بسم الله الرحمن الرحيم
Ceramic materials &
their processing
Ceramics materials:

- An organic compound which containing of metals and one or more non-metals.
- i.e. $\text{Al}_2\text{O}_3$ and pottery etc.
- Types:
  - Traditional ceramic
  - Advance ceramic
  - Glasses

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Traditional Ceramics:
• Those ceramic which are composed of clay mineral (porcelain) as well as cement and glass

Products:
• Traditional ceramic are include pottery, brick and tiles etc.

Advance ceramics:
• Those ceramic which are made by synthetically produced from raw materials.

Product:
Advance ceramic are include Al2O3, bio-ceramic etc.

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Properties:-

- These materials are insulator of heat and electricity and more resistance to high temperature.
- These materials are stronger than that of metals because of their covalent and ionic bonding.
- These materials are less density it means they are lighter than metals.
- The inability of slip of ceramic materials can cause more difficult in the processing and performance.
- Some oxide of ceramic show magnetic behaviors such as Fe₃O₄.
- They are brittle materials.
PROCESSING OF CERAMICS AND CERMETS

- Processing of Traditional Ceramics
- Processing of New Ceramics
- Processing of Cermets
- Product Design Considerations
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

- The solidification processes for glass are covered in a different slide set

- The particulate processes for traditional and new ceramics as well as certain composite materials are covered in this slide set
Overview of Ceramics Particulate Processing

- Traditional ceramics are made from minerals occurring in nature.
- Products include pottery, porcelain, bricks, and cement.
- New ceramics are made from synthetically produced raw materials.
- Products include cutting tools, artificial bones, nuclear fuels, and substrates for electronic circuits.
- The starting material for all of these items is powder.

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Overview of 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.
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 work part 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
Fabrication Techniques:

- First of all raw material usually have to go through milling or grinding operation in which particle size is reduced which is done by crusher such as jaw or roll crusher.
- The product of crusher is to screening to made powder Product having desired shape of particle size.
- The powdered product must be thoroughly mixed with water to make plastic paste for creation of traditional ceramic product.
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
Figure 17.4 - Four categories of shaping processes used for traditional ceramics, compared to water content and pressure required to form the clay.
Slip Casting

A suspension of ceramic powders in water, called a *slip*. This 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.
Overview of Plastic 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
  • Mechanized methods generally use a mixture with less water so starting clay is stiffer
Plastic Forming Methods

- Hand modeling (manual method)
- Jiggering (mechanized method)
- Plastic pressing (mechanized method)
- Extrusion (mechanized method)
Hand Modeling

Creation of the ceramic product by manipulating the mass of plastic clay into the desired geometry

- **Hand molding** - similar only a mold or form is used to define portions of the part geometry

- **Hand throwing** on a potter's wheel is another refinement of handcraft methods
  
  - *Potter's wheel* = a round table that rotates on a vertical spindle, powered either by motor or foot operated treadle
  
  - Products of circular cross-section can be formed by throwing and shaping the clay, sometimes using a mold to provide the internal shape
Jiggering

Similar to potter's wheel methods, but hand throwing is replaced by mechanized techniques

Figure 17.6 - Sequence in jiggering: (1) wet clay slug is placed on a convex mold; (2) batting; and (3) a jigger tool imparts the final product shape
Plastic Pressing

Forming process in which a plastic clay slug is pressed between upper and lower molds contained in metal rings

- Molds are made of porous material such as gypsum, so when a vacuum is drawn on the backs of the mold halves, moisture is removed from the clay
- The mold sections are then opened, using positive air pressure to prevent sticking of the part in the mold
- Advantages: higher production rate than jiggering and not limited to radially symmetric parts
Extrusion

Compression of clay through a die orifice to produce long sections of uniform cross-section, which are then cut to required piece length

- Equipment utilizes a screw type action to assist in mixing the clay and pushing it through die opening
- Products: hollow bricks, shaped tiles, drain pipes, tubes, and insulators
- Also used to make the starting clay slugs for other ceramics processing methods such as jiggering and plastic pressing
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

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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

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Figure 17.8 - Volume of clay as a function of water content

Relationship shown here is typical; it varies for different clay compositions
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
Figure 17.9 - Typical drying rate curve and associated volume reduction (drying shrinkage) for a ceramic body in drying.

Drying rate in the second stage of drying is depicted here as a straight line; the function is sometimes concave or convex.
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
  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
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.
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

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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
Reference:

- ©1979 Johnson, H.V “Manufacturing process”