Ceramic and glass technology

Row materials preparation

Plastic raw materials preparation
- Aging
- Wet milling
- Mastication

Solid raw materials preparation
- Mixing
- Seving
- Grain size reduction

Milling
- Very fine milling ($\phi < 0.1 mm$)
  - Vibration mill

- Fine milling ($\phi = 0.1 - 1 mm$)
  - 1. Ball mill
  - 2. Disc mill
  - 3. Conical mill

- Fine ($\phi = 1 - 10 mm$)
  - 1. Hummer mill
  - 2. Crushing rolls

Crushing
- Coarse ($\phi > 10 mm$)
  - 1. Jaw crusher
  - 2. Gyratory crusher
  - 3. Conical crusher
Manufacturing of ceramics and glasses

**Shaping or forming** is the key stage in the manufacturing of any ceramic article, not only because it determines final geometry and thus function, but also – and above all – because it has to combine the properties of the raw materials in way that allows the subsequent stages of the production process to be completed successfully. The method used for shaping ceramic can be grouped as:

1. **wet shaping**

   A wet-mixed mass is formed to required shape by such methods as slip casting, tape casting and extrusion and then fired.

2. **dry shaping**

   This involves powder being compressed before being fired and includes die pressing, reaction bonding and injection molding.

3. **Manufacture of glass and glass ceramic**

   Glass melts are produced by heating to melting point the mixed raw materials before shaping them by some moulding machinery.

1. **wet shaping**

   **1.1 slip casting**

   In this method a slurry (the combination of dry powders with a dispersant such as water is called a *slurry*) of fine clay is called a *slip* is poured a porous gypsum mold. As capillary suction of the water from the slurry into the mold proceeds, the slurry particles coagulate near the mold surface, and the cast is formed. Variations in the slip casting process include the application of pressure (*pressure casting*), vacuum (*vacuum-assisted casting*), or centrifugal force (*centrifugal casting*), all of which serve to increase the casting rate. There are two main types of slip casting as illustrated in Figure 1: *drain casting* and *solid casting*. In drain casting, the molds are first filled with the slurry. After some initial solidification has taken place, the excess slurry is drained from the molds. This technique is suitable for the formation of objects with hollow centers, such as crucibles or tubes. In solid casting, the entire amount of slurry in the mold is used to form a dense, finished shape. The important steps of the slip casting process that will be elaborated upon here include slurry preparation, mold filling, draining, and partial drying while in the mold.
Slurries are prepared from a mixture of liquid (typically water), milled powders or granules, and additives

1.1.1 pressure casting

This method involves increasing the pressure, $\Delta P$, which causes liquid migration from the slip into the mold. For a typical gypsum mold, $\Delta P$ is less than about 200 kPa. In pressure casting, the cast thickness can be increased by a factor of 2–3 through application of external pressures on the slip of up to 1.5 MPa. Furthermore, pressure casting can reduce the residual water content in the cast from 1% to 3.5%, but shrinkage anisotropy also tends to increase. Increasing the casting pressure reduces the cycle time for a cast as shown in fig (2), but the higher pressure increases the equipment requirements. High-pressure slip casting at up to 4 MPa is used for the small volume production of small shapes. One disadvantage of pressure casting is the larger differential pressure produced across the cast. A large gradient in the effective stress is produced, which produces a density gradient in the cast. The density gradient can cause differential shrinkage and shape distortion upon drying. A variation on pressure casting is used to
form hard ferrite magnets which have a highly oriented microstructure. In this process, a die set with pistons that are magnetically permeable is drilled to permit flow of liquid. The die set is charged with a well-dispersed slurry of the ferrite particles. A magnetic field is applied to orient the particles, and the pistons are forced into the die to form a dense cast with oriented particles.

Fig (2): casting kinetics for various applied pressure.

1.1.2 Vacuum casting

is widely used for forming very porous refractory insulation having a complex shape. The slurry typically contains partially deflocculated ceramic powder and chopped refractory fiber. The fiber increases the viscosity and liquid requirement and increases the porosity of the cast. Vacuum casting may also be used to describe the process of applying a vacuum to the external surface of the gypsum mold during slip casting to increase the casting rate.

1.1.3 Centrifugal casting

is used for forming advanced ceramics having a complex shape where a very high cast density is required. Centrifuging increases the drive force for the settling of the particles, and liquid is displaced to the top of a centrifuge cell. The particles having a greater size or density settle at a faster rate and a structural gradient is produced. The casting rate increases with centrifugal speed and the flow rate of the liquid away from the deposition surface. Casts of complex shapes having a uniform density and sedimentation rates of 0.6 mm/min can be obtained with this process.
1.2 Tape casting

As with slip casting, a tape casting slurry is prepared that contains deflocculated powders or granules, binders and/or plasticizers, and a solvent such as water. Unlike slip casting, however, the slurry can be processed into thin, flexible sheets called green sheets, which are then cut and dried. The term “green” refers to the fact that it is a pre-fired or pre-sintered product and has nothing to do with color. The dried tape is rubbery and flexible due to the high binder content, and has a very smooth surface. Tape-cast ceramics are used primarily as substrates for electronic conductors, resistors, capacitors, photovoltaic cells, electrical sensors, and solid electrolytes for batteries. The electronic materials can be printed on the tape surface and they become an integral part of the ceramic component upon firing. Ceramic powders used for tape casting typically have a maximum particle size of 1–5 μm. Because the tapes are often used for electronic component fabrication, chemical homogeneity is critical. Particle size and dispersion also affect dimensional stability during the drying and firing processes. Therefore, the liquid–solvent system must dissolve the additives yet permit their adsorption on the ceramic particles. A solvent blend is thus typically used. Organic solvents have a low viscosity, low boiling point, low heat of vaporization, and high vapor pressure, all of which promote short drying times.

Binder and plasticizer concentrations for tape casting are much higher than for slip casting and for most other types of slurry processing such as extrusion and pressing. More flexible molecules such as acrylics and vinyls are common. The combination of binder and plasticizer must be carefully controlled to provide the required mechanical properties but permit a high concentration of ceramic particles in the slurry. The slurry is cast on a smooth, clean, impervious surface called the carrier, which is typically made of Teflon or cellulose acetate. Casting machines range in size up to 25 m in length, are several meters in width, and have casting speeds up to 1500 mm/min. Tape thicknesses are in the range of 25–150 μm. The tape is formed when the slurry flows beneath a blade, forming a film on the carrier. The thickness of the tape varies directly with the height of the blade or gate above the carrier, the speed of the carrier, and the drying shrinkage. A flow model that gives the dependence of the tape thickness, \( H \), as a function of the carrier velocity, \( v \), can be obtained using the parameters in Figure(3)

\[
H = AD_r h_0 \left( 1 + \frac{h_0^2 \Delta P}{6 \eta_s v L} \right) \quad \text{.............. (2)}
\]

Where:
\( A \) : is a constant that depends on the amount of side flow.
\( D_r \) : is the ratio of the density of the slurry to the density of the as-dried tape.
\( h_0 \) : is the cast thickness at the blade.
\( \Delta P \) : is the pressure that causes the slurry to flow.
\( \eta_s \): is the viscosity of the slurry,
\( L \): is the length of the casting

Fig (3): Tape casting flow model.

Equation (2) indicates that the tape thickness is nearly independent of variations in the carrier speed when the ratio \( h_0/\eta_s \) is small. A high slurry viscosity and a carrier velocity exceeding about 0.5 cm cm/s are desirable for thickness uniformity, as illustrated in Fig(4)

Fig (4): Variation of tape thickness with carrier velocity and slurry viscosity.
1.2.1 Non-continuous tape casting

A blade spreads a suspension on fixed support (glass, stainless steel, plastic film). For given suspension, the height of the blade and speed of the reservoir will determine the thickness of the tape. This casting technique suitable for high thickness products.

![Diagram of non-continuous tape casting](image)

Fig (5) principles of non-continuous tape casting

1.2.2 Continuous tape casting

the mobile support (stainless steel tape, plastic film) moves under fixed reservoir in which the level of suspension is maintained constant. In this method the thickness is adjusted by the speed of the supporting tape and the angular position of the tank with respect to cylinder. The speed of the support is continuously controlled by the measurement of tape thickness. The coating technology is largely used in production of low thickness.
Fig (6) principles of continuous tape casting: A) coating, B) surface application.

Notes:
- **Slurry**: The combination of dry powders with a dispersant such as water.
- The solids contents of slurries are very high, typically 50 wt% solids and above.
- A solution or suspension has solids contents less than 50 wt% solids.
- Semidry materials of controlled powder agglomerates called granules.