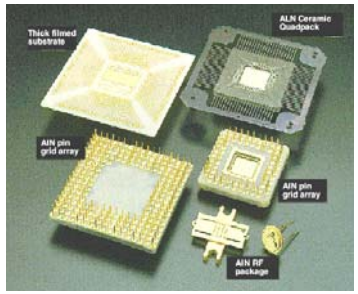
Outline

- Introduction: Ceramic materials
- Carbon based materials
- Applications of ceramics
- Ceramic Processing
- Mechanical properties of Ceramics

Ceramics

- Why study ceramic materials?
  - Very "traditional" (crude civil engineering material)
  - BUT also new **high-tech** ceramics and applications.
    - Optical (transparency) opto-electronic.
    - Electronic (piezoelectrics, sensors, superconductors)
    - Thermo-mechanical (engine materials)
    - Cutting tools

In 1974, the U.S. market for the ceramic industry was estimated at **$20 million**. Today, the U.S. market is estimated to be over **$35 billion**.

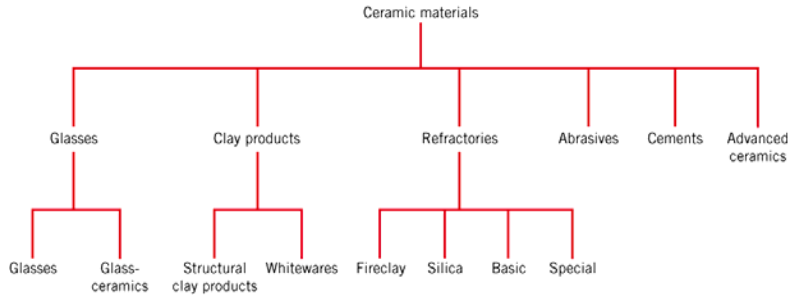


Courtesy of NTK Technical Ceramics

Ceramics / Introduction

- *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)
- Bonds are partially or totally ionic, and can have …….. of ionic and covalent bonding
- Ceramics are typically characterized as possessing a high melting temperature (i.e., "refractory"),
- Generally hard and brittle
- *Generally* electrical and thermal **insulators** (exceptions: graphite, diamond, AlN… and others)
- Can be optically opaque, semi-transparent, or transparent
- Traditional ceramics – based on clay (china, bricks, tiles, porcelain), glasses.
- New ceramics for electronic, computer, aerospace industries.

Classifications of Ceramics



Carbon- based materials

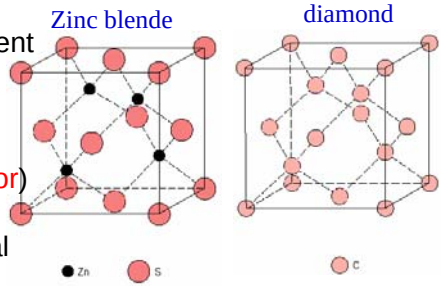
Since graphite is often considered a ceramic material, and since the crystal structure of diamond is related to the zinc blende structure, discussion of carbon- based materials typically accompanies ceramics.

We will review the crystal structure and major properties of the three known polymorphs of carbon:

- **diamond (metastable)**
- **graphite (stable)**
- **fullerene (stable)**

DIAMOND

- chemical bonding is purely covalent
- highly symmetrical unit cell
- extremely hard (……. known)
- low electrical conductivity
- high thermal conductivity (superior)
- optically transparent
- used as gemstones and industrial Grinding, machining and cutting



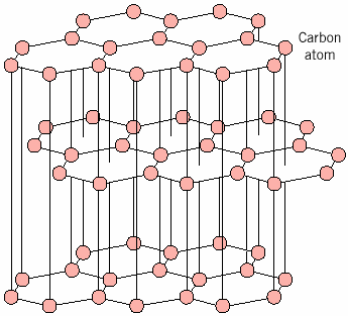
same crystal structure as ZnS but with carbon atoms exclusively

- Chemical vapor deposition (CVD)
- Thin films up to a few hundred microns Polycrystalline
- Applications: hard coatings (tool bits etc), machine components, "heat sinks" for high power semiconductor devices

GRAPHITE

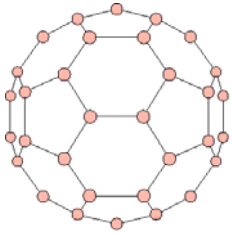
- Layered structure with strong bonding within the planar layers and weak, van der Waals bonding between layers
- Easy interplanar cleavage, applications as a lubricant and for writing (pencils)
- Good electrical conductor
- Chemically stable even at high temperatures
- excellent thermal shock resistance

Applications:
Commonly used as heating elements (in non- oxidizing atmospheres), metallurgical crucibles, casting molds, electrical contacts, brushes and resistors,
high temperature refractories, welding Electrodes, air purification systems, and in rocket nozzles.



FULLERENE

- discovered in 1985 by spark synthesis
- carbon bond to form a hollow spherical molecule, each consisting of 60 carbon atoms
- commonly called *"Buckminsterfullerene"* after R. Buckminster Fuller, original designer of the geodesic dome.
- The highly symmetrical nature of the bonding gives rise to a highly stable molecule.
- Individual C60 molecules bond together to form a FCC lattice
- other forms have recently been discovered including tubes and rods *(buckytubes)*
- reported to possess the **highest** ?

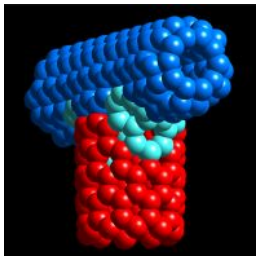


Buckminsterfullerenes (buckyballs)

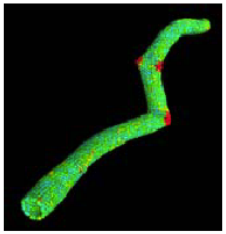
Possible applications:
- drug delivery
- low mass structural members

Carbon Nanotubes

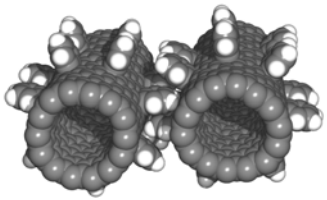
carbon nanotubes are expected to play an important role in future ***nanotechnology*** applications (nanoscale materials, sensors, machines, and computers)



Carbon nanotube T-junction



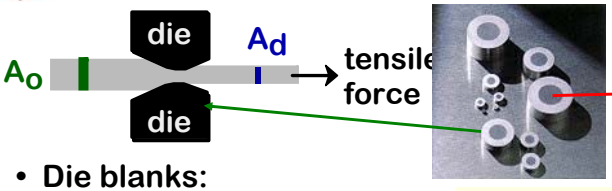
Nanotubes as reinforcing fibers in nanocomposites

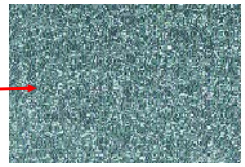


carbon nanotube gear

http://www.nas.nasa.gov/Groups/SciTech/nano/

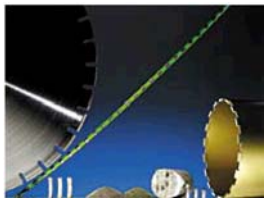
Applications





- **Die blanks:**
  - **Need wear resistant properties!**
- **Die surface:**
  - **4 μm polycrystalline diamond particles that are sintered on to a cemented tungsten carbide substrate.**

oil drill bits



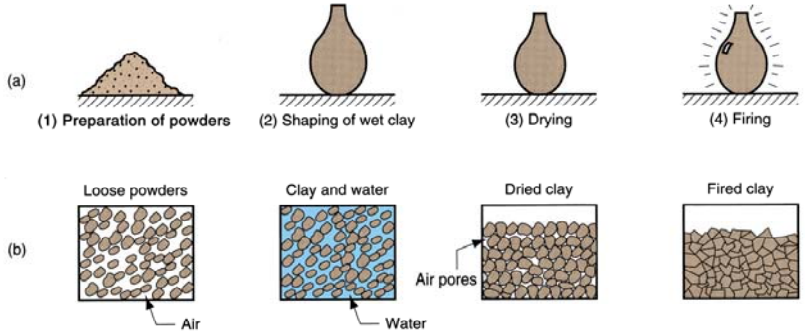
blades

- **Tools:**
  - **for grinding glass, tungsten, carbide, ceramics**
  - **for cutting Si wafers**
  - **for oil drilling**

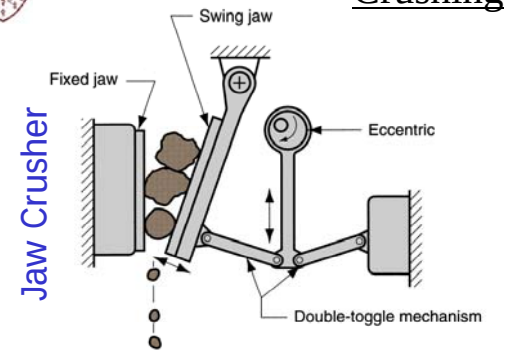
Traditional Ceramic Processing

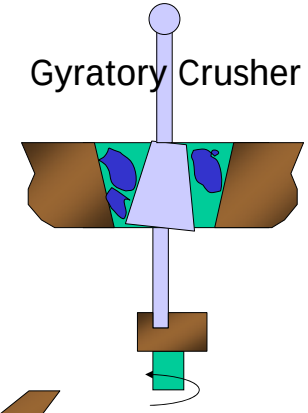
- Processing sequence
  - Preparing powders
  - Shaping of wet clay
  - Drying
  - Firing
- Preparation of Raw Materials
  - Comminution: Crushing and Grinding

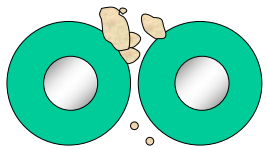
The more water in the mixture, the easier to form. But cracking during drying and sintering.



Crushing



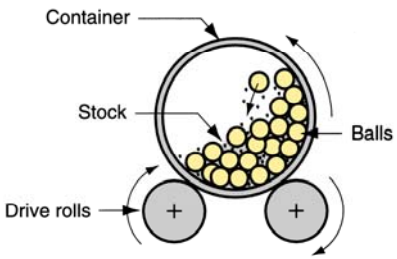




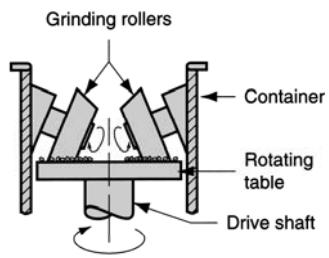
Roll Crusher

Hammer Mill

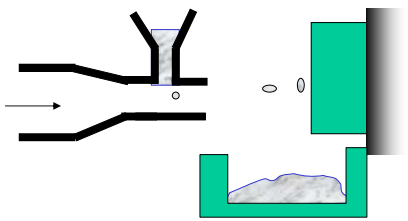
Grinding



Ball Milling

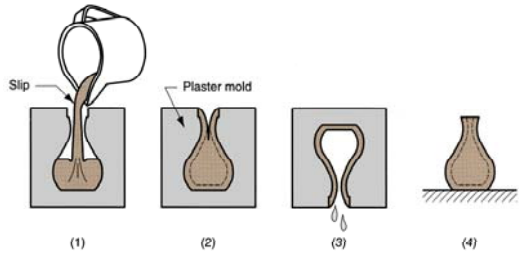


Roller Milling



Impact Grinding

Shaping: *Slip Casting*

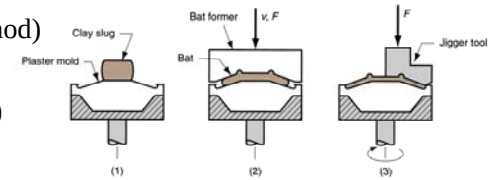


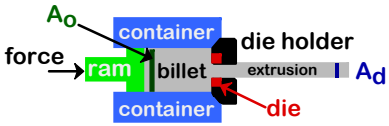
- A suspension of ceramic powders in water, called a *slip*, is poured into a porous plaster of paris mold so that water from the mix is absorbed into the plaster to form a firm layer of clay at the mold surface
- The slip composition is 25% to 40% water
- Two principal variations:
  - *Drain casting* - 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: *Plastic Forming*

- The starting mixture must have a plastic consistency, with 15% to 25% water
- Variety of manual and mechanized methods

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

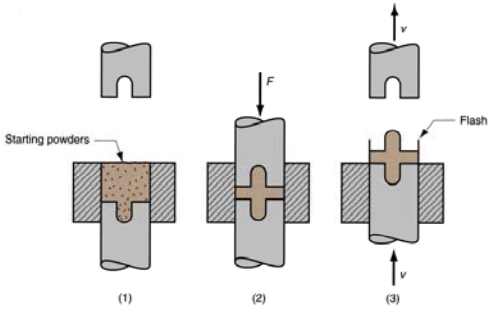




– Manual methods use clay with ……. **water** because it is more easily formed (*More water means greater shrinkage in drying*)

– Mechanized methods generally use a mixture with less water so starting clay is stiffer

Pressing Processes

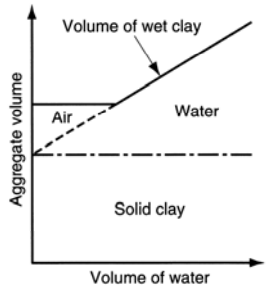


Semi-dry Pressing: Uses high pressure to overcome the clay's low plasticity and force it into a die cavity

- 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 ……..
- 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

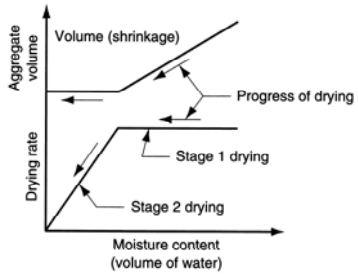
- Water must be removed from the clay piece *before firing*
- Shrinkage is a problem during drying because water contributes volume to the piece, and the volume is reduced when it is removed



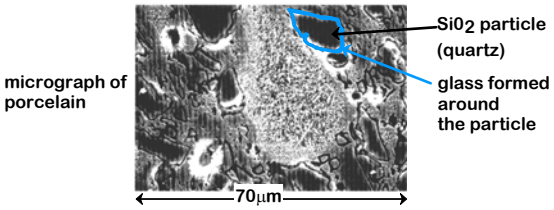
The drying process occurs in two stages:

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***

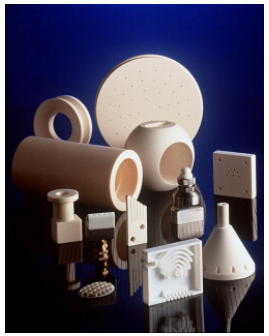


Firing and Glazing



- **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
- **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

New Ceramic Processing



- Simpler chemistry such as oxides, carbides and nitrides
- Water does not necessarily enhance the flow properties.
- Higher strength, hardness
- Additives into starting powder
  - *Plasticizer, binders, wetting, deflocculants and lubricants*

Processing steps

Greater Control of the starting powders is required

- Preparation of powder
  - **Freeze drying:** Salt dissolved into water, which freezes into droplets. Then water is removed. Salt decomposes during heating to form the ceramic powder.
  - **Precipitation from solution:** dissolved and filtered
- Shaping
  - Slip, casting, extrusion and dry pressing
  - Hot & Isostatic Pressing
  - Doctor-blade Process
  - Powder Injection Molding
- Sintering at …….. of melting temperature
- Finishing
  - surface finish, minor change geometry

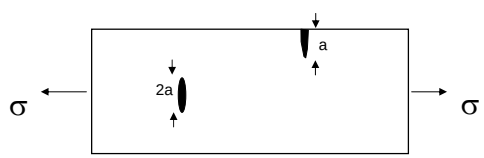
Cermet Processing

- Cemented Carbides (WC-Co, TiC-Ni & Cr_3C_2-Ti)
  - Carbide powders are sintered with metal (4-20%)
- Compaction – 20% Linear shrinkage, usually cold pressing but isostatic or hot pressing and extrusion are also used.
- Sintering – Liquid-phase sintering, free of porosity
- Secondary Operation – grinding, EDM and Ultrasonic machining

Design Consideration

- Good for …… loading not tensile loading
- Brittle and no ductility
- …… in shape
- Edge and corner: radii and chamfers except cutting tool (sharp edges)
- Shrinkage
- No Screw threads

Mechanical properties of ceramics



Plane strain fracture toughness, K_{IC}, is a measure of a material's ability to resist fracture when a crack is present.

$$K_{IC} = Y\sigma_f\sqrt{\pi a}$$

Y = a dimensionless constant (usually ≈ 1)

σ_f = fracture stress (MPa)

a = the length of an external crack or half the length of the internal one.

K_{IC} = Plane strain fracture toughness (for most ceramics is less than 10 MPa.m$^{1/2}$)

Values for K_{ic} for ceramic materials are usually *at least* an order of magnitude less than that for metals (1/10 of that for metal).

Next time

Mechanical Shaping of Polymers