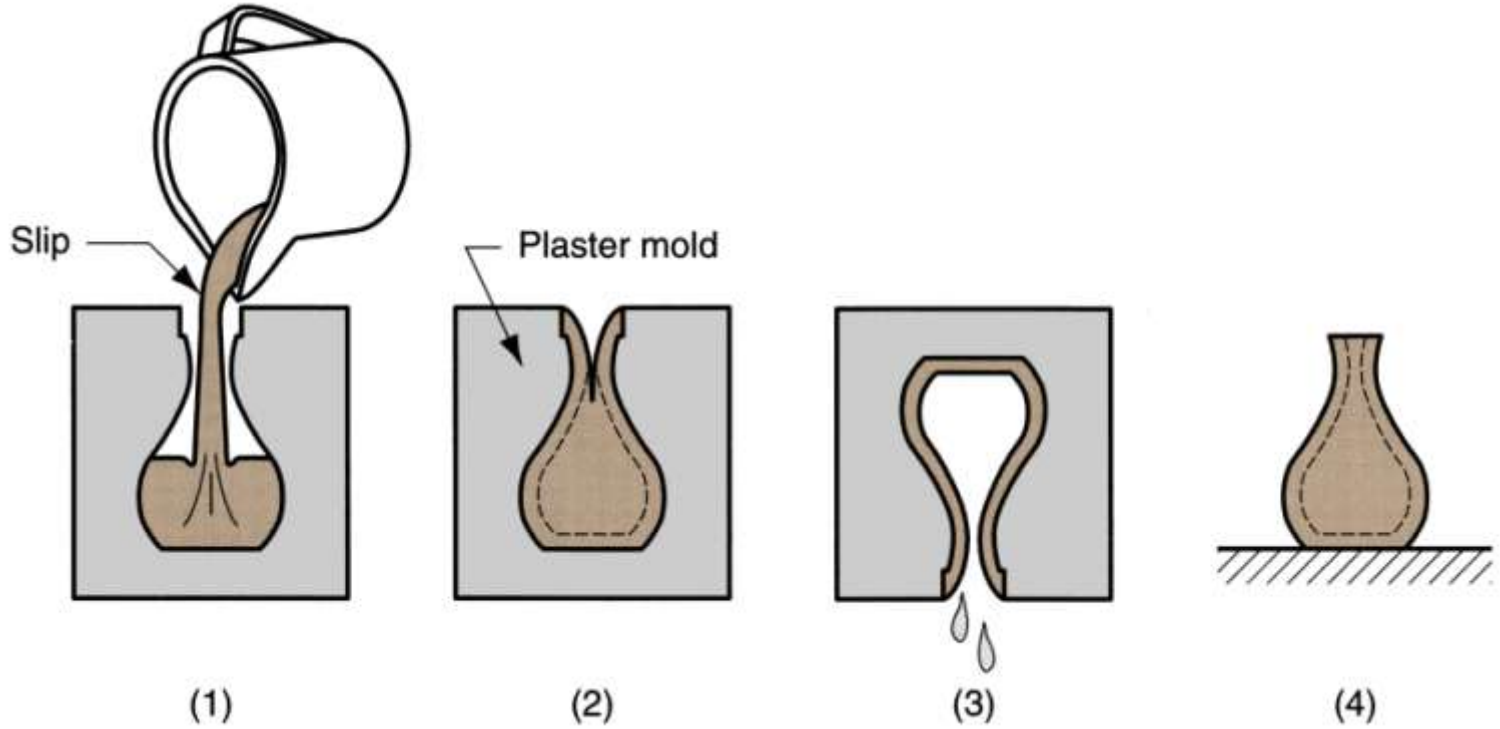

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