Module 1: Introduction to Composites

Lecture 4: Matrix Materials

The Lecture Contains:

Previous Next

Lecture 4: Matrix Materials

Introduction

In the previous lecture we have introduced various advanced fibres along with their fabrication processes, precursor materials and key features. In the present lecture we will introduce some matrix materials, their key features and applications.

What are the matrix materials used in composites?

The matrix materials used in composites can be broadly categorized as: Polymers, Metals, Ceramics and Carbon and Graphite.

The polymeric matrix materials are further divided into:

1. Thermoplastic – which soften upon heating and can be reshaped with heat and pressure.
2. Thermoset – which become cross linked during fabrication and does not soften upon reheating.

The metal matrix materials are: Aluminum, Copper and Titanium.

The ceramic materials are: Carbon, Silicon carbide, Silicon nitride.

The classification of matrix materials is shown in Figure 1.11.

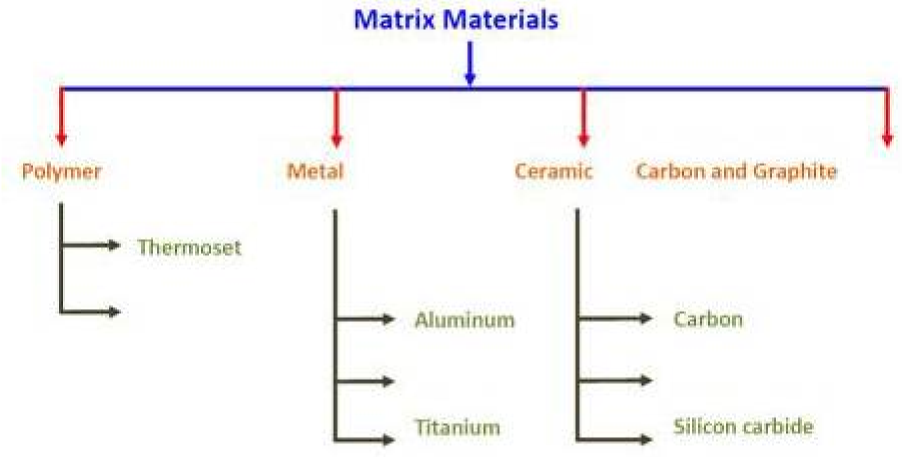

Figure 1.11: Matrix materials

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What are the thermoplastic matrix materials? What are their key features?

The following are the thermoplastic materials:

1. polypropylene,
2. polyvinyl chloride,
3. nylon,
4. polyurethane,
5. poly-ether-ether ketone (PEEK),
6. polyphenylene sulfide (PPS),
7. polysulpone.

The key features of the thermoplastic matrix materials are:

1. higher toughness
2. high volume
3. low cost processing
4. The use temperature range is upto 225 °C .

What are the thermoset matrix materials? What are their key features?

The thermoset matrix materials are:

1. polyesters,
2. epoxies,
3. polyimides

The key features of these materials are given for individual material in the following.

Polyesters

1. Used extensively with glass fibers
2. Inexpensive
3. Light weight
4. Temperature range upto 100 °C.
5. Resistant to environmental exposures

Epoxy

1. Expensive
2. Better moisture resistance
3. Lower shrinkage on curing
4. Use temperature is about 175 °C

Polyimide

1. Higher use temperature about 300 °C
2. Difficult to fabricate

What are the problems with the use of polymer matrix materials?

1. Limited temperature range.
2. Susceptibility to environmental degradation due to moisture, radiation, atomic oxygen (in space)
3. Low transverse strength.
4. High residual stress due to large mismatch in coefficients of thermal expansion between fiber and matrix.
5. Polymer matrix cannot be used near or above the glass transition temperature.

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Comparison between Thermoplastics and Thermosets:

The comparison between the thermoplastic and thermoset matrix materials is given in Table 1 below:

Table 1.1: Comparison between thermoplastics and thermosets.

Thermoplastics	**Thermosets**
Soften upon heat and pressure	Decompose upon heating
Hence, can be repaired	Difficult to repair
High strains are required for failure	Low strains are required for failure
Can be re-processed	Can not be re-processed
Indefinite shelf life	Limited shelf life
Short curing cycles	Long curing cycles
Non tacky and easy to handle	Tacky and therefore, difficult to handle
Excellent resistance to solvents	Fair resistance to solvents
Higher processing temperature is required. Hence, viscosities make the processing difficult.	Lower processing temperature is required.

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What are the common metals used as matrix materials? What are their advantages and disadvantages?

The common metals used as matrix materials are aluminum, titanium and copper.

Advantages:

1. Higher transfer strength,
2. High toughness (in contrast with brittle behavior of polymers and ceramics)
3. The absence of moisture and
4. High thermal conductivity (copper and aluminum).

Dis-advantages:

1. Heavier
2. More susceptible to interface degradation at the fiber/matrix interface and
3. Corrosion is a major problem for the metals

The attractive feature of the metal matrix composites is the higher temperature use. The aluminum matrix composite can be used in the temperature range upward of 300ºC while the titanium matrix composites can be used above 800 °C.

What are the ceramic matrix materials? What are their advantages and disadvantages?

The carbon, silicon carbide and silicon nitride are ceramics and used as matrix materials.

***Ceramic*:**

The advantages of the ceramic matrix materials are:

1. The ceramic composites have very high temperature range of above 2000 °C .
2. High elastic modulus
3. Low density

The disadvantages of the ceramic matrix materials are:

1. The ceramics are very brittle in nature.
2. Hence, they are susceptible to flows.

Carbon

The advantages of the carbon matrix materials are:

1. High temperature at 2200 °C.
2. Carbon/carbon bond is stronger at elevated temperature than room temperature.

The disadvantages of the carbon matrix materials are:

1. The fabrication is expensive.

2. The multistage processing results in complexity and higher additional cost.

It should be noted that a composite with carbon fibres as reinforcement as well as matrix material is known as ***carbon-carbon composite***. The application of carbon-carbon composite is seen in leading edge of the space shuttle where the high temperature resistance is required. The carbon-carbon composites can resist the temperatures upto 3000°C .

The advantages of these composites are:

1. Very strong and light as compared to graphite fibre alone.
2. Low density.
3. Excellent tensile and compressive strength.
4. Low thermal conductivity.
5. High fatigue resistance.
6. High coefficient of friction.

The disadvantages include:

1. Susceptible to oxidation at elevated temperatures.
2. High material and production cost.
3. Low shear strength.

Figure 1.12 depicts the range of use temperature for matrix material in composites. It should be noted that for the structural applications the maximum use temperature is a critical parameter. This maximum temperature depends upon the maximum use temperature of the matrix materials.

Figure 1.12: Range of use temperature for matrix materials in composites

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What are the different forms of composites?

1. ***Unidirectional lamina***:
    - It is basic form of continuous fiber composites.
    - A lamina is also called by *ply* or *layer*.
    - Fibers are in same direction.
    - Orthotropic in nature with different properties in principal material directions.
    - For sufficient number of filaments (or layers) in the thickness direction, the effective properties in the transverse plane (perpendicular to the fibers) may be isotropic. Such a composite is called as transversely isotropic.
2. ***Woven fabrics***:
    - Examples of woven fabric are clothes, baskets, hats, etc.
    - Flexible fibers such as glass, carbon, aramid can be woven in to cloth fabric, can be impregnated with a matrix material.
    - Different patterns of weaving are shown in Figure 1.13.

Typical weaving patterns are shown in Figure 1.13.

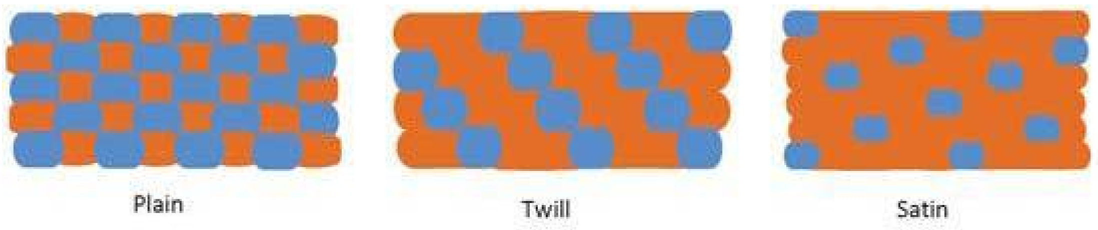

Figure 1.13: Types of weave

3. ***Laminate***:
    1. Stacking of unidirectional or woven fabric layers at different fiber orientations.
    2. Effective properties vary with:
        1. orientation
        2. thickness
        3. stacking sequence

A symmetric laminate is shown in Figure 1.14.

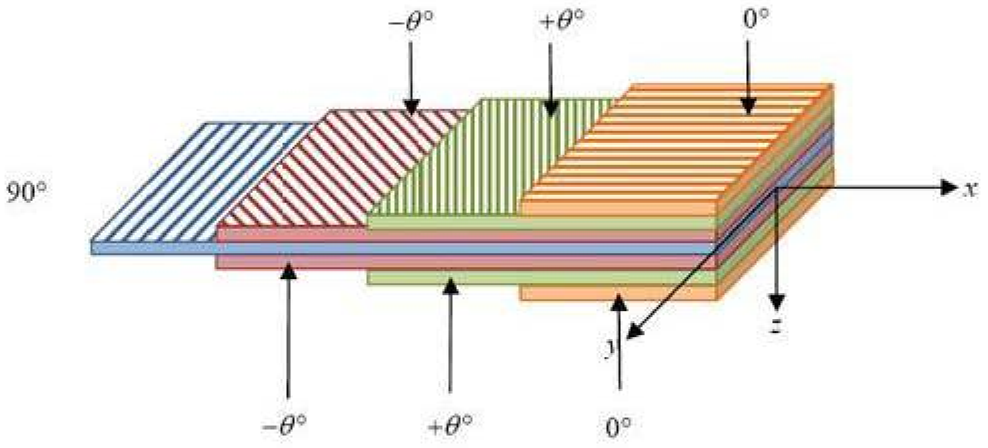

Figure 1.14: A symmetric laminate

4. ***Hybrid composites***:

   The hybrid composite are composites in which two or more types of fibres are used. Collectively, these are called as *hybrids*. The use of two or more fibres allows the combination of desired properties from the fibres. For example, combination of aramid and carbon fibres gives excellent tensile properties of aramid and compressive properties of carbon fibers. Further, the aramid fibres are less expensive as compared to carbon fibres.

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What are the factors that affect the composite properties?

There are various factors upon which the properties of the composite depend. Following are the various factors:

1. Properties of the constituent materials. Apart from this, the properties of other phases present, like additives, fillers and other reaction phases also affect the properties of the composite.
2. Length of the fibre.
3. Orientation of the fibres (with respect to the loading direction).
4. Cross sectional shape of the fibre.
5. Distribution and arrangement of the fibres in the matrix material.
6. Proportions of the fibre and matrix material, that is, volume fractions of the constituent materials.

Notation for Composite Designation:

The composites are designated by the combination of the fibre and matrix system. The fibre and matrix materials are separated by a slash $(/)$, that is, ***fibre material/matrix material*.** Further, one needs to specify the volume fractions of the constituents. In general, the fibre volume fraction is specified. For example: AS4/PEEK, $v_f = 45\%$, that is, a carbon composite with AS4 fibres and PEEK as the matrix material with fibre volume fraction of 45%. Other examples are: T300/5208, T700/M21, Kevlar/Epoxy, Boron/Al, SCS-6/Ti-15-3, S$_2$ Glass/Epoxy.

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Chapter 13: Applications and Processing of Ceramics

ISSUES TO ADDRESS...

- How do we classify ceramics?
- What are some applications of ceramics?
- How is processing different than for metals?

Scanning electron micrograph showing the microstructure of a glass–ceramic material. The long acicular blade-shaped particles yield a material with unusual strength and toughness. 65,000×. (Photograph courtesy of L. R. Pinckney and G. J. Fine of Corning Incorporated.)

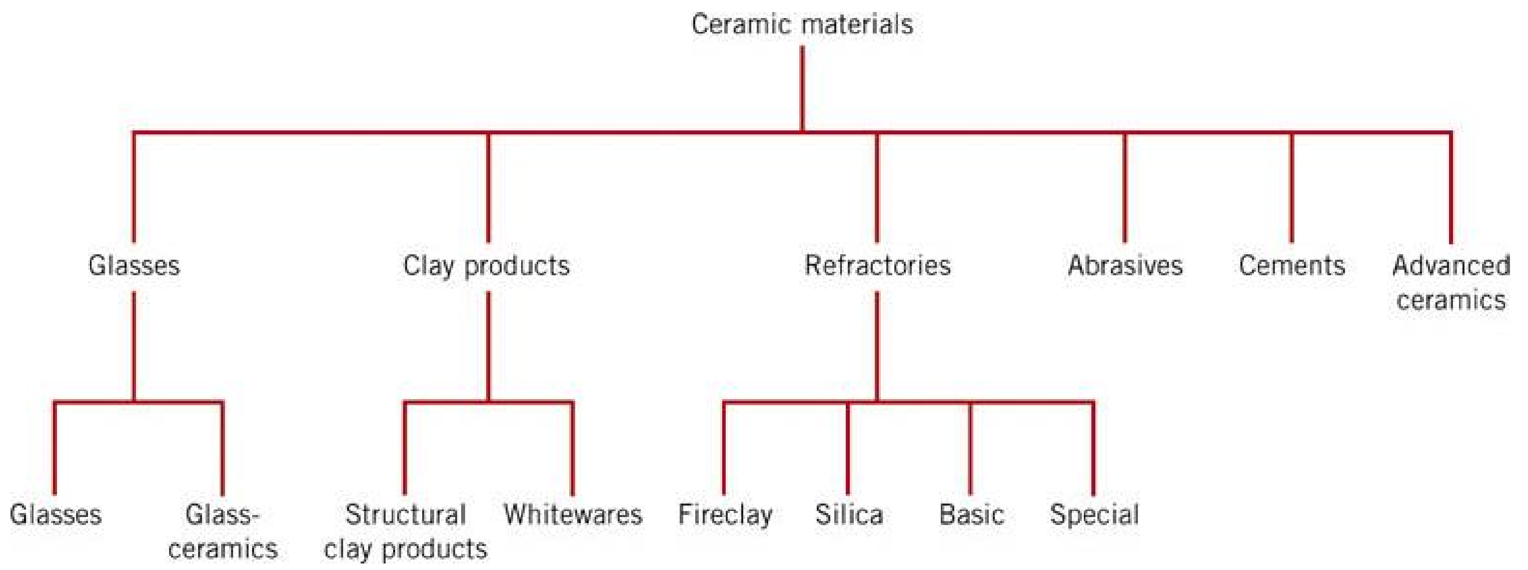
CHAPTER 13

APPLICATIONS AND PROCESSING OF CERAMICS

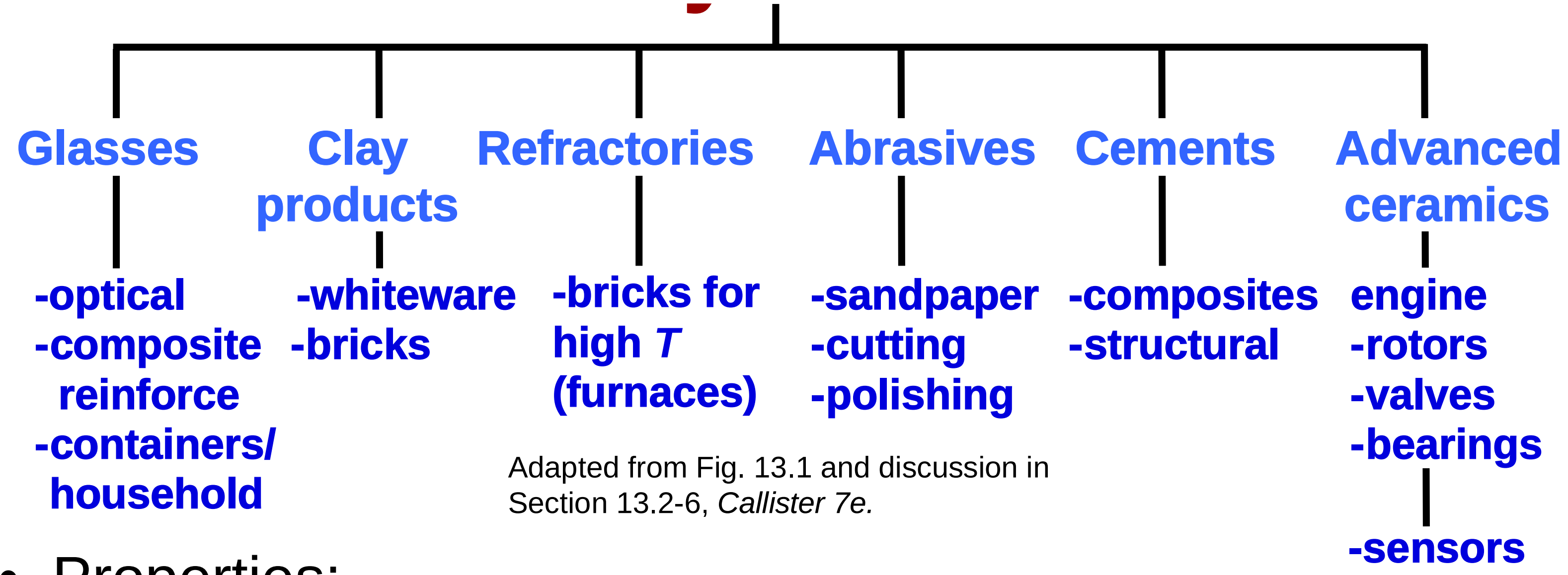
LEARNING OBJECTIVES

1. List the three primary ingredients of a soda-lime glass.
2. Cite the two prime assets of glass materials.
3. Define *devitrification*.
4. (a) Briefly describe the process by which glass-ceramics are produced.
   (b) Note two properties of these materials that make them superior to glass.
5. Name the two types of clay products, and then give two examples of each.
6. For the refractory ceramics do the following:
   (a) Cite three important requirements that normally must be met by this group of materials.
   (b) For each of the four classifications discussed, cite the primary ingredients and typical applications.
7. For the abrasive ceramics do the following:
   (a) Cite three important requirements that normally must be met by this group of materials.
   (b) Name four different ceramic materials that are commonly used as abrasives.
   (c) Cite the three different forms of abrasives.
8. Briefly describe the process by which portland cement is produced.
9. Briefly explain the mechanism by which cement hardens when water is added.
10. Briefly explain the role of cement in a concrete mix.
11. List three advanced ceramics applications, and, for each, note its important characteristics and/or the function(s) it performs.

Figure 13.1 classification of ceramic materials on the basis of application



Types and Applications of Ceramics



Glasses
- -optical
- -composite reinforce
- -containers/ household

Clay products
- -whiteware
- -bricks

Refractories
- -bricks for high *T* (furnaces)

Abrasives
- -sandpaper
- -cutting
- -polishing

Cements
- -composites
- -structural

Advanced ceramics
- engine
- -rotors
- -valves
- -bearings
- -sensors

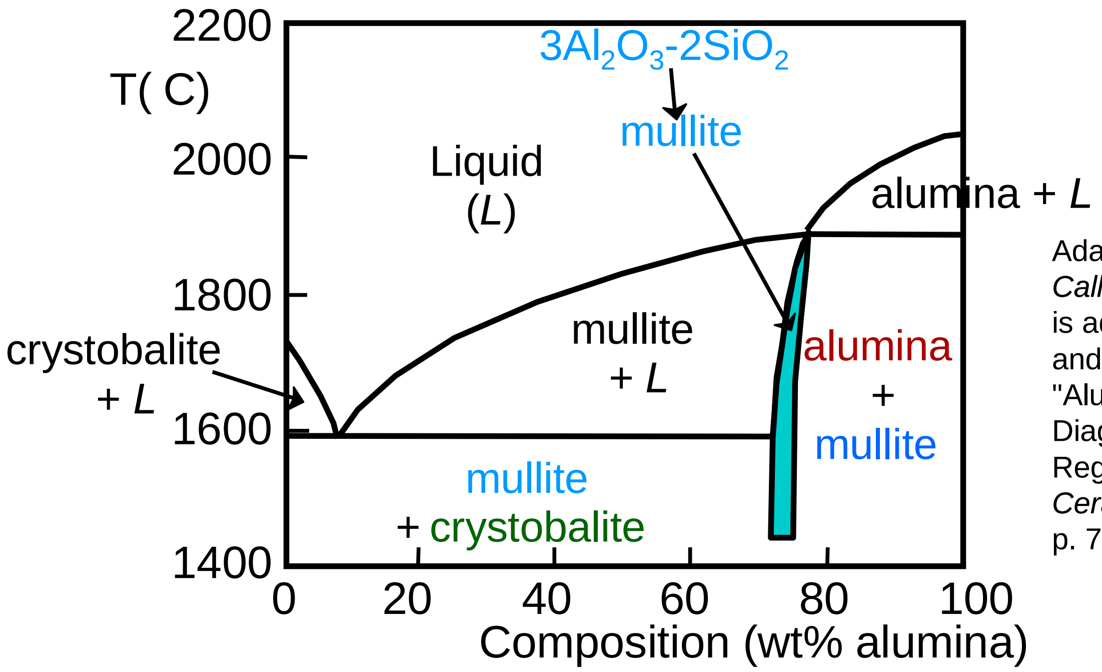
Adapted from Fig. 13.1 and discussion in Section 13.2-6, *Callister 7e.*

- Properties:
  - -- T_m for glass is moderate, but large for other ceramics.
  - -- Small toughness, ductility; large moduli & creep resist.
- Applications:
  - -- High *T*, wear resistant, novel uses from charge neutrality.
- Fabrication
  - -- some glasses can be easily formed
  - -- other ceramics can not be formed or cast.

Application: Refractories

- Need a material to use in high temperature furnaces.
- Consider the Silica (SiO_2) - Alumina (Al_2O_3) system.
- Phase diagram shows:

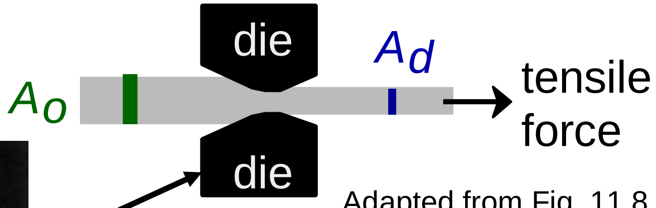
  mullite, alumina, and crystobalite as candidate refractories.



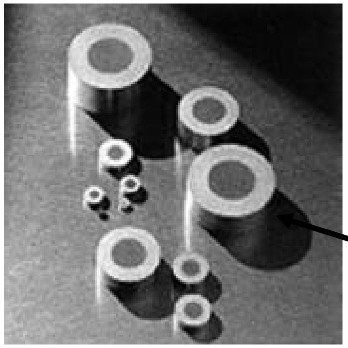
Adapted from Fig. 12.27, *Callister 7e.* (Fig. 12.27 is adapted from F.J. Klug and R.H. Doremus, "Alumina Silica Phase Diagram in the Mullite Region", *J. American Ceramic Society* **70**(10), p. 758, 1987.)

Application: Die Blanks

- Die blanks:
  - -- Need wear resistant properties!

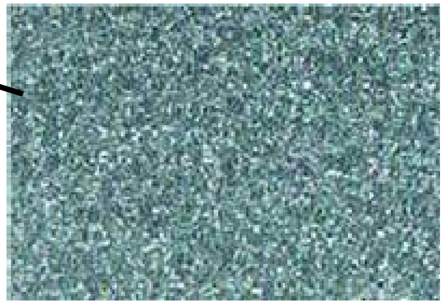


Adapted from Fig. 11.8 (d), *Callister 7e*.



Courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

- Die surface:
  - -- 4 μm polycrystalline diamond particles that are sintered onto a cemented tungsten carbide substrate.
  - -- polycrystalline diamond helps control fracture and gives uniform hardness in all directions.



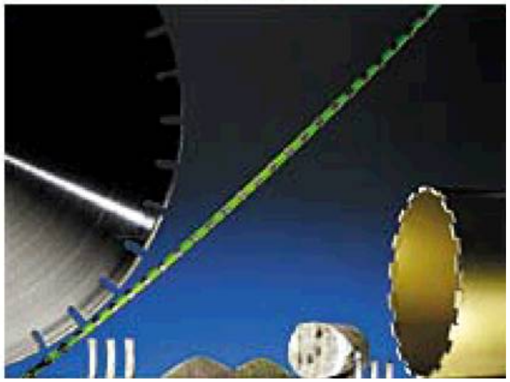
Courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

Application: Cutting Tools

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

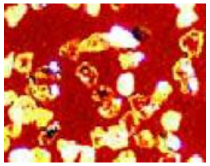
- Solutions:
  - -- manufactured single crystal or polycrystalline diamonds in a metal or resin matrix.
  - -- optional coatings (e.g., Ti to help diamonds bond to a Co matrix via alloying)
  - -- polycrystalline diamonds resharpen by microfracturing along crystalline planes.

oil drill bits



blades

coated single crystal diamonds



polycrystalline diamonds in a resin matrix.

Photos courtesy Martin Deakins, GE Superabrasives, Worthington, OH. Used with permission.

Application: Sensors

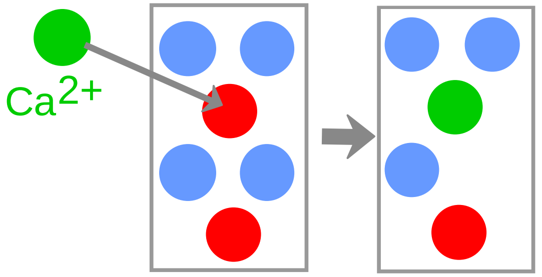
- Example: Oxygen sensor ZrO_2
- Principle: Make diffusion of ions fast for rapid response.
- Approach:

  Add Ca impurity to ZrO_2:

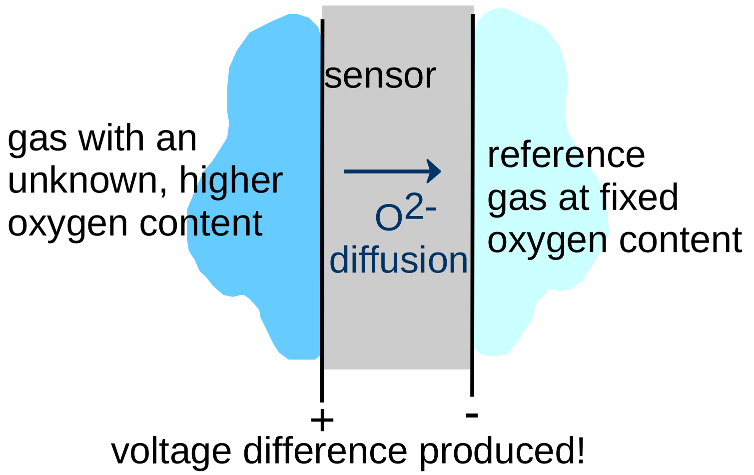
  -- increases O^{2-} vacancies

  -- increases O^{2-} diffusion rate
- Operation:

  -- voltage difference produced when O^{2-} ions diffuse from the external surface of the sensor to the reference gas.



A Ca^{2+} impurity removes a Zr^{4+} and a O^{2-} ion.



voltage difference produced!

13.2glasses

Table 13.1 compositions and characteristics of some of the common commercial glasses

	Composition (wt%)						
Glass Type	***SiO_2***	***Na_2O***	***CaO***	***Al_2O_3***	***B_2O_3***	***Other***	***Characteristics and Applications***
Fused silica	>99.5						High melting temperature, very low coefficient of expansion (thermally shock resistant)
96% Silica (Vycor™)	96				4		Thermally shock and chemically resistant—laboratory ware
Borosilicate (Pyrex™)	81	3.5		2.5	13		Thermally shock and chemically resistant—ovenware
Container (soda–lime)	74	16	5	1		4MgO	Low melting temperature, easily worked, also durable
Fiberglass	55		16	15	10	4MgO	Easily drawn into fibers—glass–resin composites
Optical flint	54	1				37PbO, $8K_2O$	High density and high index of refraction—optical lenses
Glass–ceramic (Pyroceram™)	43.5	14		30	5.5	$6.5TiO_2$, $0.5As_2O_3$	Easily fabricated; strong; resists thermal shock—ovenware

13.3 glasses-ceramics

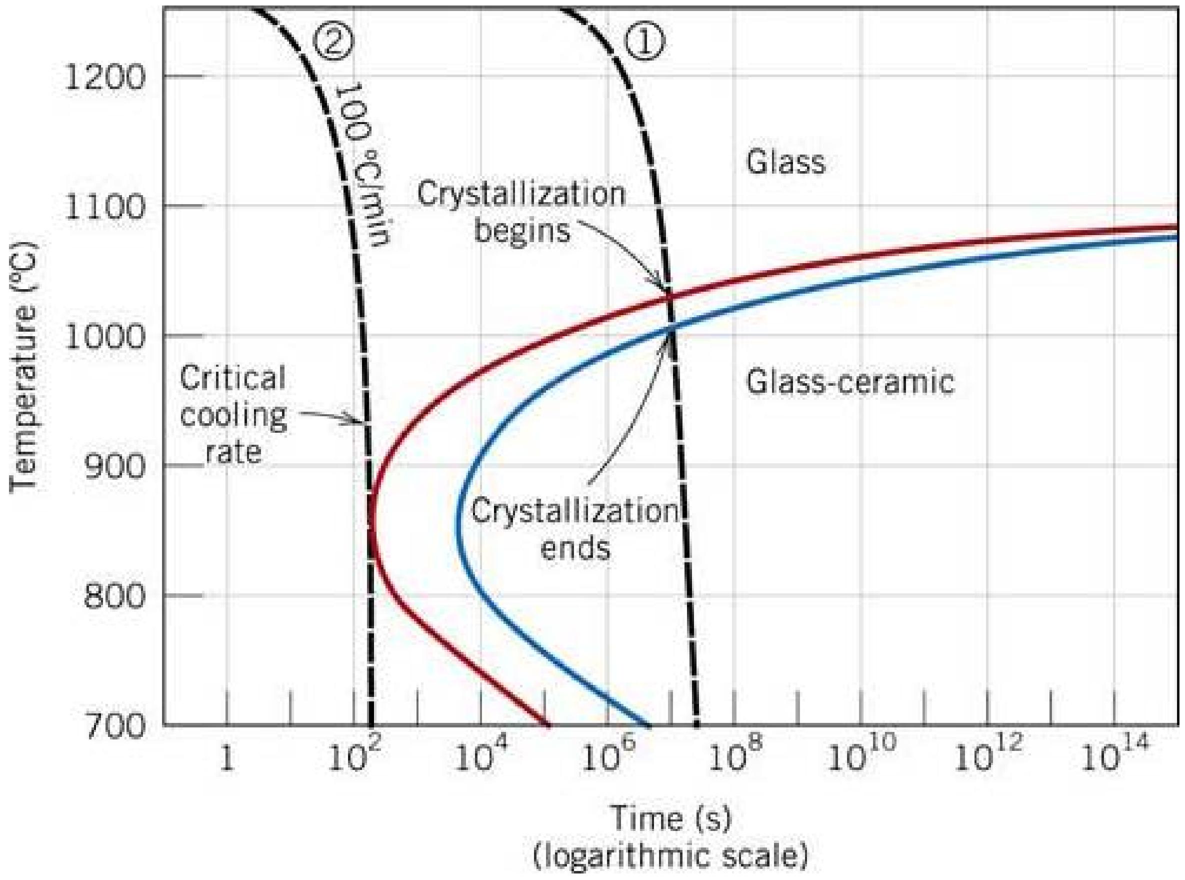


Figure 13.2continuous cooling transformation diagram for the crystallization of a lunar glass

13.4 clay products

- Structural clay product
- whitewares

13.5 refractories

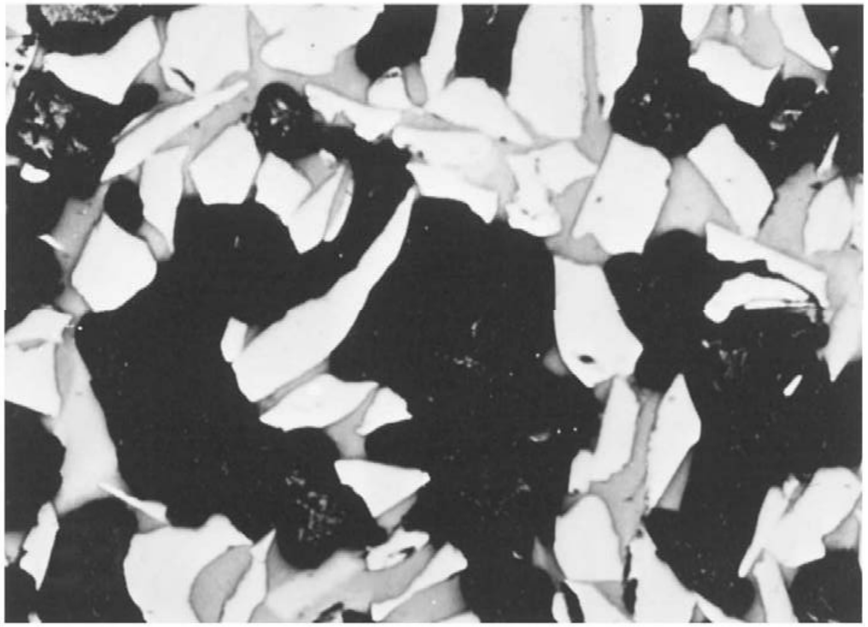
Table 13.2 compositions of five common ceramic refractory materials

	Composition (wt%)							*Apparent Porosity (%)*
Refractory Type	Al_2O_3	SiO_2	MgO	Cr_2O_3	Fe_2O_3	CaO	TiO_2	
Fireclay	25–45	70–50	0–1		0–1	0–1	1–2	10–25
High-alumina fireclay	90–50	10–45	0–1		0–1	0–1	1–4	18–25
Silica	0.2	96.3	0.6			2.2		25
Periclase 方鎂石	1.0	3.0	90.0	0.3	3.0	2.5		22
Periclase–chrome ore	9.0	5.0	73.0	8.2	2.0	2.2		21

Source: From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics,* 2nd edition. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.

13.6 abrasives SiC, WC, Al_2O_3

Figure 13.3 Photomicrograph of an aluminum oxide bonded ceramic abrasive. The light regions are the Al_2O_3 abrasive grains; the gray and dark areas are the bonding phase and porosity, respectively. 100×. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition, p. 568. Copyright © 1976 by John Wiley & Sons. Reprinted by permission of John Wiley & Sons, Inc.)



13.7 cements

- **CLAY +LIME-bearing minerals at 1400℃ calicination(鍛燒) →clinker(熔渣) → ground into a very fine powder to which is added a small amount of gypsum (CaSO4-$2H_2O$) to retard the setting process. The product is portland cement.**
- **Hydration reaction 2CaO-SiO2＝2CaO-SiO2-XH2O**

13.8 advanced cermics

- **1.Microelectromechanical systems(MEMS)**

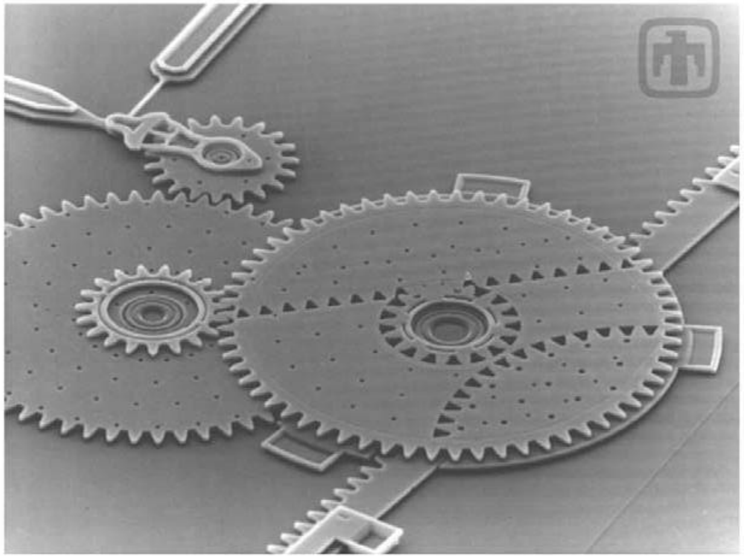


Figure 13.4 Scanning electron micrograph showing a linear rack gear reduction drive MEMS. This gear chain converts rotational motion from the top-left gear to linear motion to drive the linear track (lower-right). Approximately 100×. (Courtesy Sandia National Laboratories, SUMMiT* Technologies, www.mems.sandia.gov.)

線性齒條齒輪減速機構:**SiC or** Si3N4

  - 2.optical fiber
  - 3.ceramic ball bearings:Si3N4

Fabrication and Processing of Ceramics

13.9 Fabrication and Processing of Glasses and Glass-Ceramics

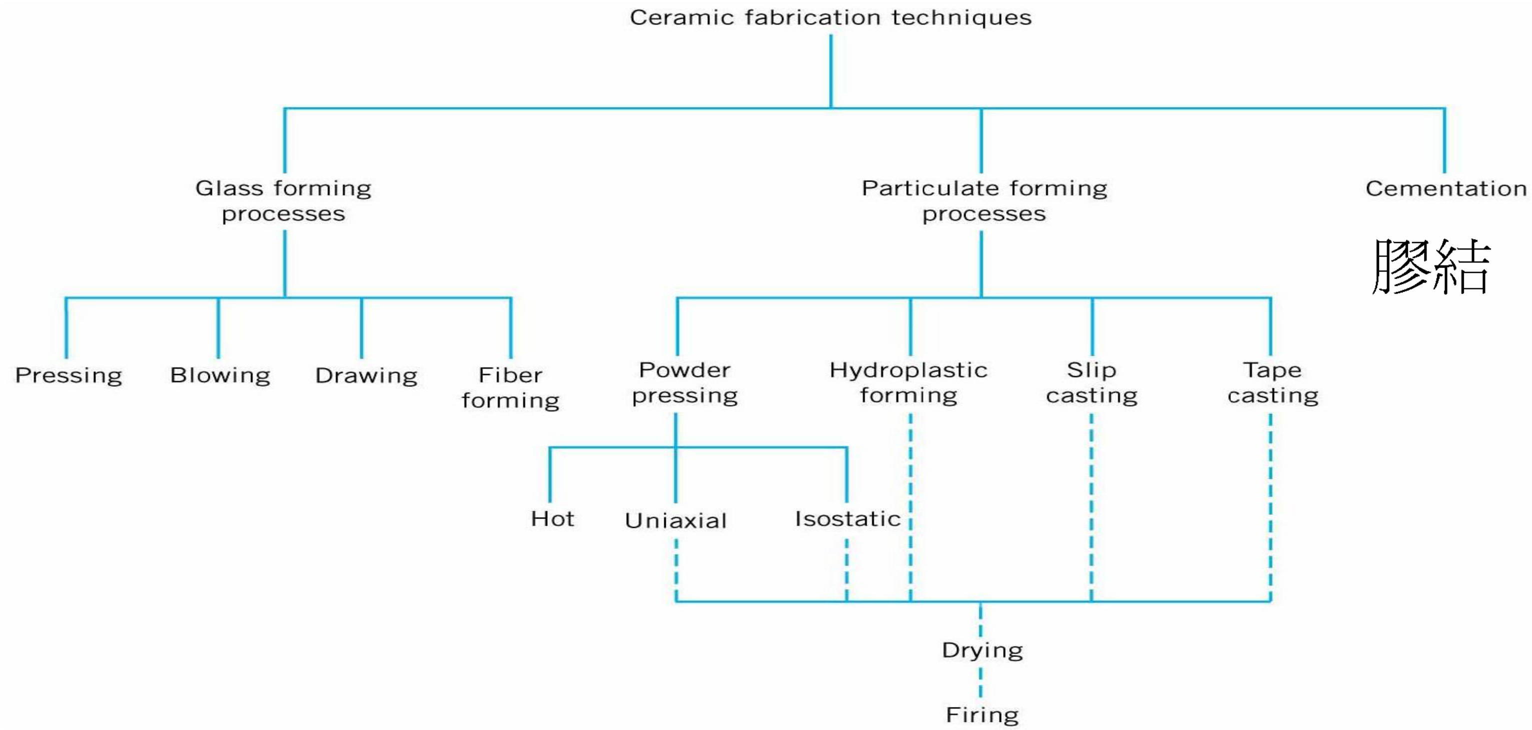
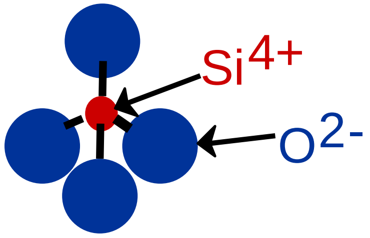


Figure 13.5 A classification scheme for the ceramic-forming techniques discussed in this chapter.

Glass Structure

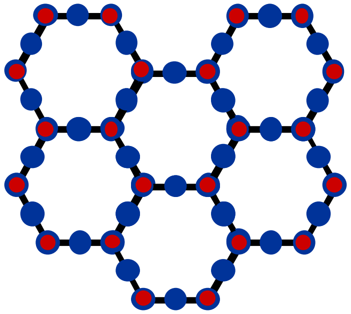
- Basic Unit:

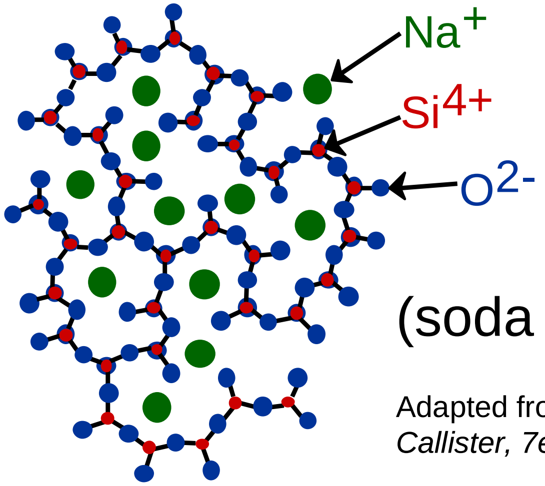
SiO_4^{4-} tetrahedron



- Glass is amorphous
- Amorphous structure occurs by adding impurities (Na^+,Mg^{2+},Ca^{2+}, Al^{3+})
- Impurities: interfere with formation of crystalline structure.

- Quartz is crystalline SiO_2:



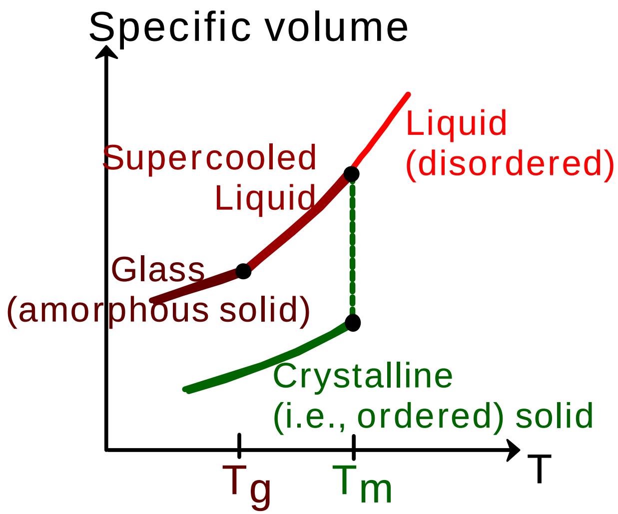


(soda glass)

Adapted from Fig. 12.11, *Callister, 7e*.

GLASS PROPERTIES

- Specific volume (1) vs Temperature (T):

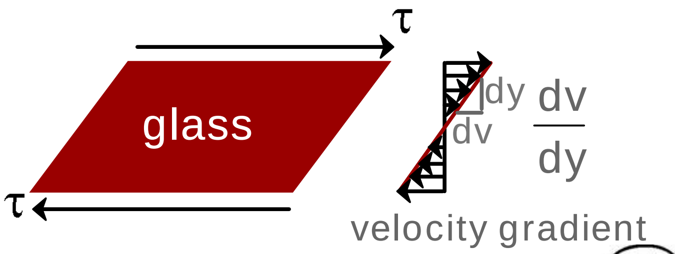


Adapted from Fig. 13.5, ***Callister, 6e***.

- Crystalline materials:
  --crystallize at melting temp, T_m
  --have abrupt change in spec. vol. at T_m
- Glasses:
  --do not crystallize
  --spec. vol. varies smoothly with T
  --Glass transition temp, T_g

- Viscosity:
  --relates shear stress & velocity gradient:
  --has units of (Pa-s)

$$\tau = \eta \frac{dv}{dy}$$



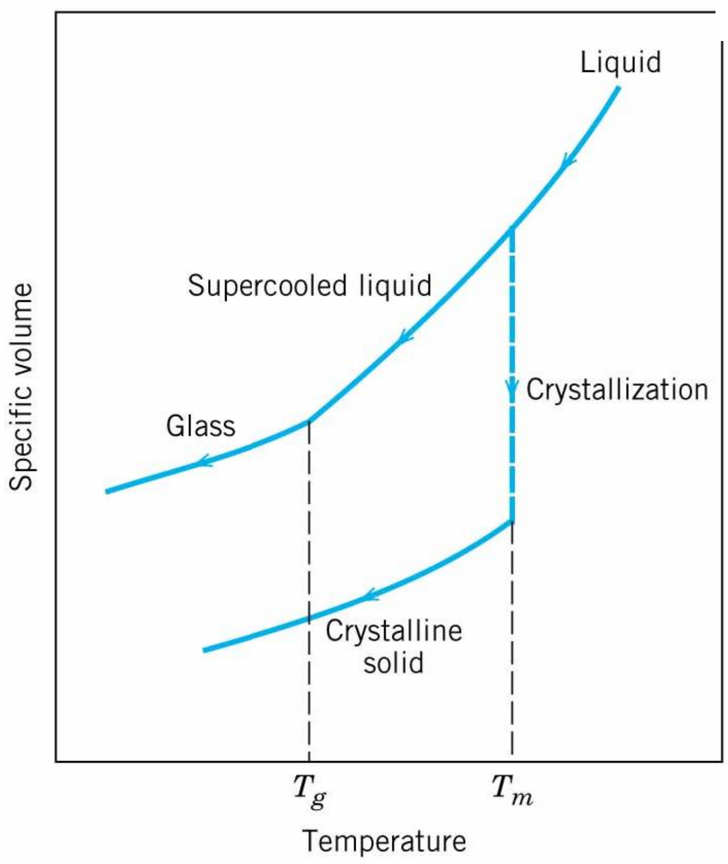
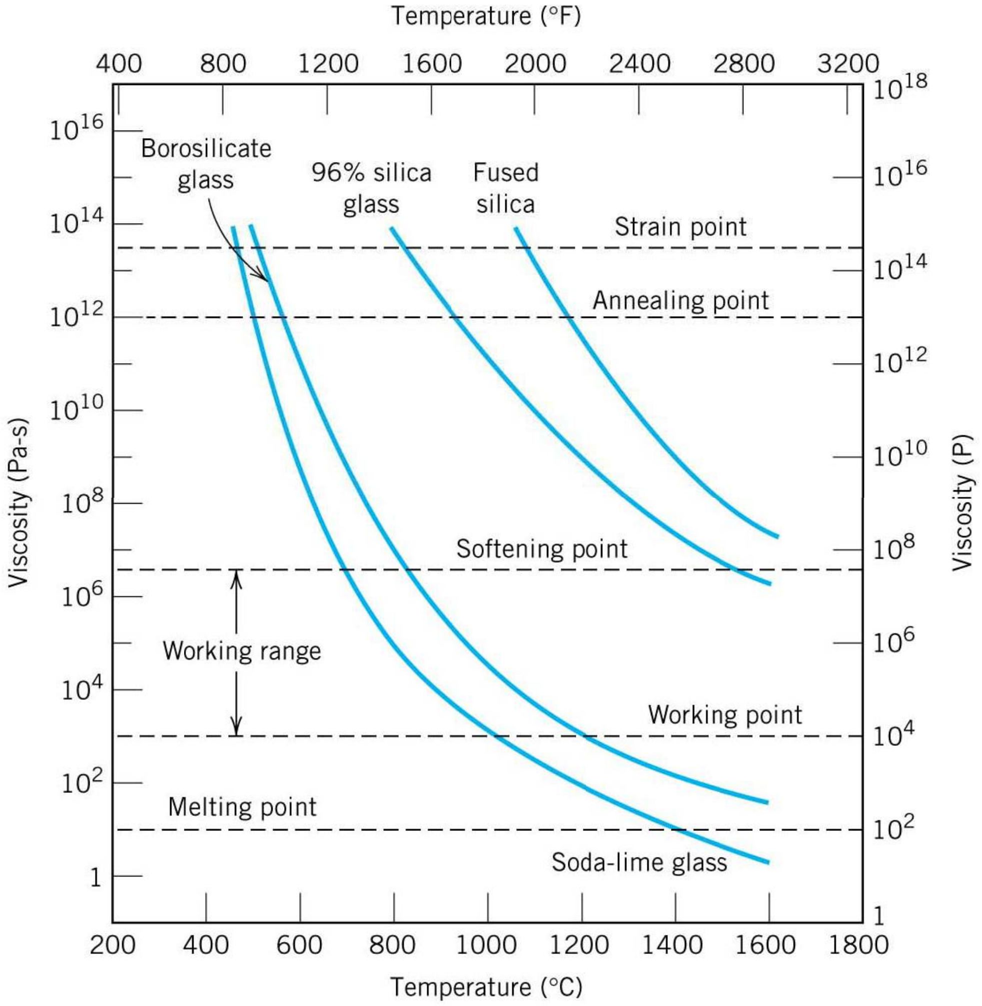


Figure 13.6 Contrast of specific volume-versus-temperature behavior of crystalline and noncrystalline materials. Crystalline materials solidify at the melting temperature T_m. Characteristic of the noncrystalline state is the glass transition temperature T_g.

Figure 13.7

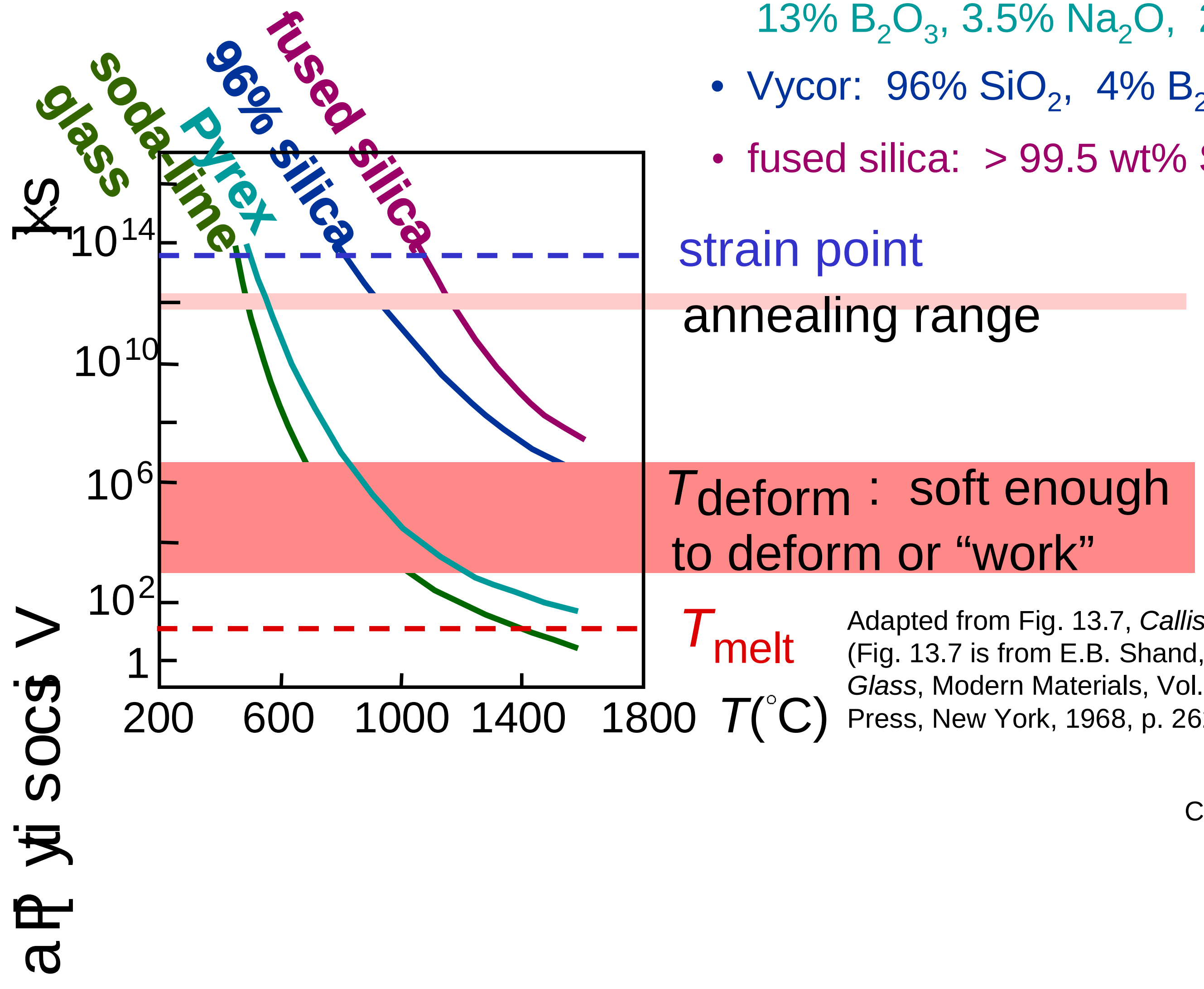
Logarithm of viscosity versus temperature for fused silica and three silica glasses. (From E. B. Shand, *Engineering Glass,* Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)



Glass Viscosity vs. T and Impurities

- Viscosity decreases with *T*
- Impurities lower *T*deform

- soda-lime glass: 70% SiO_2 balance Na_2O (soda) & CaO (lime)
- borosilicate (Pyrex): 13% B_2O_3, 3.5% Na_2O, 2.5% Al_2O_3
- Vycor: 96% SiO_2, 4% B_2O_3
- fused silica: > 99.5 wt% SiO_2



Adapted from Fig. 13.7, *Callister, 7e.* (Fig. 13.7 is from E.B. Shand, *Engineering Glass*, Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)

glass

- The melting point corresponds to the temperature at which the viscosity is 100P.
- The working point represents the temperature at which the viscosity is 10^3P；the glass is easily deformed at this viscosity.
- The soft point, the viscosity is 4×10^6P,is the maximum temperature at which a glass piece may be handled without causing significant dimension alterations.
- The annealing point, the viscosity is 10^{12}P,at this temperture, atomic diffusion is sufficiently rapid that any residual stresses may be removed within about 15 min.
- The strain point, the viscosity is 3×10^{13}P:below the strain point, fracture will occur before the onset of plastic deformation.

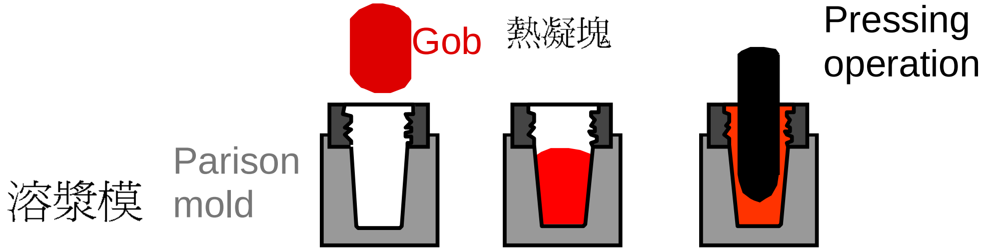
Ceramic Fabrication Methods-I

GLASS FORMING

PARTICULATE FORMING

CEMENTATION

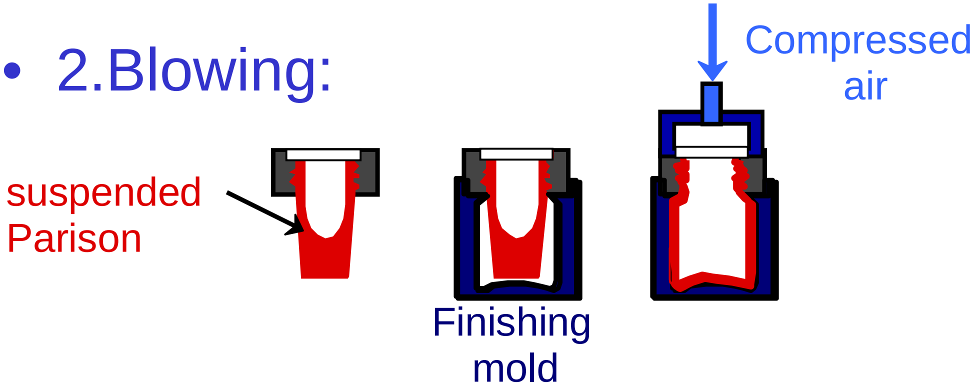
- 1.Pressing:



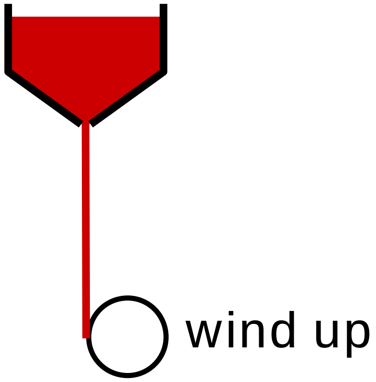
plates, dishes, cheap glasses

--mold is steel with
graphite lining

- 2.Blowing:



- 3.Fiber drawing:



Adapted from Fig. 13.8, *Callister, 7e.* (Fig. 13.8 is adapted from C.J. Phillips, *Glass: The Miracle Maker*, Pittman Publishing Ltd., London.)

Glass forming-pressing and blow

1.Pressing:

2. **blow:**

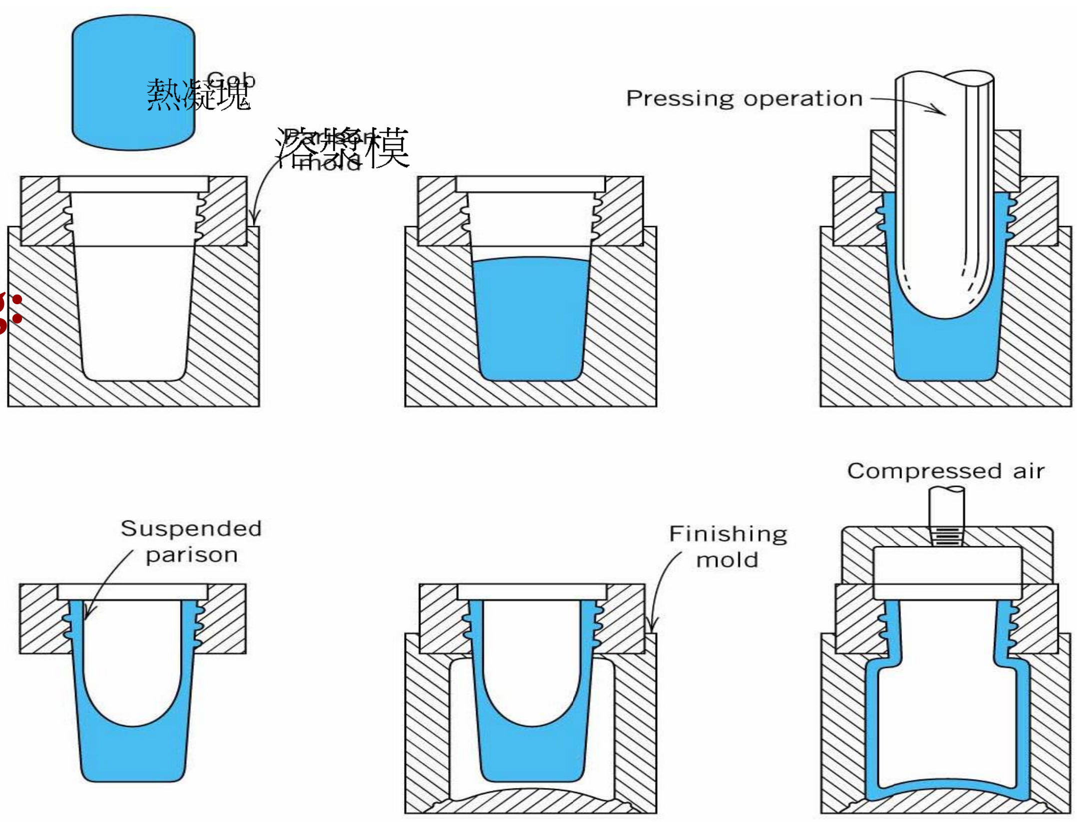


FIGURE 13.7 The press-and-blow technique for producing a glass bottle. (Adapted from C. J. Phillips, *Glass: The Miracle Maker*. Reproduced by permission of Pitman Publishing Ltd., London.)

4.drawing

- Sheet forming – continuous draw
  - originally sheet glass was made by “floating” glass on a pool of mercury

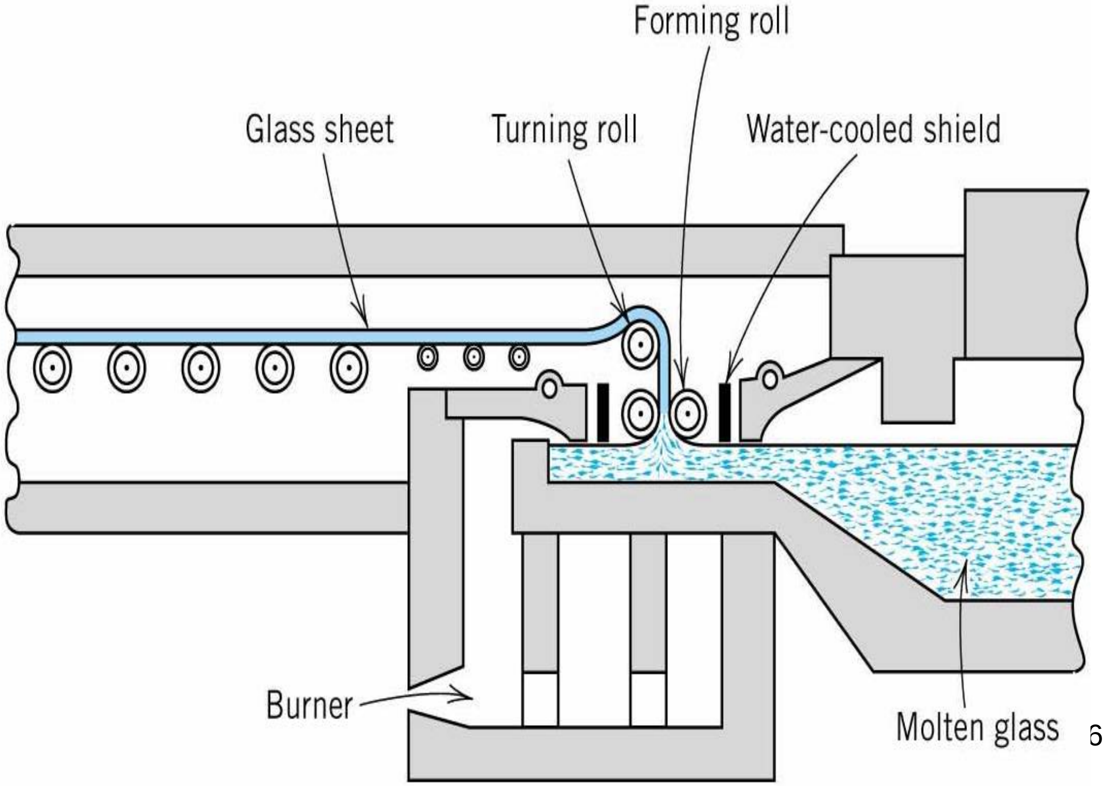


Figure 13.9 A process for the continuous drawing of sheet glass. (From W. D. Kingery, *Introduction to Ceramics*. Copyright © 1960 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

HEAT TREATING GLASSES

1• Annealing:退火

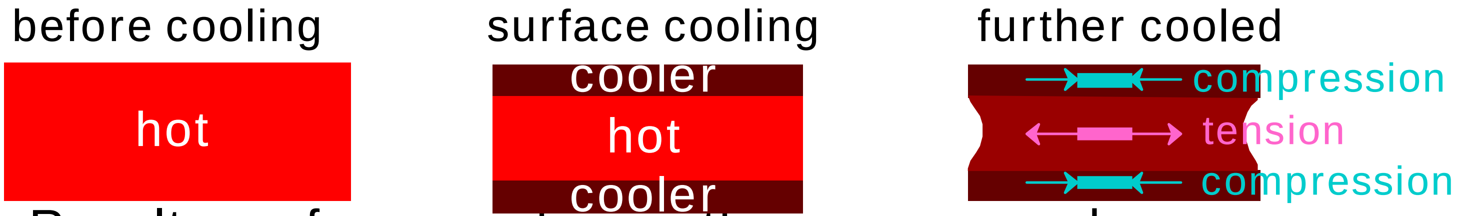
--removes internal stress caused by uneven cooling rate between th
surface and interior regions.

2• Tempering:回火

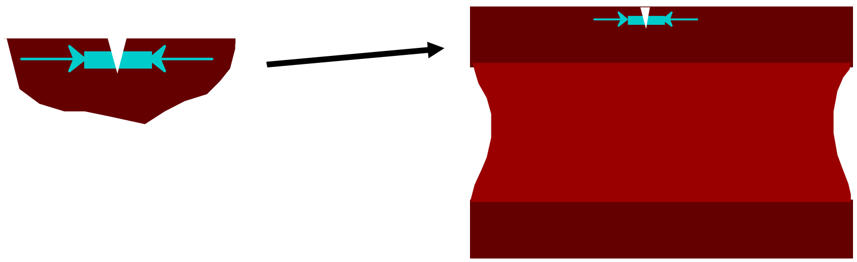
--puts surface of glass part into compression

--suppresses growth of cracks from surface scratches.

--sequence: the glassware is heated to a temperature above the Tg
yet below the softening point. It is then cooled to room temperature
jet of air or, in some cases, an oil bath.



--Result: surface crack growth is suppressed.



Tempered glass plate

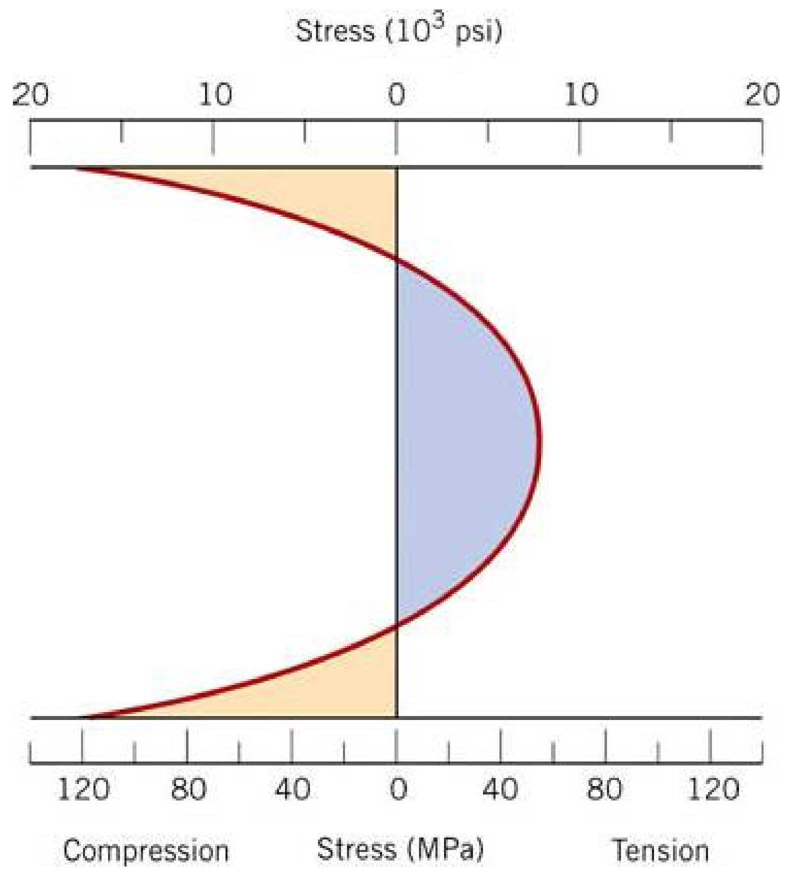


Figure 13.10 room-temperature residual stress distribution over the cross section of a tempered glass plate.

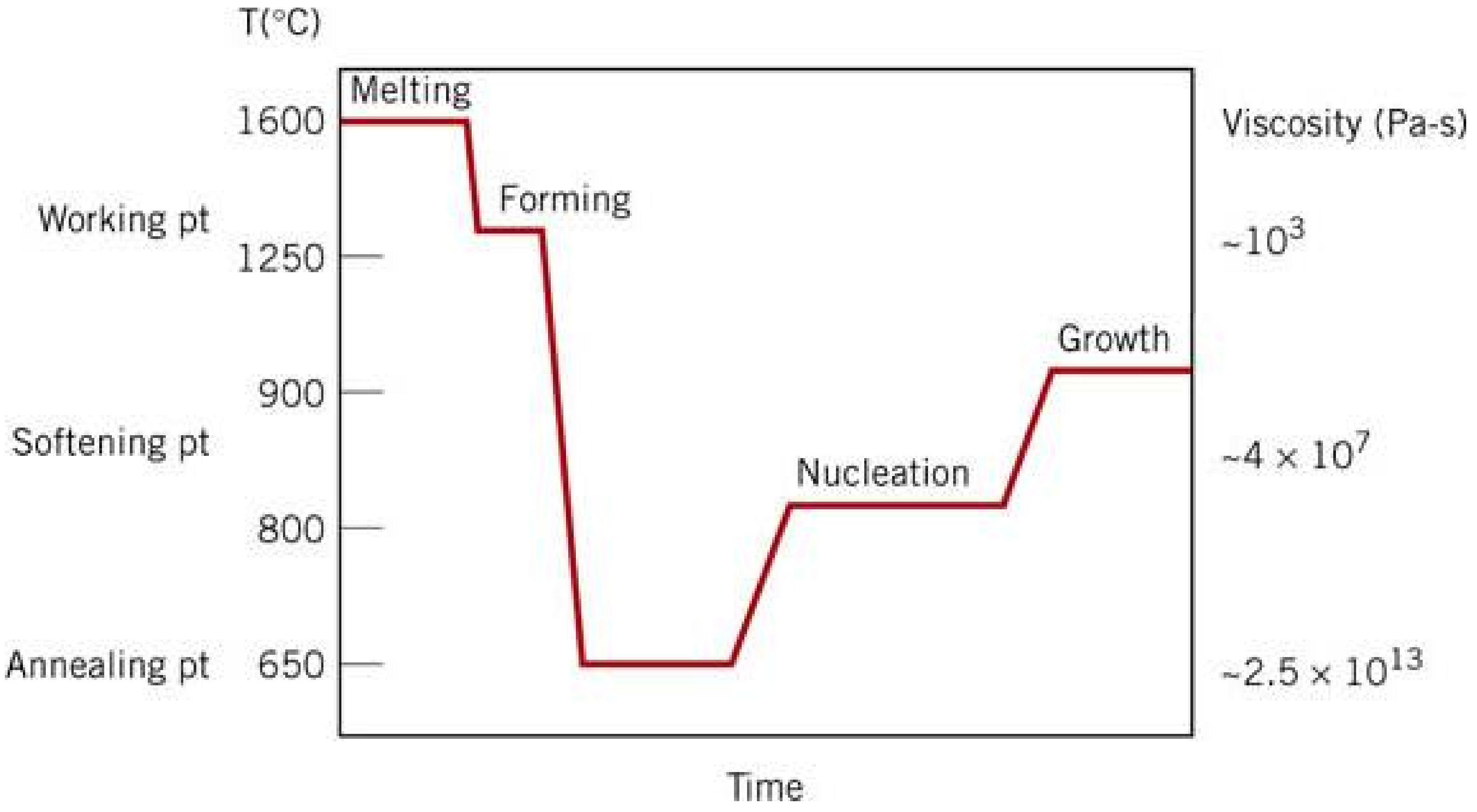


Figure 13.11 Typical time-versus-temperature processing cycle for a Li2O-Al2O3-SiO2 glass-ceramic

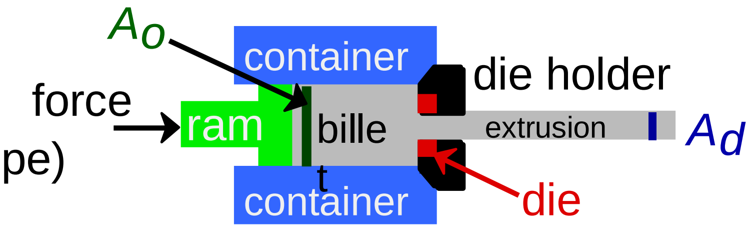
13.10 fabrication and processing of clay products

Ceramic Fabrication Methods-IIA

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

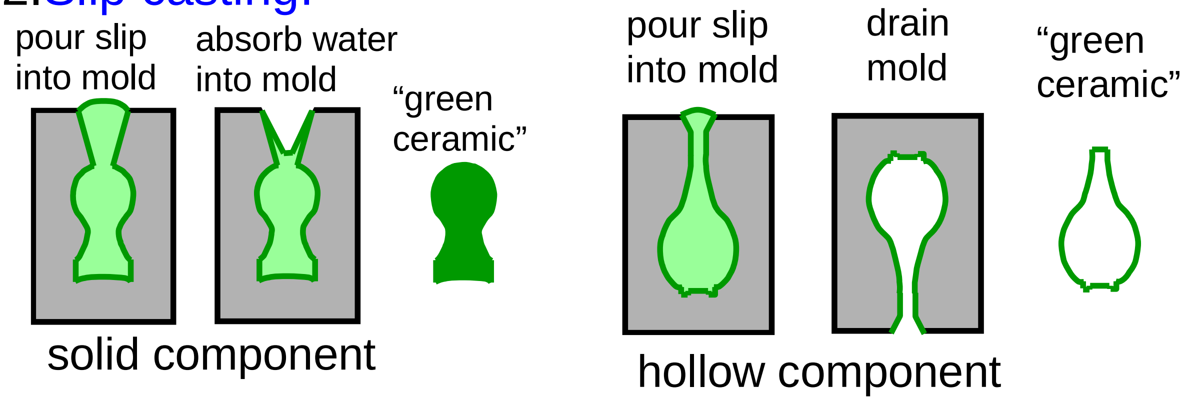
- Milling and screening: desired particle size
- Mixing particles & water: produces a "slip"
- Form a "green" component

--1.Hydroplastic forming:
extrude the slip (e.g., into a pipe)



Adapted from Fig. 11.8 (c), *Callister 7e*.

--2.Slip casting:



Adapted from Fig. 13.12, *Callister 7e*. (Fig. 13.12 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

- Dry and fire the component

FEATURES OF CLAY

Al2O3, SiO2

- **Clay is inexpensive**
- **Adding water to**

clay(hydroplasticity)水塑性

--allows material to shear easily
along weak van der Waals bonds

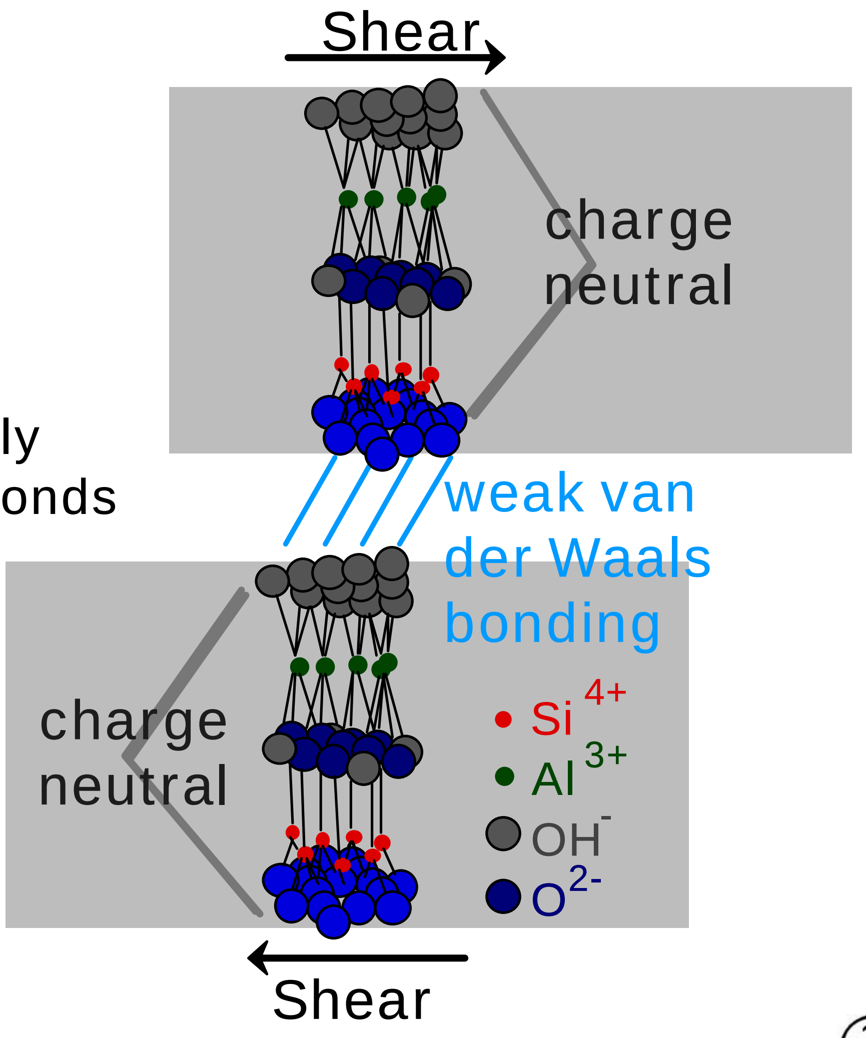
--enables extrusion

--enables slip casting

- **Structure of**

Kaolinite Clay:$Al_2(Si_2O_5)(OH)_4$

Adapted from Fig. 12.14, ***Callister 6e***.
(Fig. 12.14 is adapted from W.E. Hauth,
"Crystal Chemistry of Ceramics",
American Ceramic Society Bulletin,
Vol. 30 (4), 1951, p. 140.)



Composition of Clay product

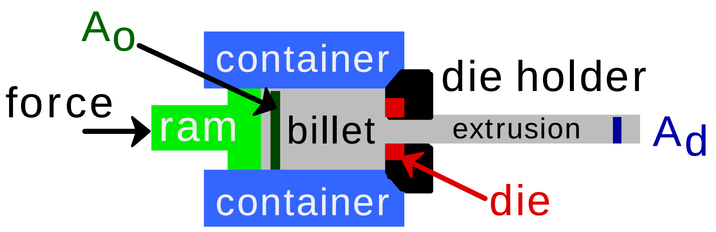
A mixture of components used:a typical porcelain

(50%) 1. Clay
(25%) 2. Filler – e.g. quartz (finely ground)
(25%) 3. Fluxing agent 助熔劑:長石(Feldspar):
binds it together
長石:含 K^+, Na^+, Ca^+ aluminosilicates

Particulate forming :1.Hydroplastic forming 2.Slip Casting
3. Powder pressing 4. Tape casting

1.Hydroplastic Forming水塑性成形

- **Brick**
- **Pipe**
- **Ceramic Block**



Adapted from
Fig. 11.7,
Callister 6e.

2.Slip Casting:泥漿鑄造

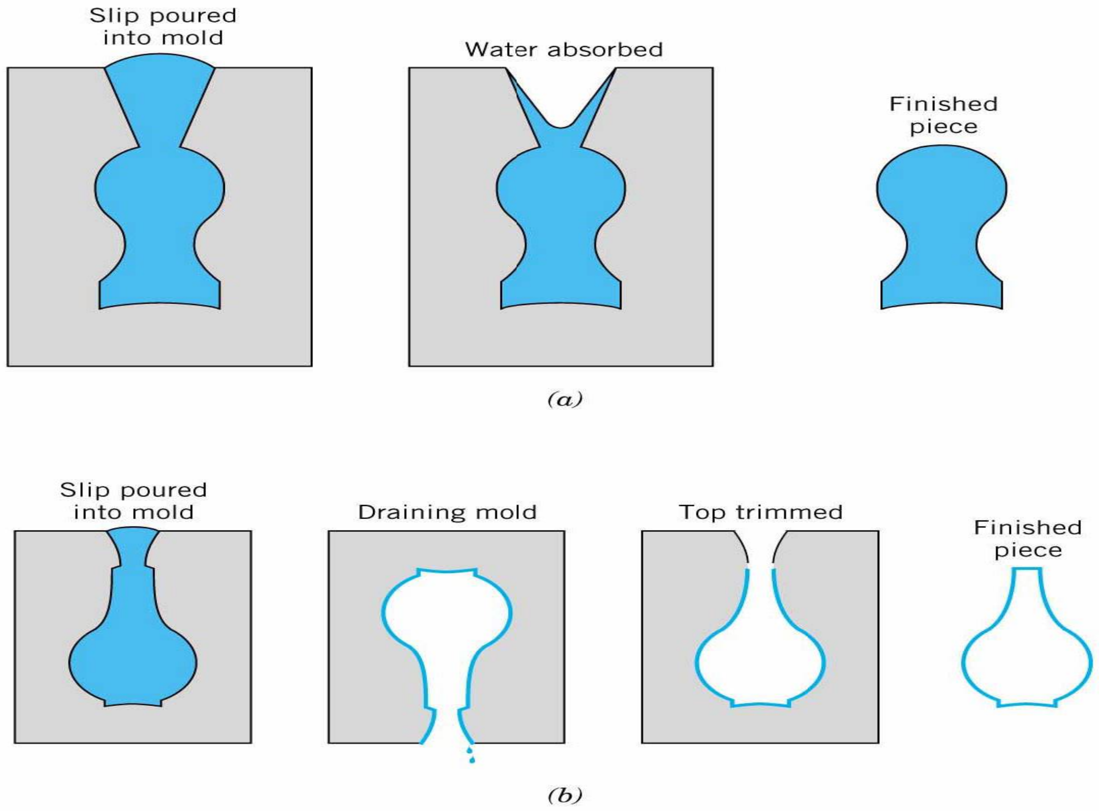
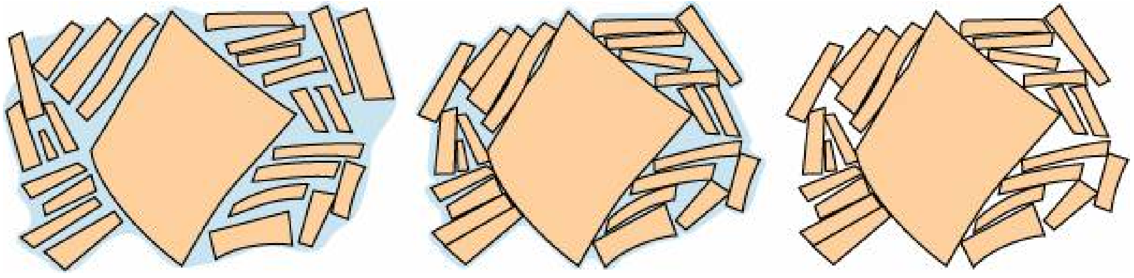


FIGURE 13.10 The steps in (*a*) solid and (*b*) drain slip casting using a plaster of paris mold. (From W. D. Kingery, *Introduction to Ceramics*. Copyright © 1960 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

Drying and Firing

- **Drying**: layer size and spacing decrease.



wet slip partially dry "green" ceramic

Adapted from Fig. 13.13, *Callister 7e*. (Fig. 13.13 is from W.D. Kingery, *Introduction to Ceramics*, John Wiley and Sons, Inc., 1960.)

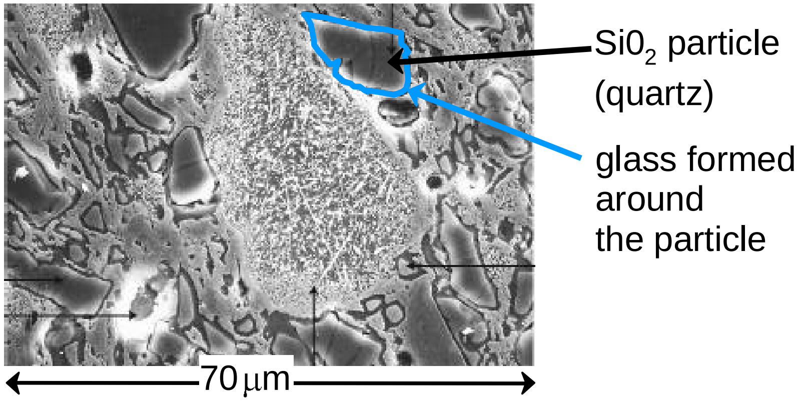
Drying too fast causes sample to warp or crack due to non-uniform shrinkage

- **Firing**焙燒:

--*T* raised to (900-1400 C)

--vitrification: liquid glass forms from clay and flows between SiO_2 particles. Flux melts at lower *T*.

micrograph of porcelain



Adapted from Fig. 13.14, *Callister 7e*.
(Fig. 13.14 is courtesy H.G. Brinkies, Swinburne University of Technology, Hawthorn Campus, Hawthorn, Victoria, Australia.)

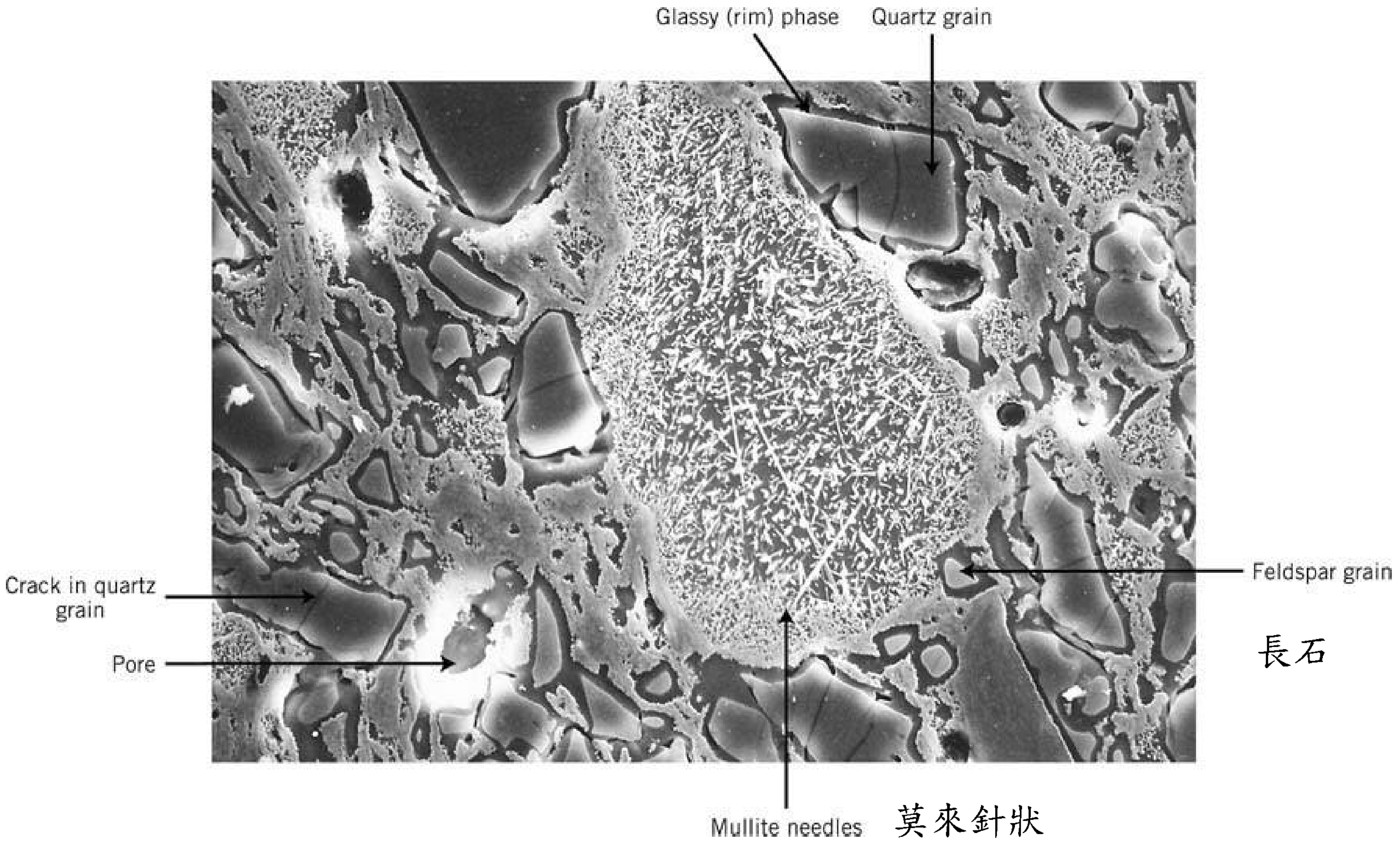


Figure 13.14 SEM of a fired porcelain specimen (etched 15 s, 5C,10% HF)

Ceramic Fabrication Methods-IIB

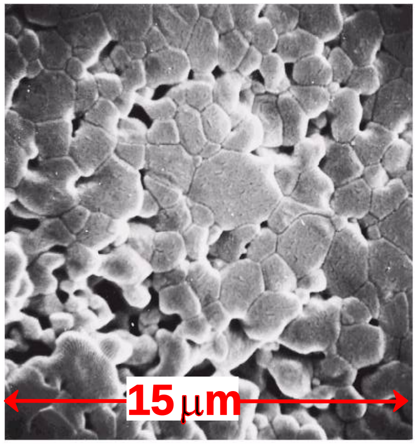
GLASS FORMING

PARTICULATE FORMING

CEMENTATION

Sintering: useful for both clay and non-clay compositions.

- Procedure:
  - -- produce ceramic and/or glass particles by grinding
  - -- place particles in mold
  - -- press at elevated T to reduce pore size.
- Aluminum oxide powder:
  - -- sintered at 1700 C for 6 minutes.



Adapted from Fig. 13.17, *Callister 7e*. (Fig. 13.17 is from W.D. Kingery, H.K. Bowen, and D.R. Uhlmann, *Introduction to Ceramics*, 2nd ed., John Wiley and Sons, Inc., 1976, p. 483.)

13.11 Powder Pressing

Uniaxial, isostatic and hot pressing

Procedure:

- **grind to produce ceramic and/or glass particles**
- **inject into mold**

13.11 Powder Pressing

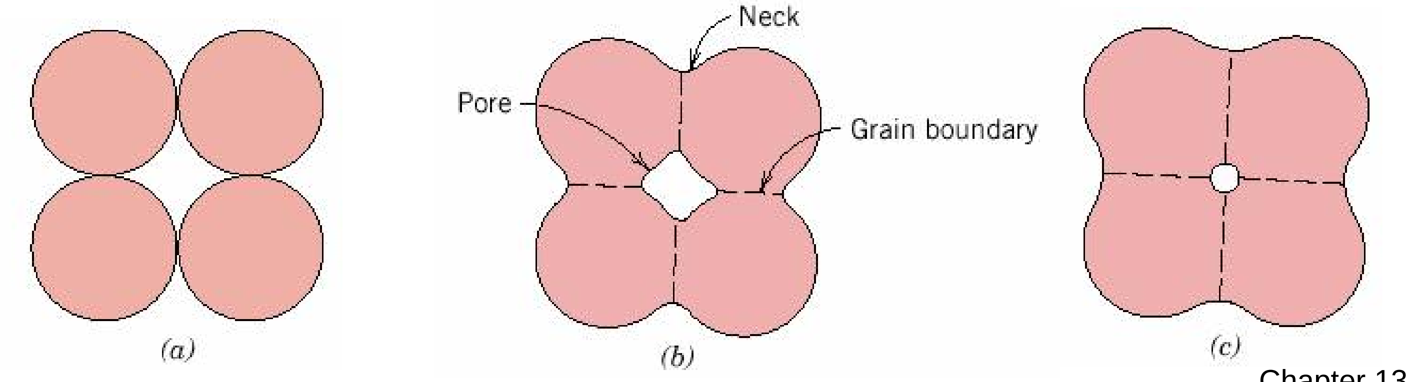
Sintering - powder touches - forms neck & gradually neck thickens

- add processing aids to help form neck
- little or no plastic deformation

Uniaxial compression - compacted in single direction

Isostatic (hydrostatic) compression - pressure applied by fluid - powder in rubber envelope

Hot pressing - pressure + heat



Adapted from Fig. 13.16, *Callister 7e*.

Uniaxial Pressing

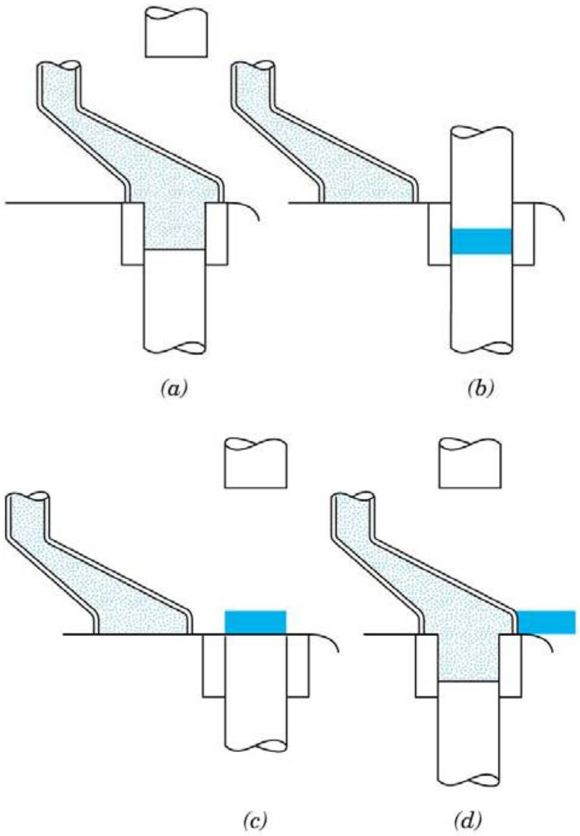


Figure 13.15 hematic representation of the steps in uniaxial powder pressing. (*a*) The die cavity is filled with powder. (*b*) The powder is compacted by means of pressure applied to the top die. (*c*) The compacted piece is ejected by rising action of the bottom punch. (*d*) The fill shoe pushes away the compacted piece, and the fill step is repeated. (From W. D. Kingery, Editor, *Ceramic Fabrication Processes,* MIT Press. Copyright © 1958 by the Massachusetts Institute of Technology.)

Pressing → sintering燒結

Sintering: During firing the formed piece shrinks, and experiences a reduction of porosity and an improvement in mechanical integrity. These changes occur by the coalescence of the particle into a more dense mass.

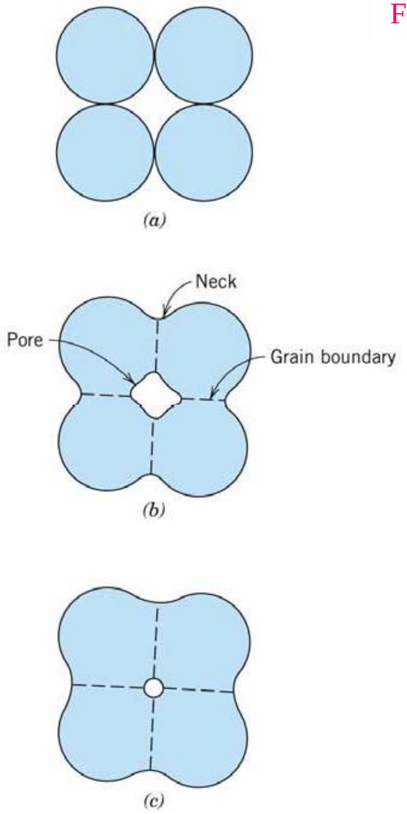


Figure 13.16 r a powder compact, microstructural changes that occur during firing. (*a*) Powder particles after pressing. (*b*) Particle coalescence and pore formation as sintering begins. (*c*) As sintering proceeds, the pores change size and shape.

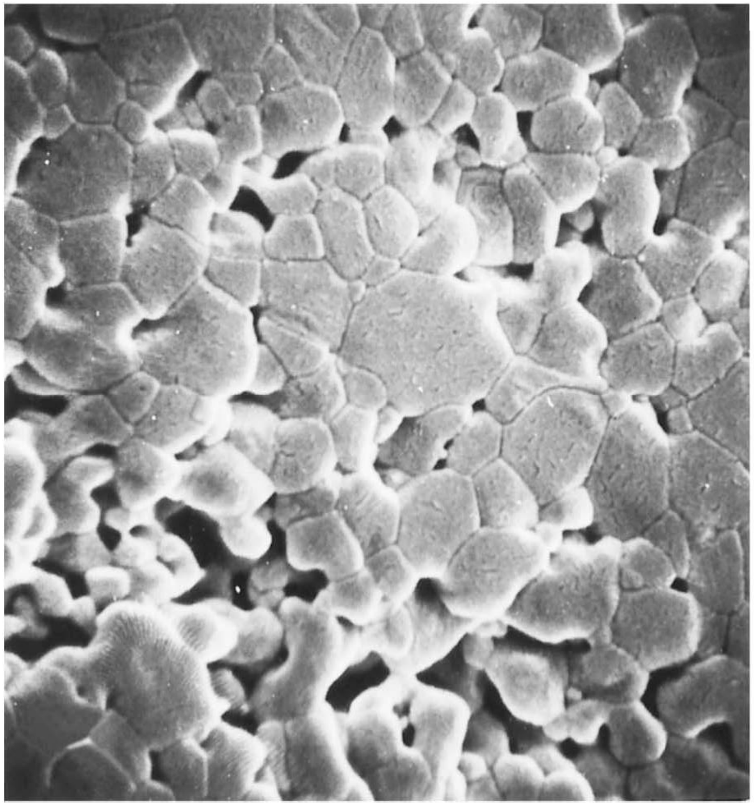
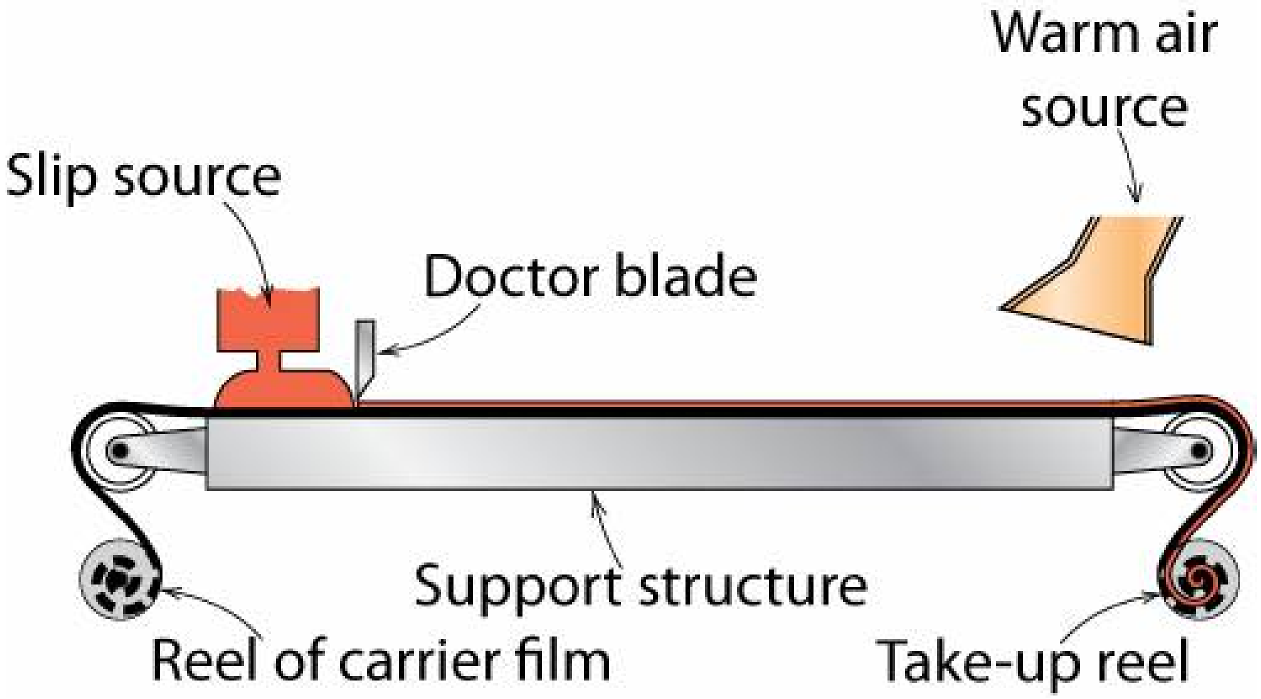


Figure 13.17 canning electron micrograph of an aluminum oxide powder compact that was sintered at 1700°C for 6 min. 5000×. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition, p. 483. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

Al2O3 sintered at
1700℃ for 6 minutes

13.12 Tape Casting帶狀鑄造

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



Adapted from Fig. 13.18,Schematic diagram showing the tape-casting process using a doctor blade. *Callister 7e.*

Ceramic Fabrication Methods-III

GLASS FORMING

PARTICULATE FORMING

CEMENTATION

- Produced in extremely large quantities.
- Portland cement:
  - -- mix clay and lime bearing materials
  - -- calcinate (heat to 1400°C)
  - -- primary constituents:
    - tri-calcium silicate
    - di-calcium silicate
- Adding water
  - -- produces a paste which hardens
  - -- hardening occurs due to hydration (chemical reactions with the water).
- Forming: done usually minutes after hydration begins.

Summary

- Basic categories of ceramics:
  - -- glasses
  - -- clay products
  - -- refractories
  - --abrasives
  - -- cements
  - -- advanced ceramics
- Fabrication Techniques:
  - -- glass forming (impurities affect forming temp).
  - -- particulate forming (needed if ductility is limited)
  - -- cementation (large volume, room *T* process)
- Heat treating: Used to
  - -- alleviate residual stress from cooling,
  - -- produce fracture resistant components by putting surface into compression.

Applications: Advanced Ceramics

Heat Engines

- Advantages:
  - Run at higher temperature
  - Excellent wear & corrosion resistance
  - Low frictional losses
  - Ability to operate without a cooling system
  - Low density

- Disadvantages:
  - Brittle
  - Too easy to have voids- weaken the engine
  - Difficult to machine

- Possible parts – engine block, piston coatings, jet engines

  Ex: Si_3N_4, SiC, & ZrO_2

Applications: Advanced Ceramics

- Ceramic Armor
  - Al_2O_3, B_4C, SiC & TiB_2
  - Extremely hard materials
    - shatter the incoming projectile
    - energy absorbent material underneath

Applications: Advanced Ceramics

Electronic Packaging

- Chosen to securely hold microelectronics & provide heat transfer
- Must match the thermal expansion coefficient of the microelectronic chip & the electronic packaging material. Additional requirements include:
  - – good heat transfer coefficient
  - – poor electrical conductivity
- Materials currently used include:
  - Boron nitride (BN)
  - Silicon Carbide (SiC)
  - Aluminum nitride (AlN)
    - – thermal conductivity 10x that for Alumina
    - – good expansion match with Si