2019 Fall

Introduction to Materials Science and Engineering

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Chapter 15:
Characteristics & Applications of Polymers

- Limitations of polymers:
  -- E, σ_y, K_c, $T_{application}$ are generally small.
  -- Deformation is often time and temperature dependent.

- Thermoplastics (PE, PS, PP, PC):
  -- Smaller E, σ_y, $T_{application}$
  -- Larger K_c
  -- Easier to form and recycle

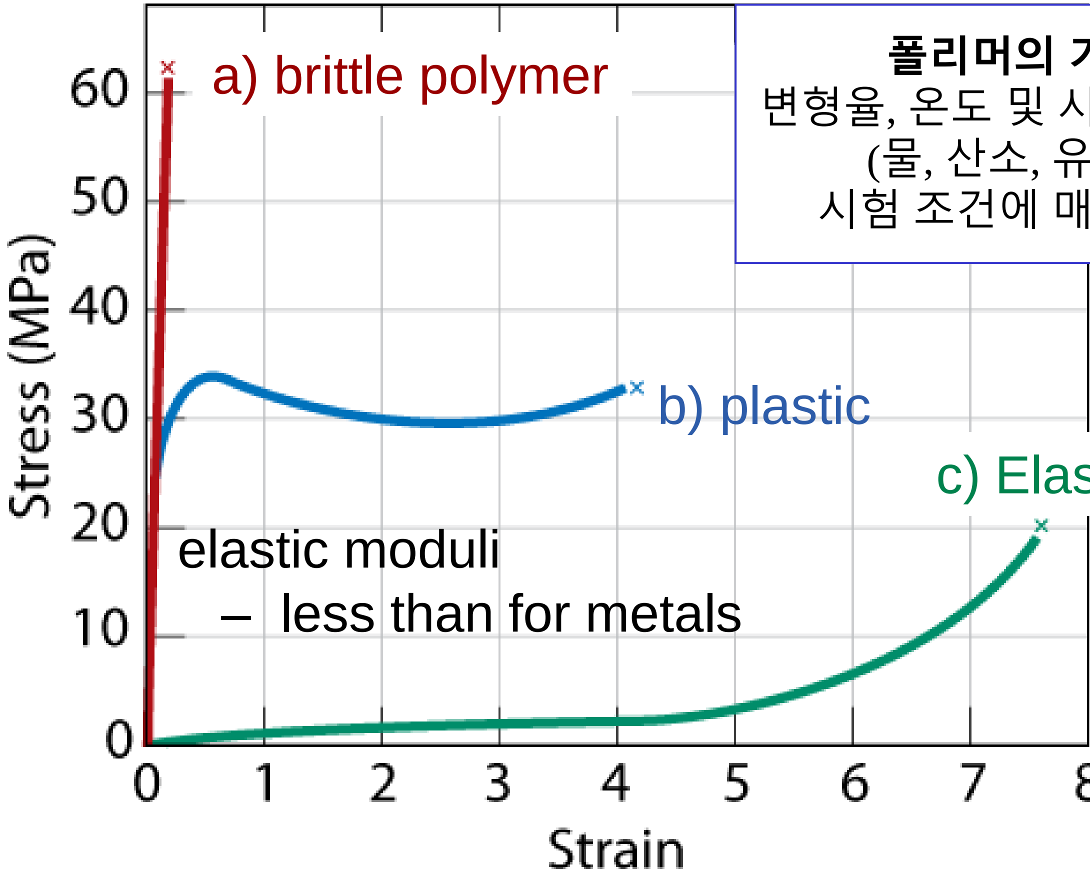
- Elastomers (rubber):
  -- Large reversible strains!

- Thermosets (epoxies, polyesters):
  -- Larger E, σ_y, $T_{application}$
  -- Smaller K_c

Table 15.3 *Callister & Rethwisch 9e*:

Good overview of applications and trade names of polymers.

Chapter 15:
Characteristics & Applications of Polymers



폴리머의 기계적 성질은
변형율, 온도 및 시험의 화학적 분위기
(물, 산소, 유기 용매 등) 등
시험 조건에 매우 민감하게 변화

elastic moduli
– less than for metals

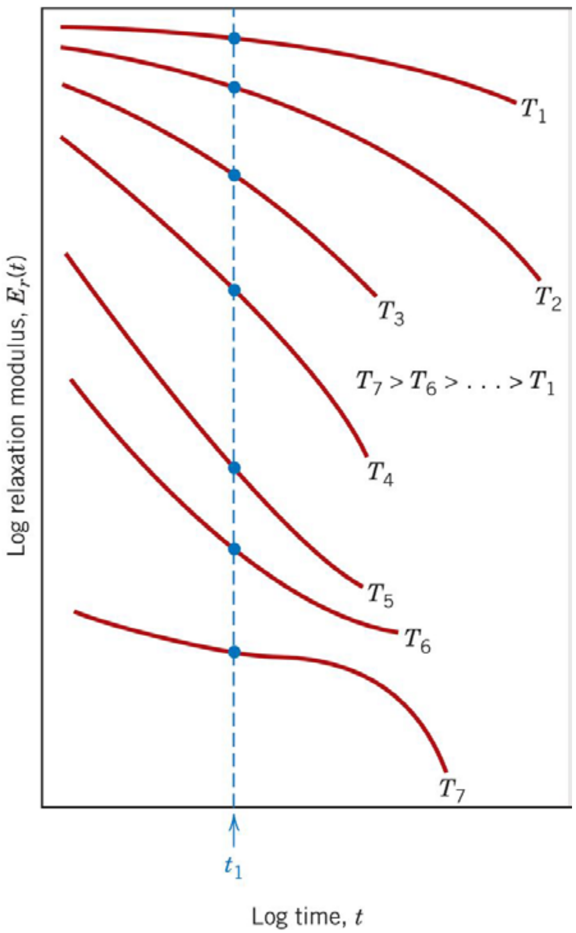
Adapted from Fig. 15.1, *Callister & Rethwisch 9e.*

- Fracture strengths of polymers ~ 10% of those for metals
- Deformation strains for polymers > 1000% (100 times for metals)
  - for most metals, deformation strains < 10%

폴리머 재료의 점탄성 거동: 시간과 온도에 따라 변화

$$E_r(t) = \frac{\sigma(t)}{\epsilon_0}$$

$E_r(t)$ 이완계수 = 시간의존성 탄성계수 ---- t, T 증가시 감소



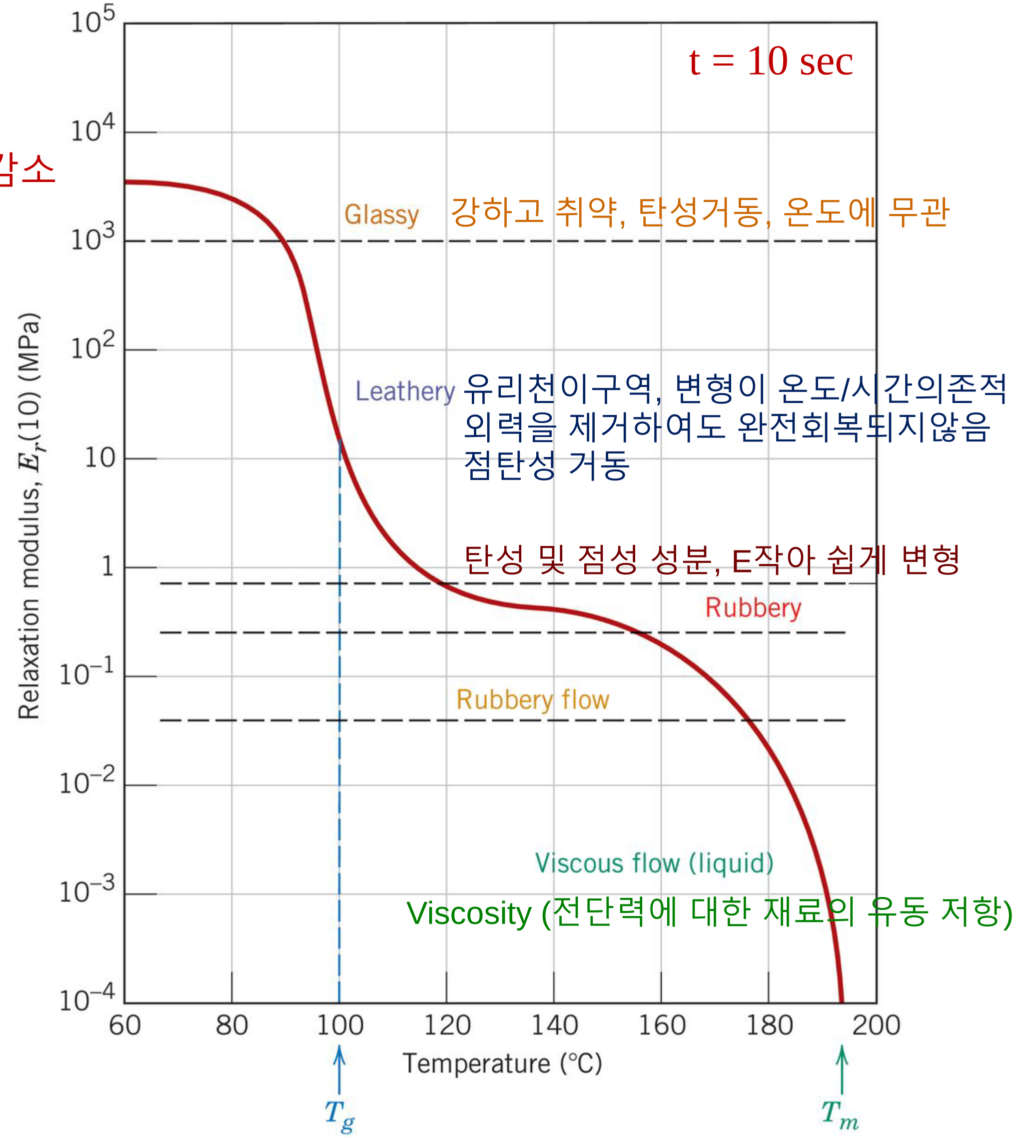


그림 15.6 탄성 폴리머의 이완계수로 로그값과 시간 로그값의 모식적 관계. 온도를 T_1에서 T_7까지 변화시킴. 이완계수의 온도 의존성은 $\log E_r(t_1)$ 온도로 나타냄.

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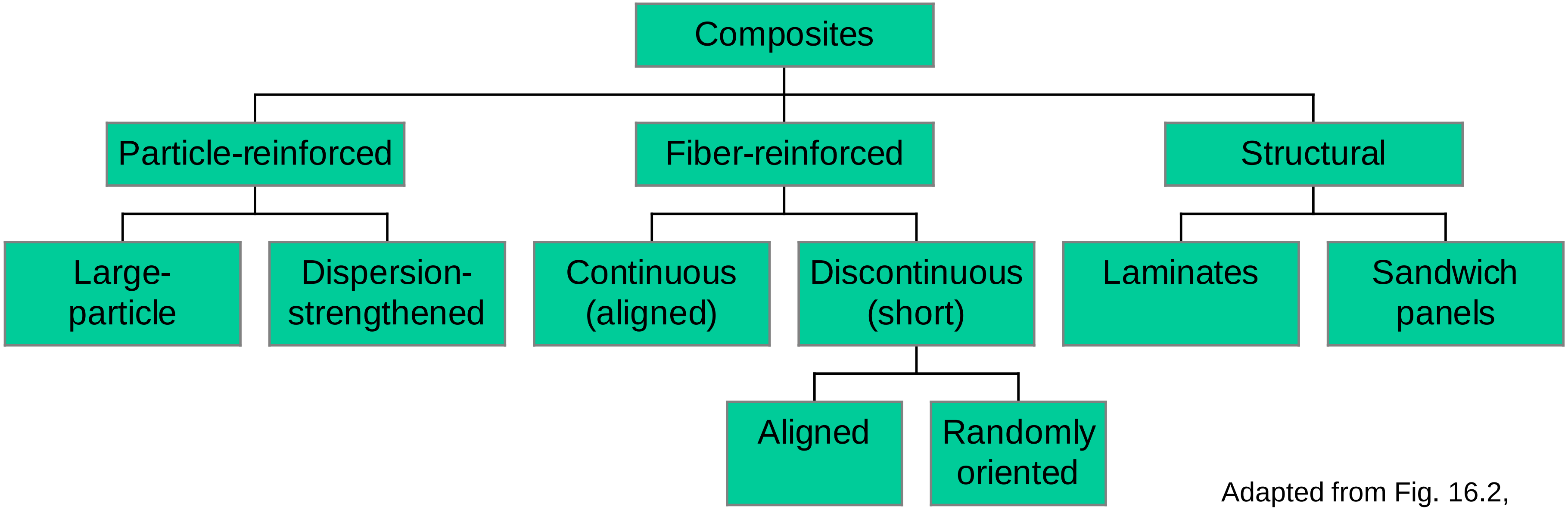
Chapter 16: Composite Materials

- Composites types are designated by:
  -- the matrix material (CMC, MMC, PMC)
  -- the reinforcement (particles, fibers, structural)
- Composite property benefits:
  -- MMC: enhanced E, σ^*, creep performance
  -- CMC: enhanced K_{Ic}
  -- PMC: enhanced E/ρ, σ_y, TS/ρ
- Particulate-reinforced:
  -- Types: large-particle and dispersion-strengthened
  -- Properties are isotropic
- Fiber-reinforced:
  -- Types: continuous (aligned)
  discontinuous (aligned or random)
  -- Properties can be isotropic or anisotropic
- Structural:
  -- Laminates and sandwich panels

Chapter 16: Composite Materials



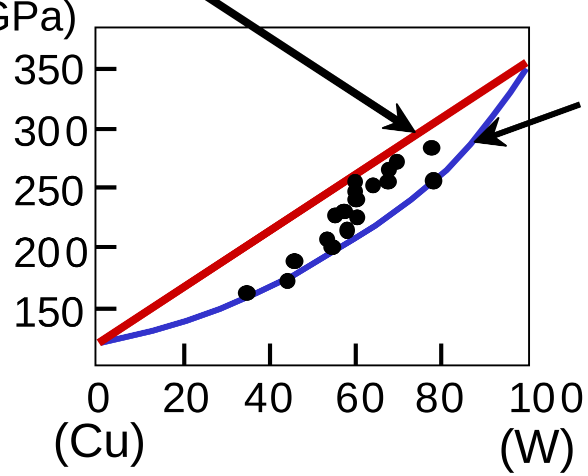
Adapted from Fig. 16.2, *Callister & Rethwisch 9e*.

Classification: Particle-Reinforced (iii)

Particle-reinforced | Fiber-reinforced | Structural

- Elastic modulus, E_c, of composites:
  - -- two "rule of mixture" extremes:

upper limit: $E_c = V_m E_m + V_p E_p$



Data:
Cu matrix
w/tungsten
particles

lower limit:

$$\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_p}{E_p}$$

Fig. 16.3, *Callister & Rethwisch 9e*. (Reprinted with permission from R. H. Krock, *ASTM Proceedings*, Vol. 63, 1963. Copyright ASTM International, 100 Barr Harbor Drive, West Conschohocken, PA 19428.)

- Application to other properties:
  - -- Electrical conductivity, σ_e: Replace E's in equations with σ_e's.
  - -- Thermal conductivity, k: Replace E's in equations with k's.

Classification: Fiber-Reinforced (v)

Particle-reinforced | **Fiber-reinforced** | Structural

- Critical fiber length for effective stiffening & strengthening:

fiber ultimate tensile strength

fiber diameter

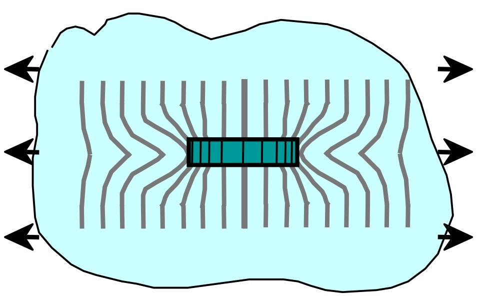
$$\text{fiber length} > \frac{\sigma_f d}{2\tau_c}$$

shear strength of fiber-matrix interface

- Ex: For fiberglass, common fiber length > 15 mm needed
- For longer fibers, stress transference from matrix is more efficient

Short, thick fibers:

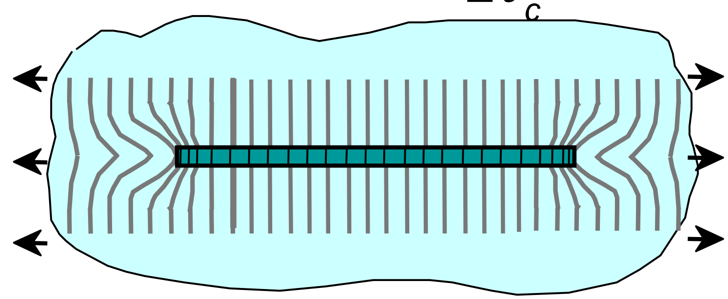
$$\text{fiber length} < \frac{\sigma_f d}{2\tau_c}$$



Low fiber efficiency

Long, thin fibers:

$$\text{fiber length} > \frac{\sigma_f d}{2\tau_c}$$



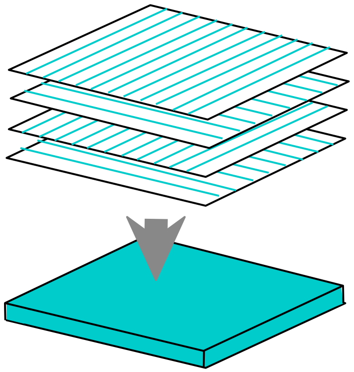
High fiber efficiency

Classification: Structural

Particle-reinforced | Fiber-reinforced | **Structural**

- Laminates -

  -- stacked and bonded fiber-reinforced sheets
  - stacking sequence: e.g., 0º/90º
  - benefit: balanced in-plane stiffness



Adapted from Fig. 16.16, *Callister & Rethwisch 8e*.

- Sandwich panels

  -- honeycomb core between two facing sheets
  - benefits: low density, large bending stiffness

face sheet
adhesive layer
honeycomb

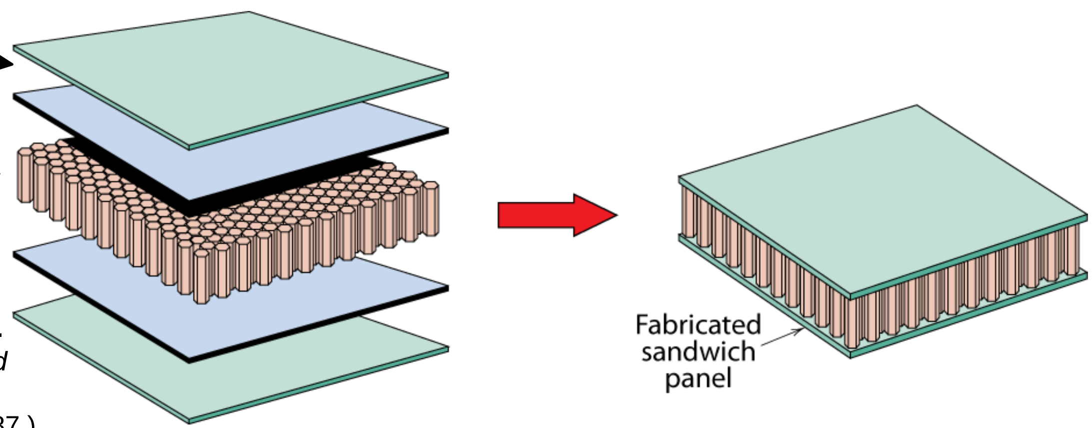
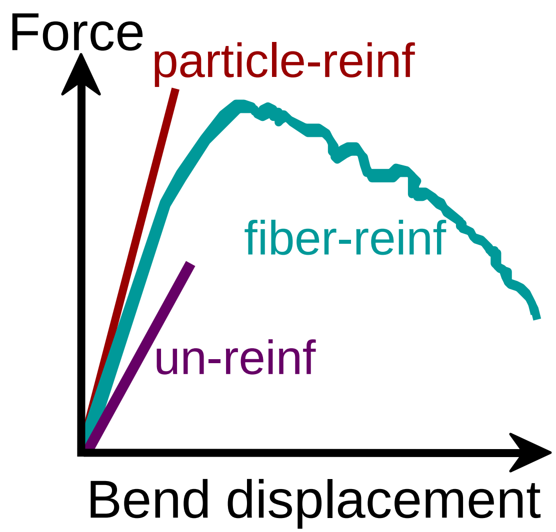


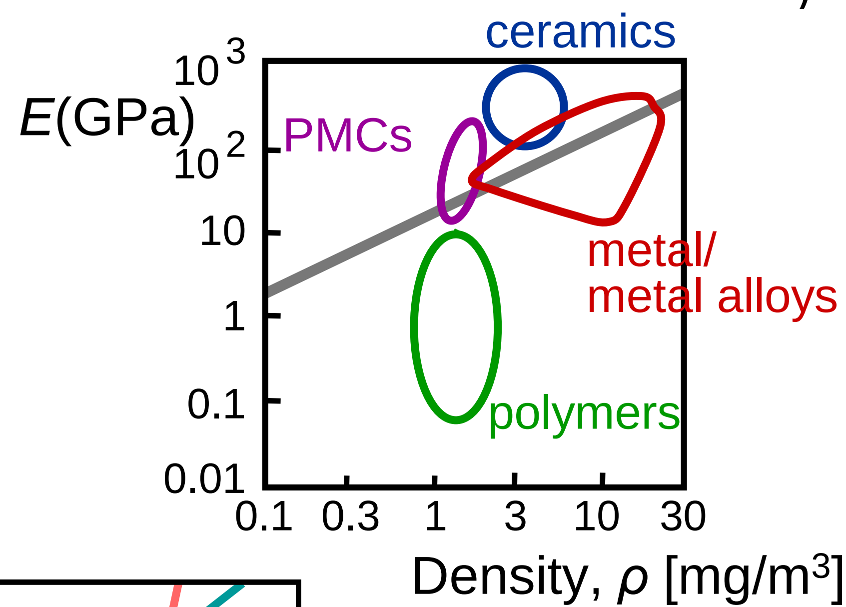
Fig. 16.18, *Callister & Rethwisch 9e*.
(Reprinted with permission from *Engineered Materials Handbook*, Vol. 1, Composites, ASM International, Materials Park, OH, 1987.)

Composite Benefits

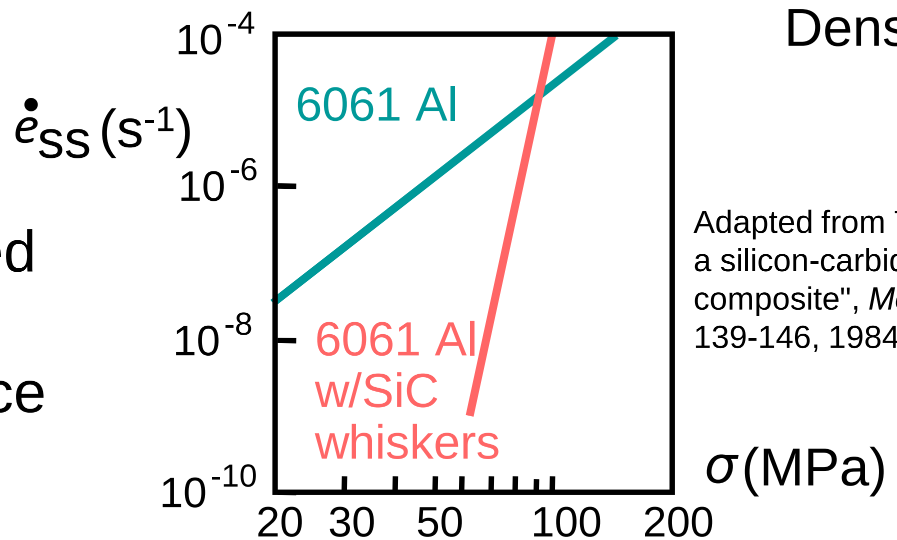
- CMCs: Increased toughness



- PMCs: Increased E/ρ



- MMCs:
  Increased creep resistance



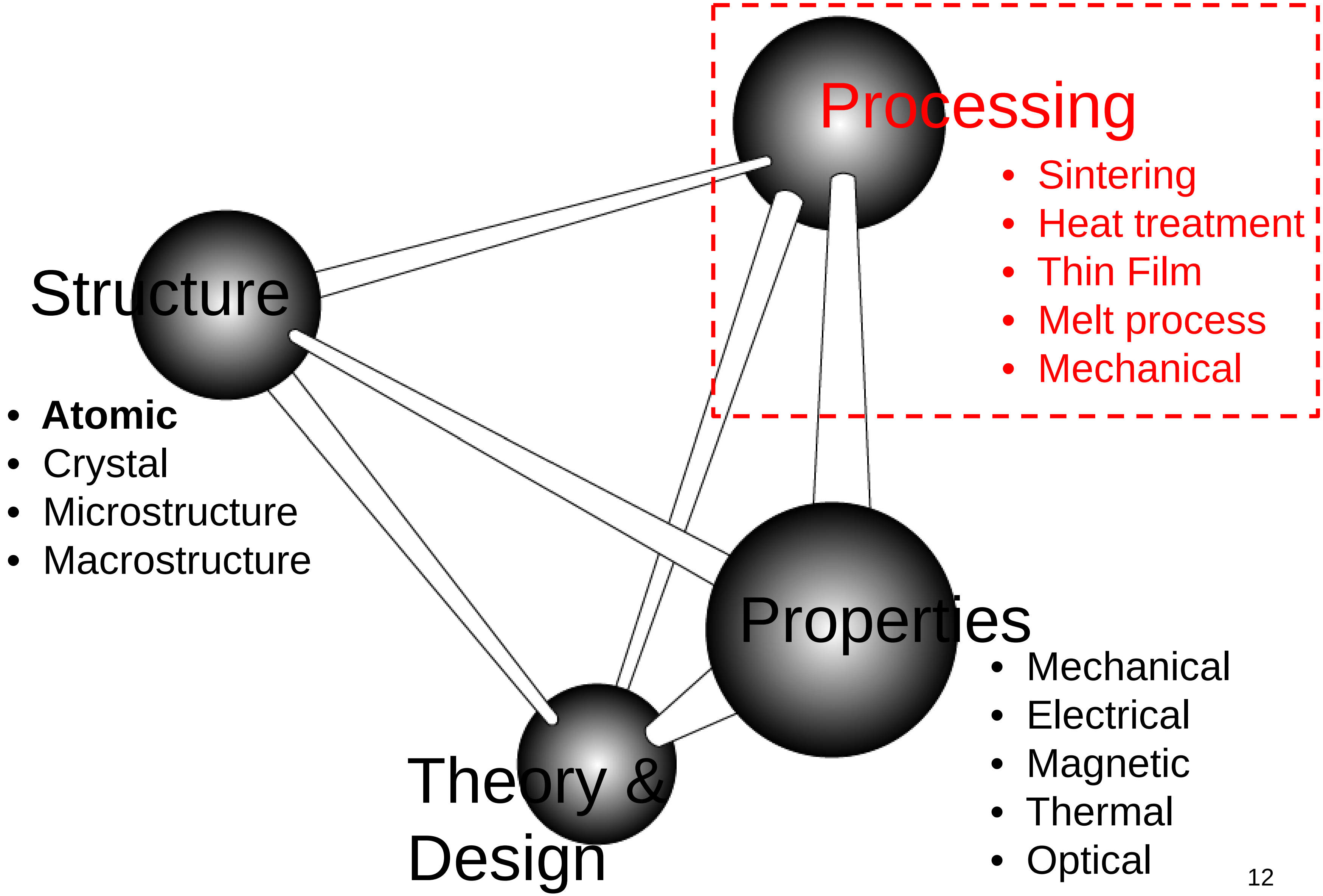
Adapted from T.G. Nieh, "Creep rupture of a silicon-carbide reinforced aluminum composite", *Metall. Trans. A* Vol. 15(1), pp. 139-146, 1984. Used with permission.

Chapter 17: Fabrication and Processing of Engineering Materials

ISSUES TO ADDRESS...

- What are some of the common fabrication techniques for metals?
- What heat treatment procedures are used to improve the mechanical properties of both ferrous and nonferrous alloys?
- How is processing of ceramics different than for metals?
- What are the primary polymer processing methods?

Materials Science and Engineering



I. Metal Fabrication

- How do we fabricate metals?
  - Blacksmith - hammer (forged)
  - Cast molten metal into mold
- Forming Operations
  - Rough stock formed to final shape

Hot working vs. Cold working

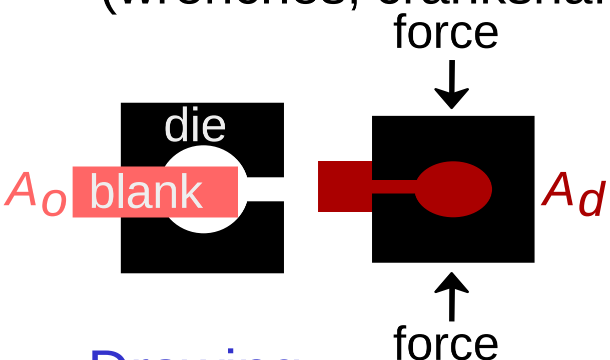
Hot working:
- Deformation temperature high enough for **recrystallization**
- Large deformations

Cold working:
- Deformation **below recrystallization temperature**
- Strain hardening occurs
- Small deformations

Metal Fabrication Methods (i)

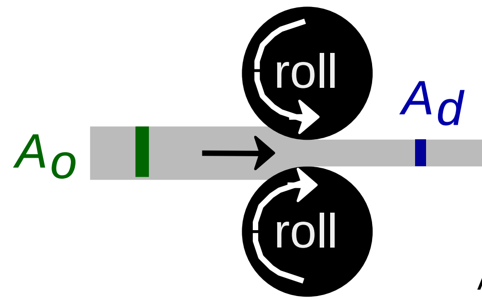
FORMING | CASTING | MISCELLANEOUS

- Forging (Hammering; Stamping)
  (wrenches, crankshafts)



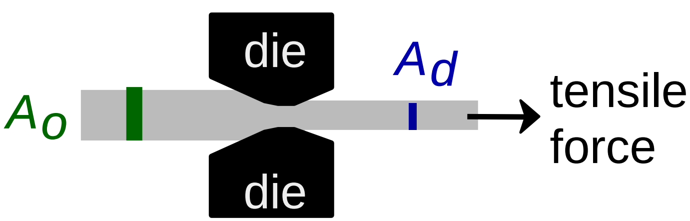
often at elev. *T*

- Rolling (Hot or Cold Rolling)
  (I-beams, rails, sheet & plate)



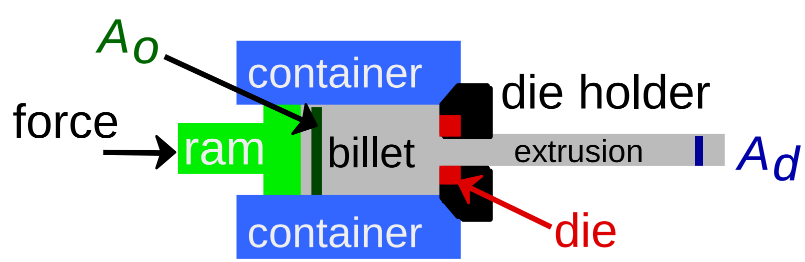
Adapted from Fig. 17.2, *Callister & Rethwisch 9e.*

- Drawing
  (rods, wire, tubing)



die must be well lubricated & clean

- Extrusion
  (rods, tubing)



ductile metals, e.g. Cu, Al (hot)

Metal Fabrication Methods (ii)

FORMING | CASTING | MISCELLANEOUS

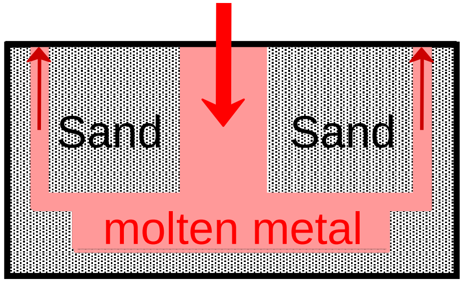
- Casting- mold is filled with molten metal
  - metal melted in furnace, perhaps alloying elements added, then cast in a mold
  - common and inexpensive
  - gives good production of shapes
  - weaker products, internal defects
  - good option for brittle materials

Metal Fabrication Methods (iii)

FORMING | **CASTING** | MISCELLANEOUS

- Sand Casting

  (large parts, e.g., auto engine blocks)

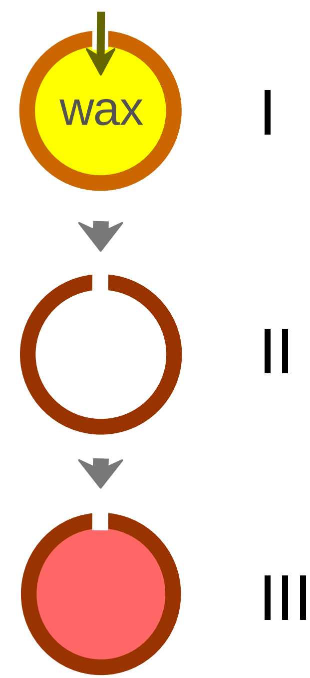


- What material will withstand T >1600°C and is inexpensive and easy to mold?
- Answer: sand!!!
- To create mold, pack sand around form (pattern) of desired shape

Metal Fabrication Methods (iv)

FORMING | CASTING | MISCELLANEOUS

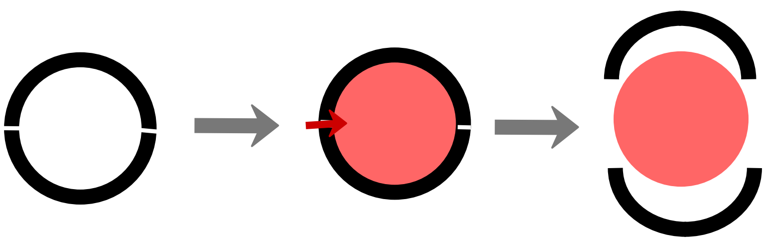
- Investment Casting
  (low volume, complex shapes
  e.g., jewelry, turbine blades)
  - Stage I — Mold formed by pouring plaster of paris around wax pattern. Plaster allowed to harden.
  - Stage II — Wax is melted and then poured from mold—hollow mold cavity remains.
  - Stage III — Molten metal is poured into mold and allowed to solidify.



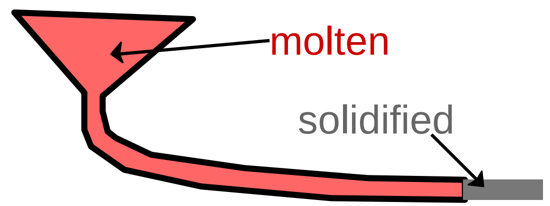
Metal Fabrication Methods (v)

FORMING | **CASTING** | MISCELLANEOUS

- Die Casting
  - -- high volume
  - -- for alloys having low melting temperatures



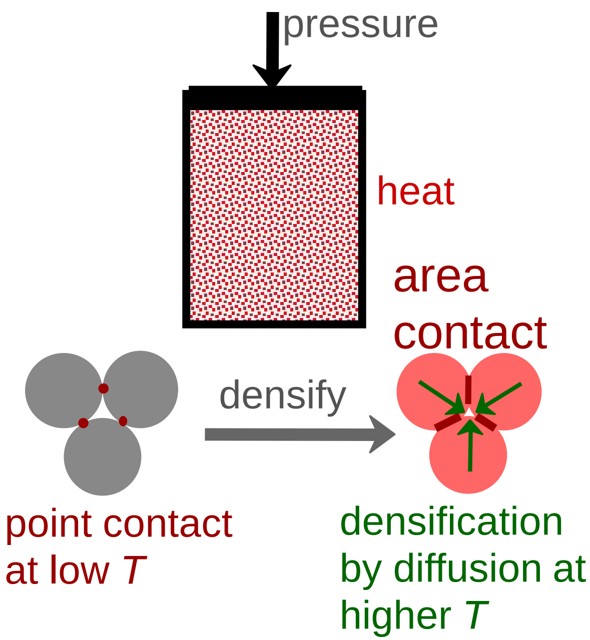
- Continuous Casting
  - -- simple shapes (e.g., rectangular slabs, cylinders)



Metal Fabrication Methods (vi)

FORMING | CASTING | **MISCELLANEOUS**

- Powder Metallurgy
  (metals w/low ductilities)



- Welding
  (when fabrication of one large part is impractical)

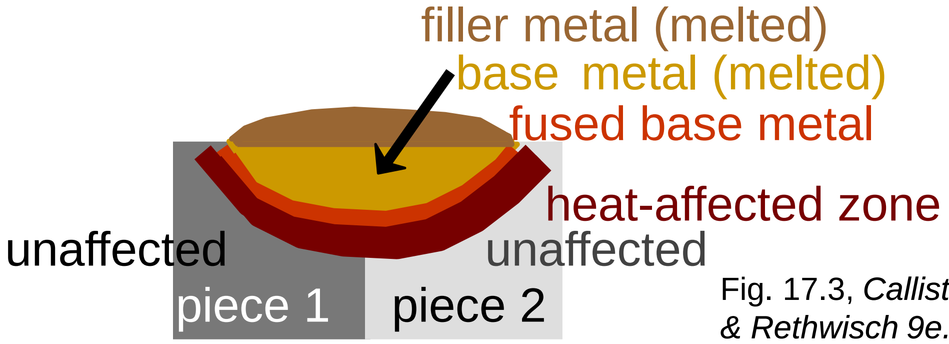


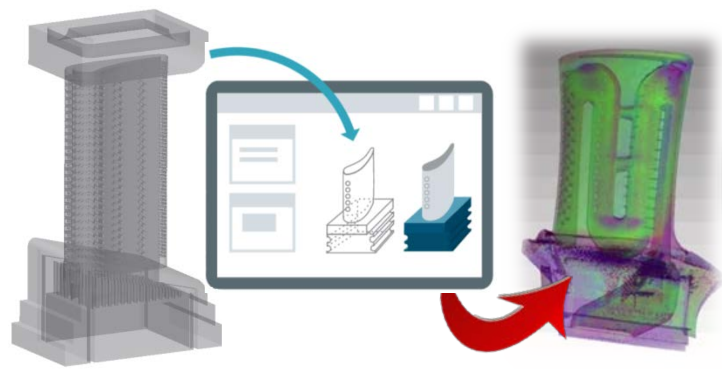
Fig. 17.3, *Callister & Rethwisch 9e.* [From *Iron Castings Handbook*, C.F. Walton and T.J. Opar (Ed.), Iron Castings Society, Des Plaines, IL,1981.]

- Heat-affected zone:
  (HAZ, region in which the microstructure has been changed).

맞춤형 구조제어 직접디지털제조 공정기술

냉각효율 극대화를 위한 3차원 구조 설계

Turbine design by 3D digital modeling

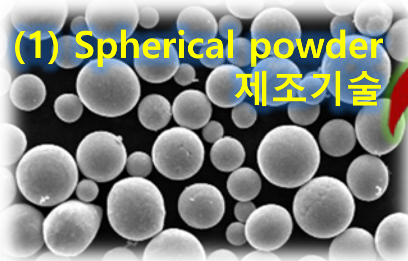


Complex internal cooling channel

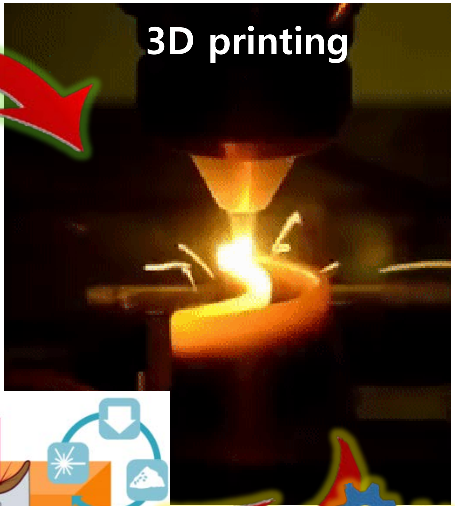
→ Cooling efficiency ↑

3D 프린팅 기반 직접 디지털 제조 공정기술 개발

(1) Spherical powder 제조기술



3D printing



Turbine Blade

Feedback

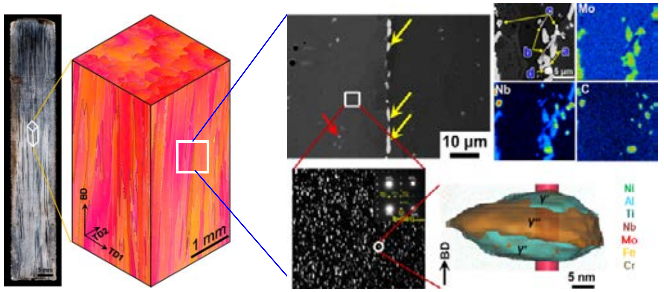
(Powder ↔ Laser ↔ Cooling)

(2) 3D printing Microstructure control

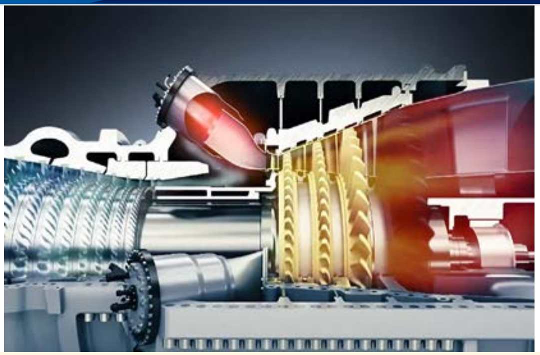
Directional solidification

\+

Fine precipitate



차세대 초고효율 터빈 부품화 기술 개발



(3) 초임계 성능 구현 터빈 부품 제조

Thermal Processing of Metals

Annealing: Heat to T_{anneal}, then cool slowly.

Types of Annealing

- **Stress Relief**: Reduce stresses resulting from:
  - plastic deformation
  - nonuniform cooling
  - phase transform.

- **Spheroidize** (steels): Make very soft steels for good machining. Heat just below $T_{eutectoid}$ & hold for 15-25 h.

- **Full Anneal** (steels): Make soft steels for good forming. Heat to get γ, then furnace-cool to obtain coarse pearlite.

- **Process Anneal**: Negate effects of cold working by (recovery/ recrystallization)

- **Normalize** (steels): Deform steel with large grains. Then heat treat to allow recrystallization and formation of smaller grains.

Based on discussion in Section 17.5, *Callister & Rethwisch 9e*.

Heat Treatment Temperature-Time Paths

a) Full Annealing

b) Quenching

c) Tempering (Tempered Martensite)

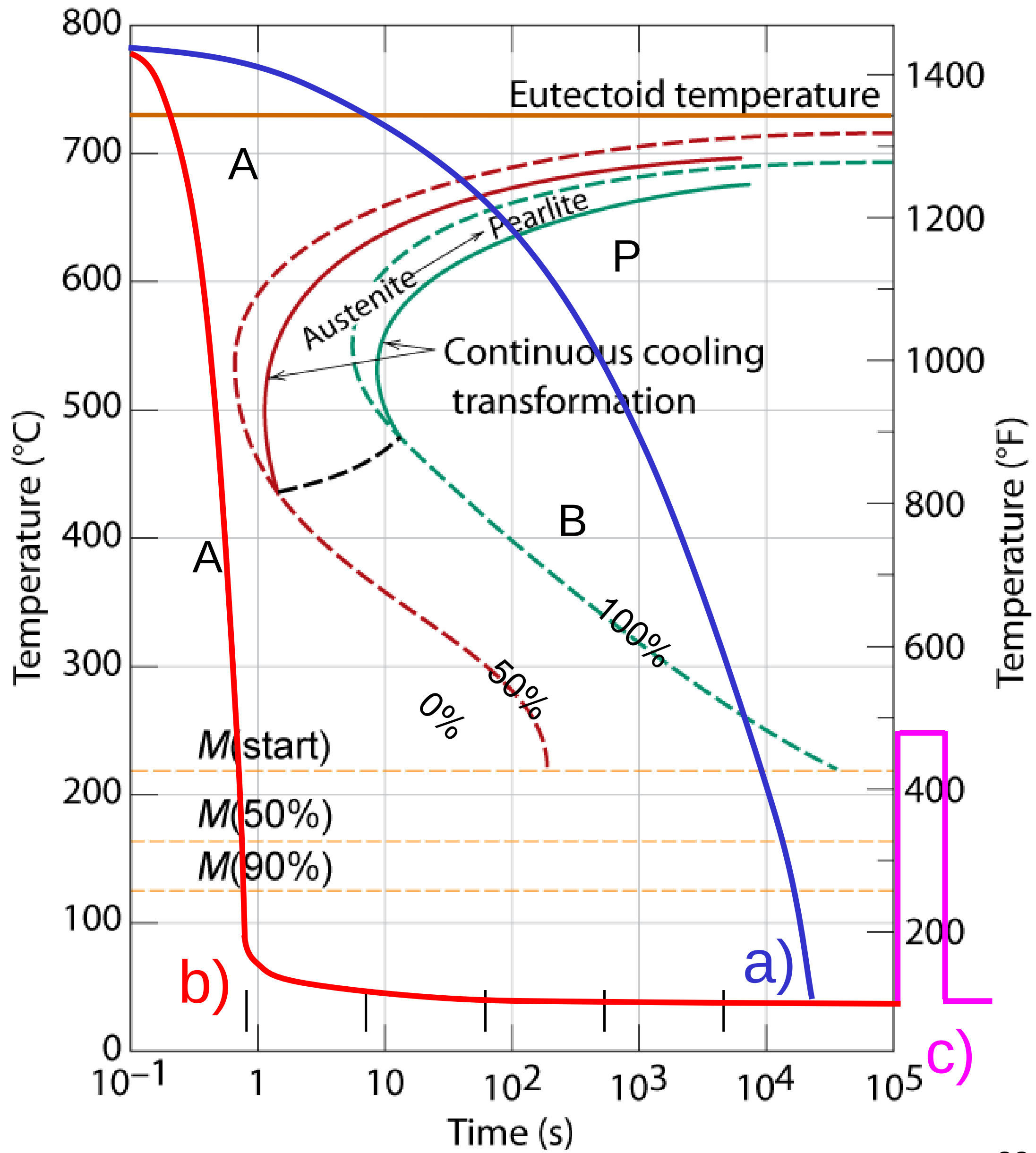


Fig. 12.25, *Callister & Rethwisch 9e*.
[Adapted from H. Boyer (Editor), Atlas of Isothermal Transformation and Cooling Transformation Diagrams, 1977. Reproduced by permission of ASM International, Materials Park, OH.]

Hardenability -- Steels

- Hardenability – measure of the ability to form martensite
- Jominy end quench test used to measure hardenability.

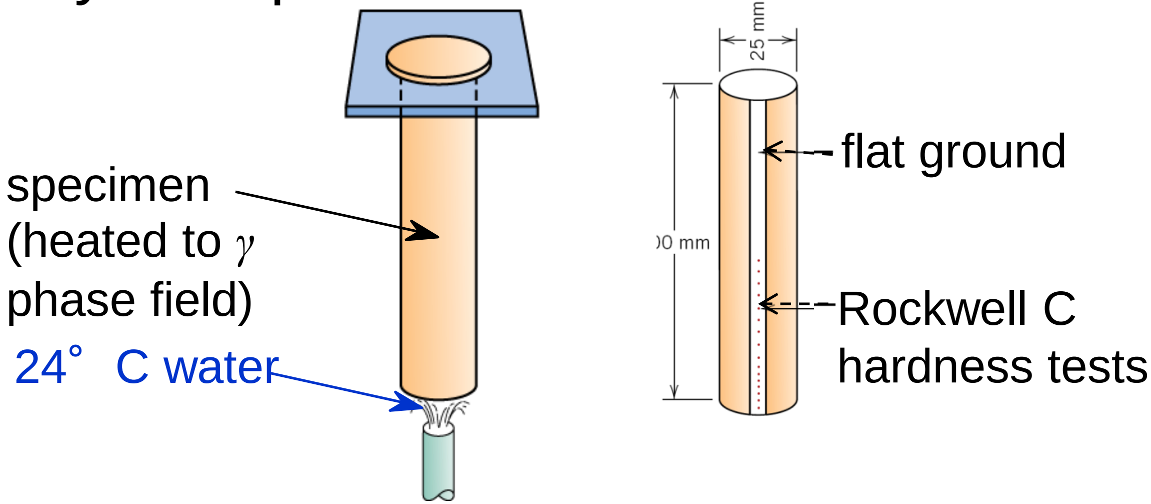


Fig. 17.5, *Callister & Rethwisch 9e*. (Adapted from A.G. Guy, *Essentials of Materials Science*, McGraw-Hill Book Company, New York, 1978.)

- Plot hardness versus distance from the quenched end.

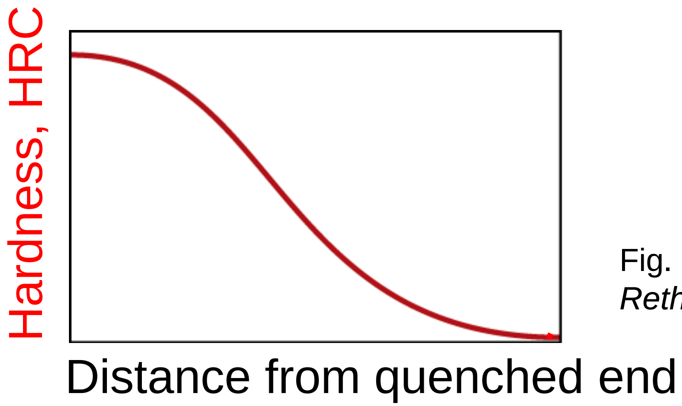


Fig. 17.6, *Callister & Rethwisch 9e*.

Reason Why Hardness Changes with Distance

- The cooling rate decreases with distance from quenched end.

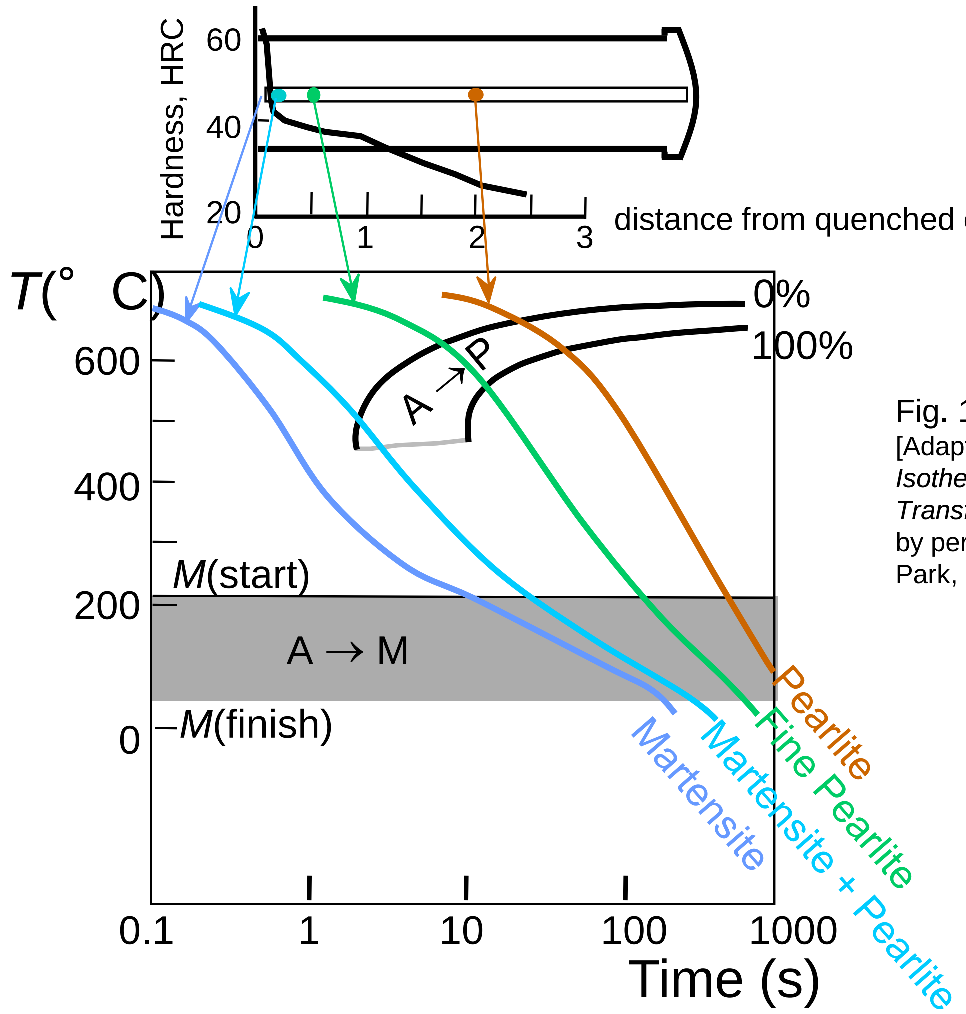


Fig. 17.7, *Callister & Rethwisch 9e*.
[Adapted from H. Boyer (Ed.), *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, 1977. Reproduced by permission of ASM International, Materials Park, OH.]

Hardenability vs Alloy Composition

- Hardenability curves for five alloys each with, *C* = 0.4 wt% C

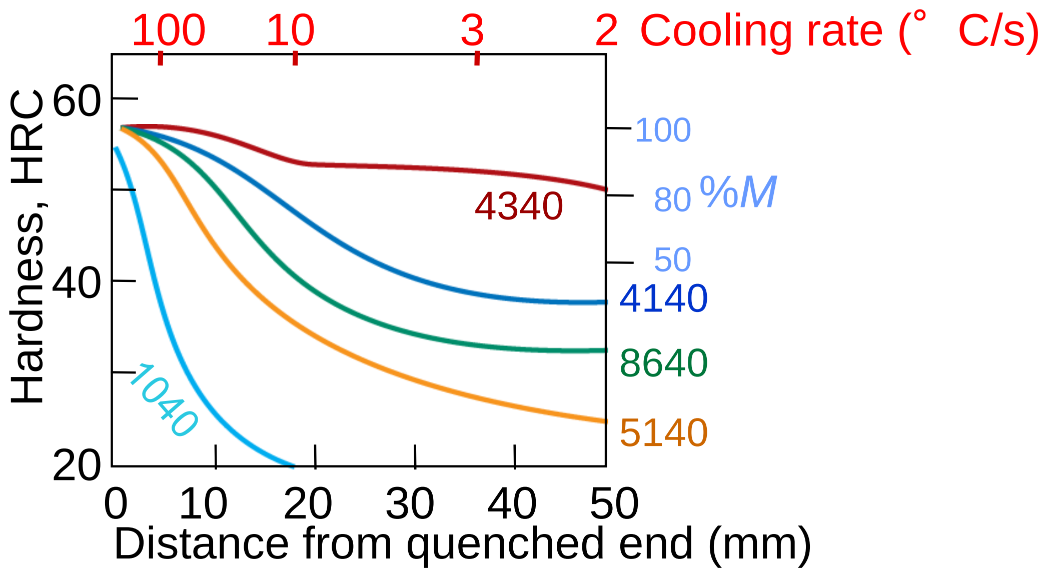
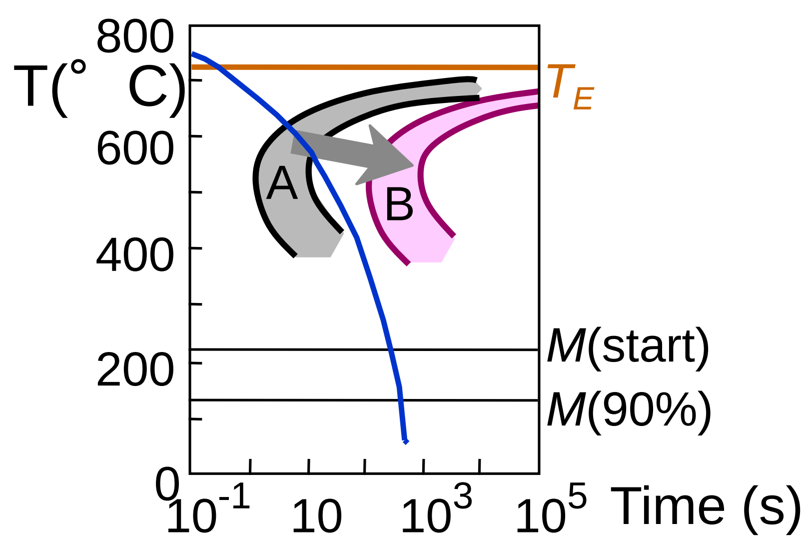


Fig. 17.8, *Callister & Rethwisch 9e*.
(Adapted from figure furnished courtesy Republic Steel Corporation.)

- "Alloy Steels"
  (4140, 4340, 5140, 8640)
  -- contain Ni, Cr, Mo
     (0.2 to 2 wt%)
  -- these elements shift
     the "nose" to longer times
     (from A to B)
  -- martensite is easier
     to form



Influences of Quenching Medium & Specimen Geometry

- Effect of quenching medium:

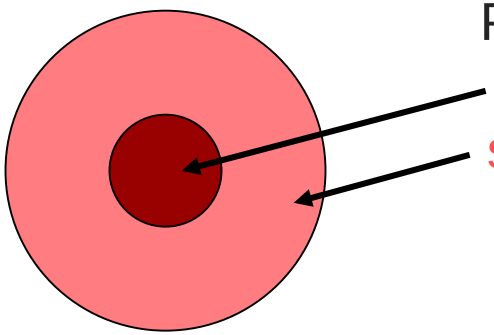
Medium	Severity of Quench	Hardness
air	low	low
oil	moderate	moderate
water	high	high

- Effect of specimen geometry:

When surface area-to-volume ratio increases:

-- cooling rate throughout interior increases

-- hardness throughout interior increases



Position	Cooling rate	Hardness
center	low	low
surface	high	high

Precipitation Hardening

- Particles impede dislocation motion.
- Ex: Al-Cu system
- Procedure:
  -- Pt A: solution heat treat (get α solid solution)
  -- Pt B: quench to room temp. (retain α solid solution)
  -- Pt C: reheat to nucleate small θ particles within α phase.

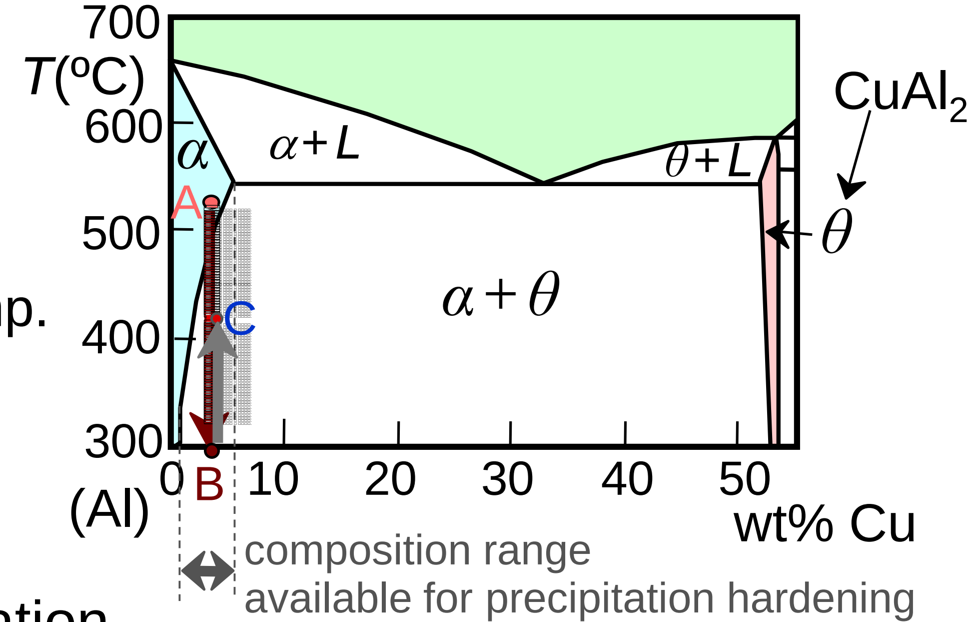
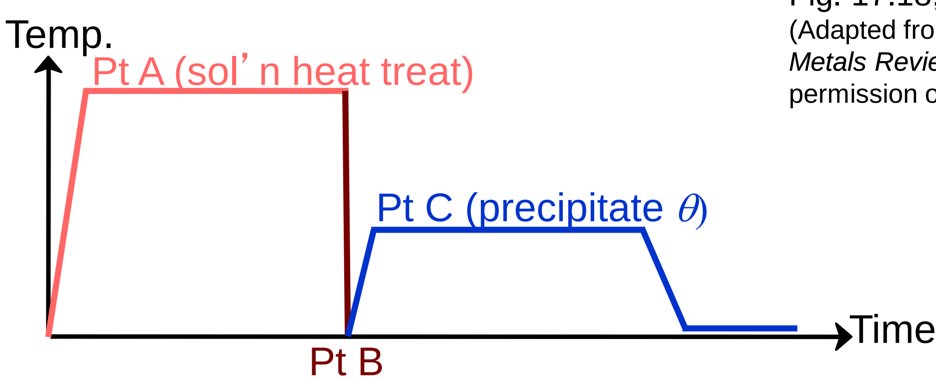


Fig. 17.18, *Callister & Rethwisch 9e*. (Adapted from J.L. Murray, *International Metals Review* **30**, p.5, 1985. Reprinted by permission of ASM International.)

- Other alloys that precipitation harden:
  - Cu-Be
  - Cu-Sn
  - Mg-Al



Adapted from Fig. 17.16, *Callister & Rethwisch 9e*.

Influence of Precipitation Heat Treatment on *TS*, %*EL*

- 2014 Al Alloy:

- Maxima on *TS* curves.
- Increasing *T* accelerates process.

- Minima on %*EL* curves.

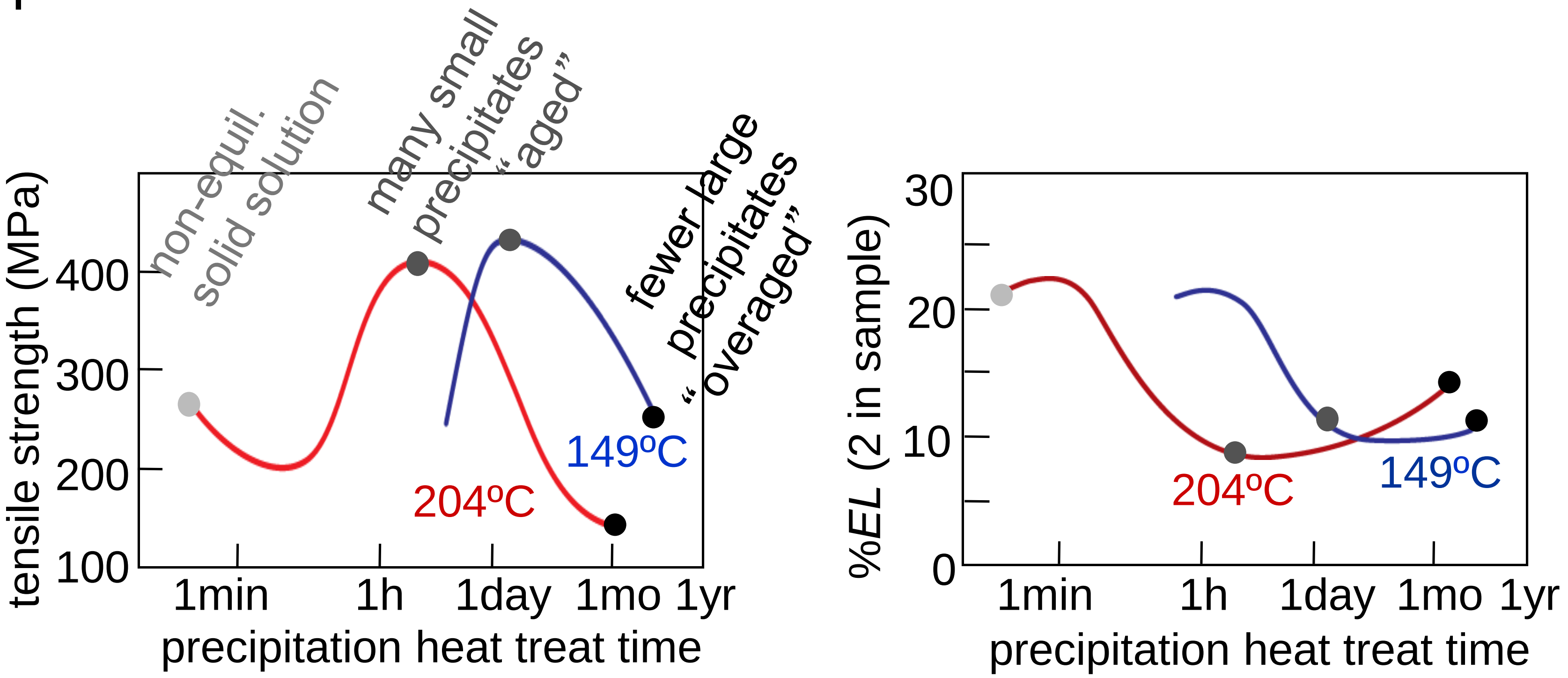


Fig. 17.21, *Callister & Rethwisch 9e*. [Adapted from *Metals Handbook: Properties and Selection: Nonferrous Alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker (Managing Ed.), 1979. Reproduced by permission of ASM International, Materials Park, OH.]

Ceramic Fabrication Methods (i)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

- **Blowing of Glass Bottles:**

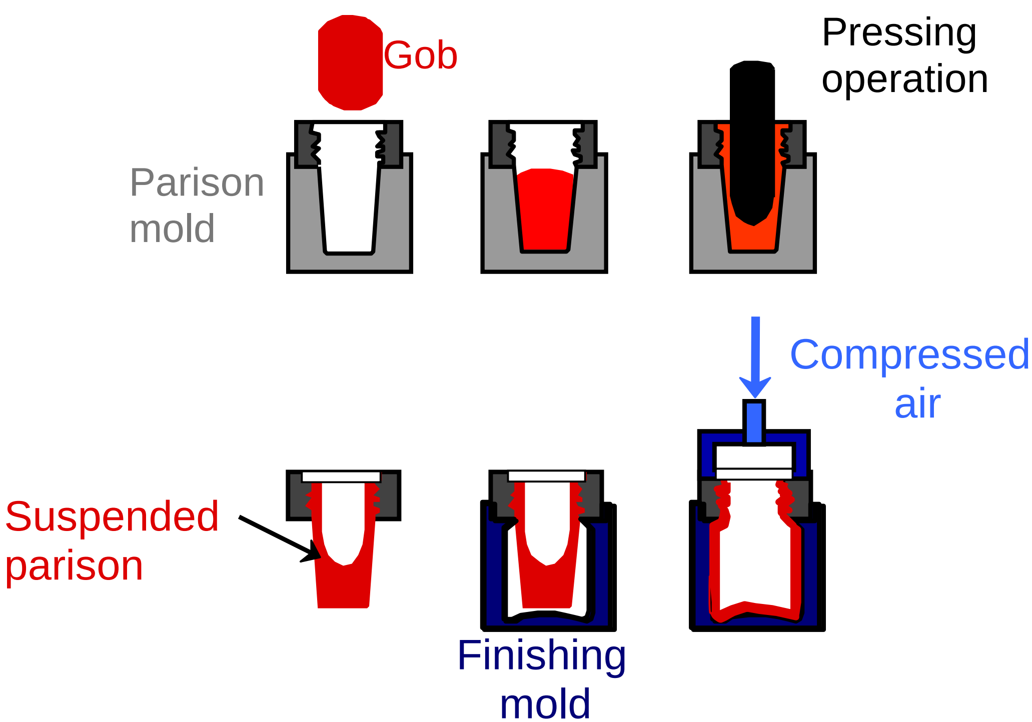
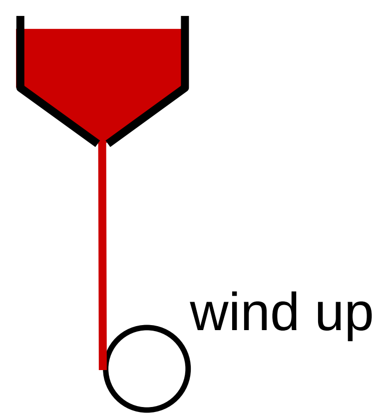


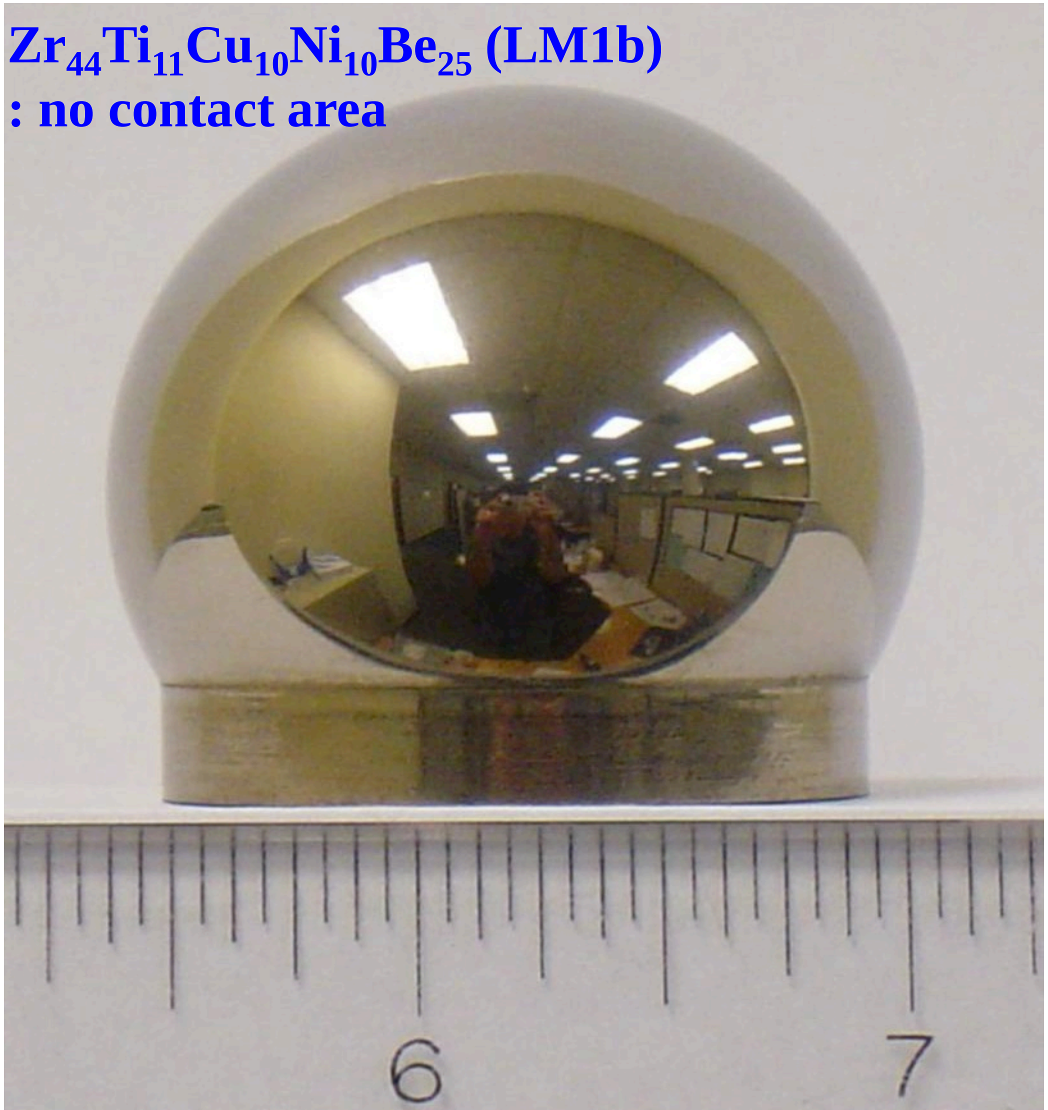
Fig. 17.25, *Callister & Rethwisch 9e*. (Adapted from C.J. Phillips, *Glass: The Miracle Maker*. Reproduced by permission of Pittman Publishing Ltd., London.)

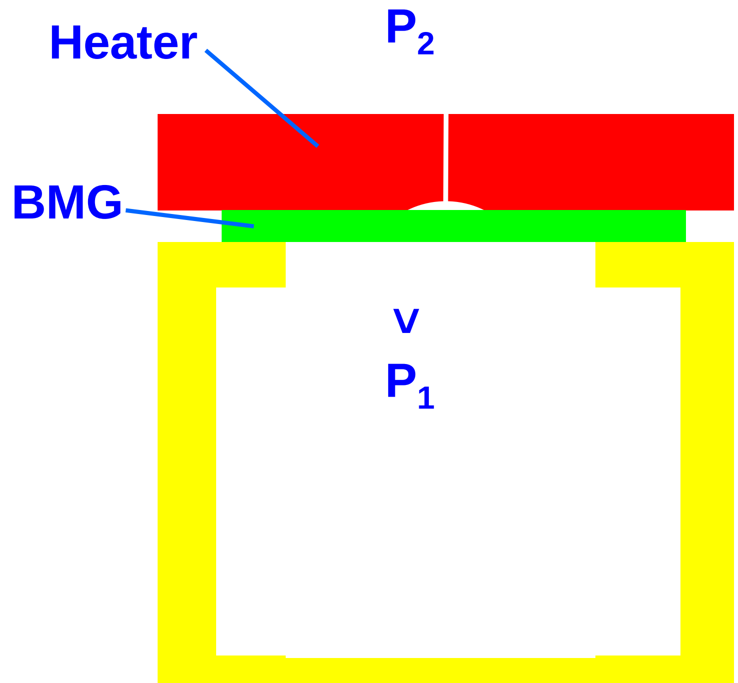
- **Pressing:** plates, cheap glasses
  - -- glass formed by application of pressure
  - -- mold is steel with graphite lining
- **Fiber drawing:**



Glassblowers in the US in 1908

BLOW-MOLDING: easy forming!



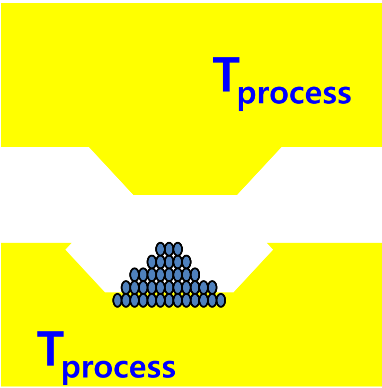


10^5 Pa, 400% strain

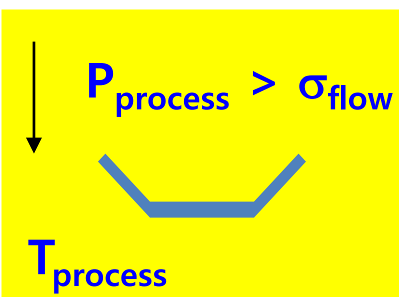
T=460° C, t =40 sec

J. Schroers, T. Nguyen, A. Peker, N. Paton, R. V. Curtis, Scripta Materialia, 57, 341 (2007)

TPF-based Compression Molding : No size limitation!



$T_g < T_{process} < T_x$



$T_{process} < t_{cryst}$

J. Schroers, JOM, 57, 34 (2005)

Sheet Glass Forming

- Sheet forming – continuous casting
  - sheets are formed by floating the molten glass on a pool of molten tin

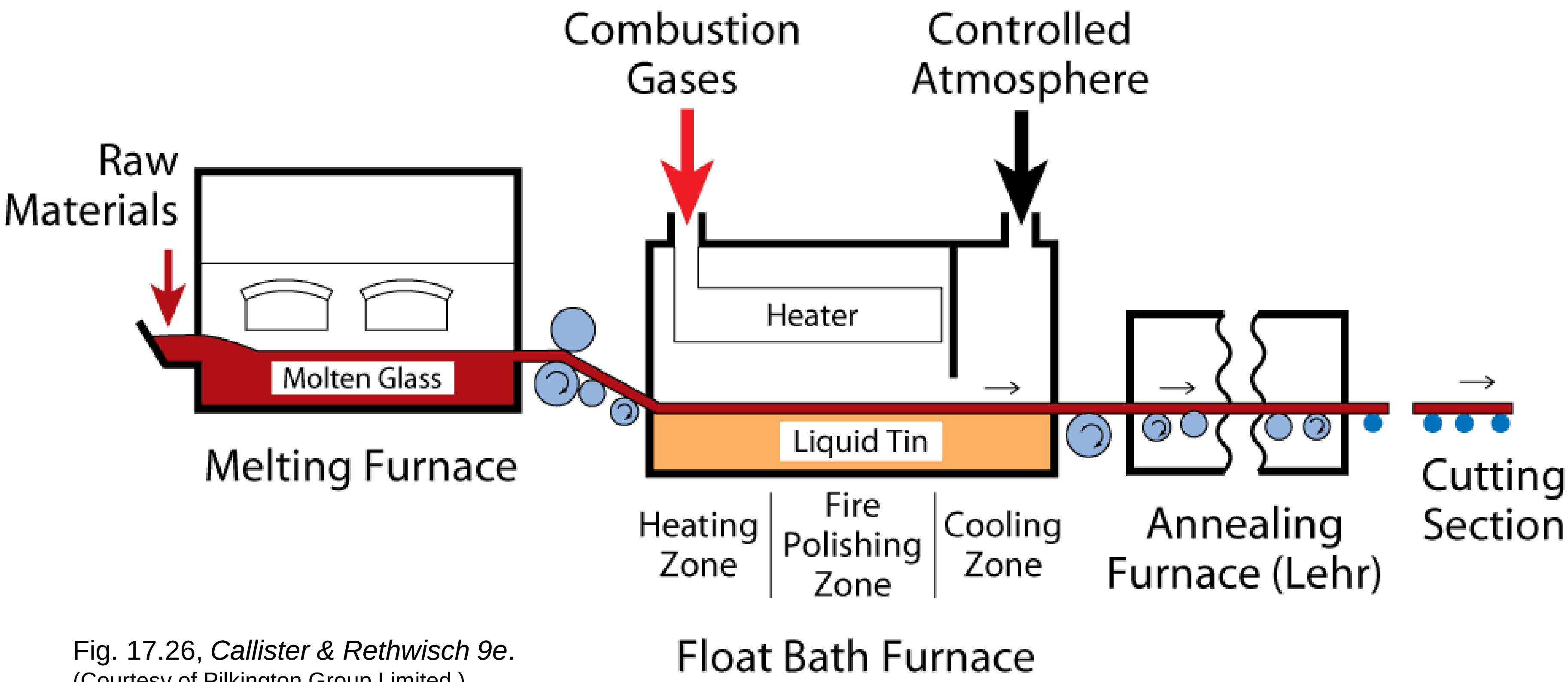
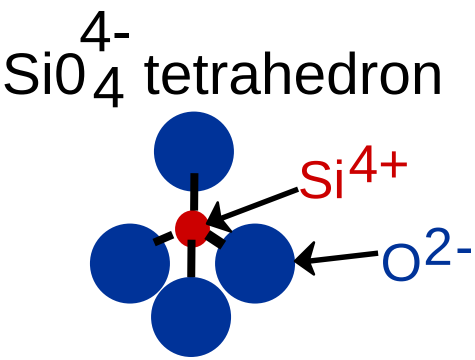


Fig. 17.26, *Callister & Rethwisch 9e*.
(Courtesy of Pilkington Group Limited.)

Glass Structure

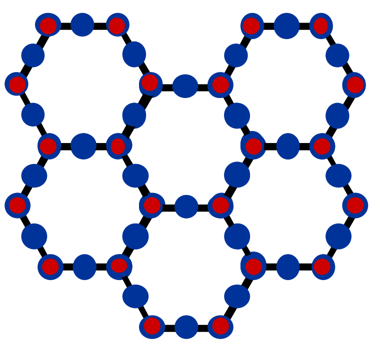
- Basic Unit:

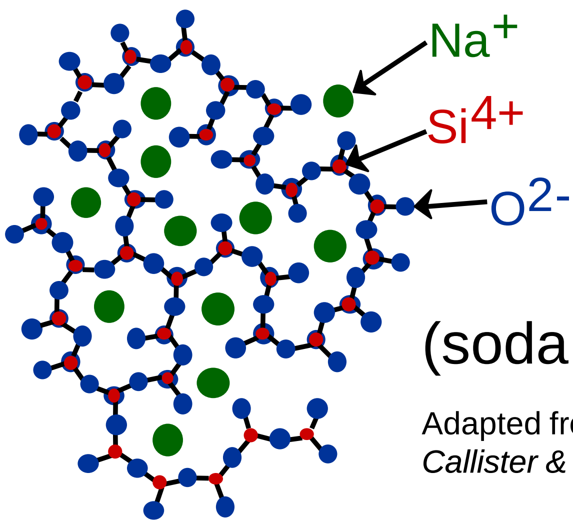


Glass is noncrystalline (amorphous)

- Fused silica is SiO_2 to which no impurities have been added
- Other common glasses contain impurity ions such as Na^+, Ca^{2+}, Al^{3+}, and B^{3+}

- Quartz is crystalline SiO_2:



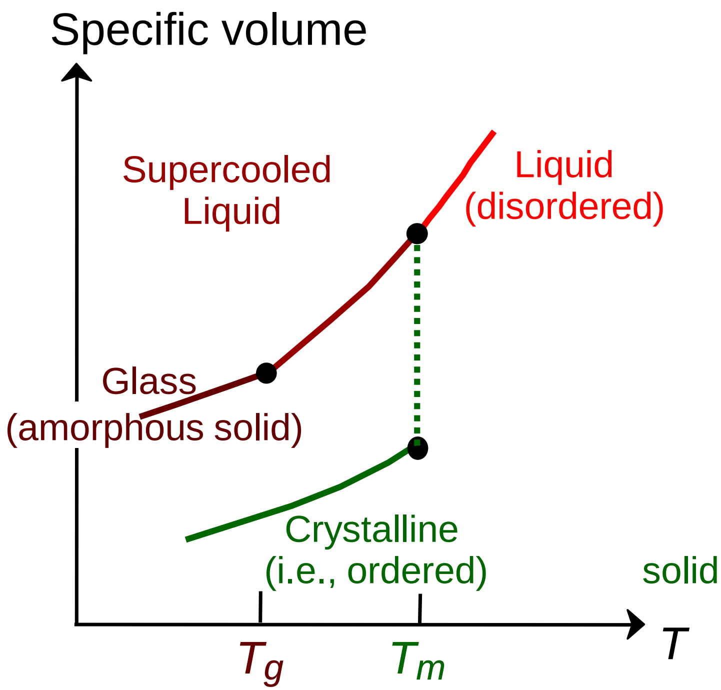


(soda glass)

Adapted from Fig. 4.12, *Callister & Rethwisch 9e*.

Glass Properties

- Specific volume ($1/\rho$) vs Temperature (T):



Adapted from Fig. 17.23, *Callister & Rethwisch 9e*.

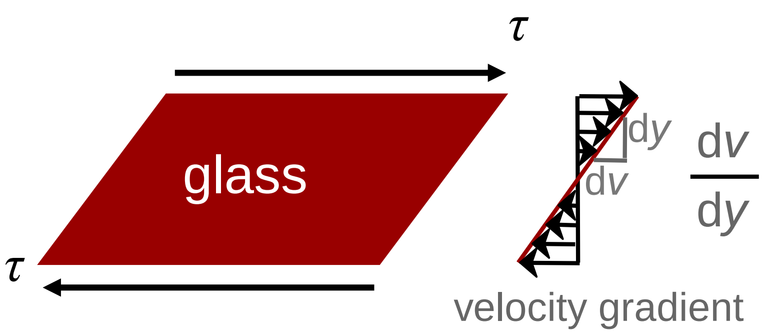
- Crystalline materials:
  -- crystallize at melting temp, T_m
  -- have abrupt change in spec. vol. at T_m

- Glasses:
  -- do not crystallize
  -- change in slope in spec. vol. curve at glass transition temperature, T_g
  -- transparent - no grain boundaries to scatter light

Glass Properties: Viscosity

- Viscosity, η:

  -- relates shear stress (τ) and velocity gradient *(dv/dy):*



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

η has units of (Pa-s)

Log Glass Viscosity vs. Temperature

- Viscosity decreases with *T*

- 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

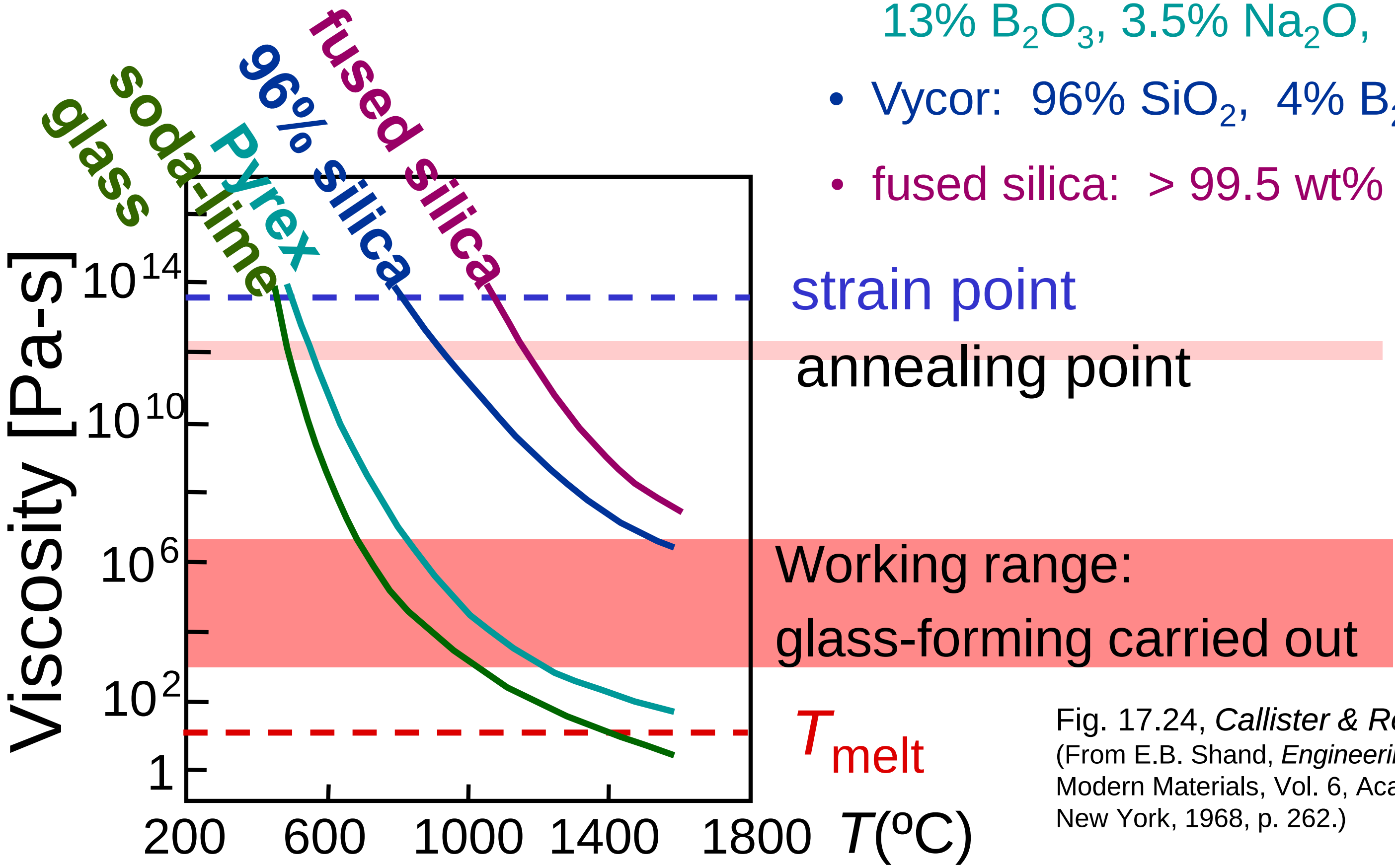


Fig. 17.24, *Callister & Rethwisch 9e*.
(From E.B. Shand, *Engineering Glass*, Modern Materials, Vol. 6, Academic Press, New York, 1968, p. 262.)

Heat Treating Glass

- Annealing:

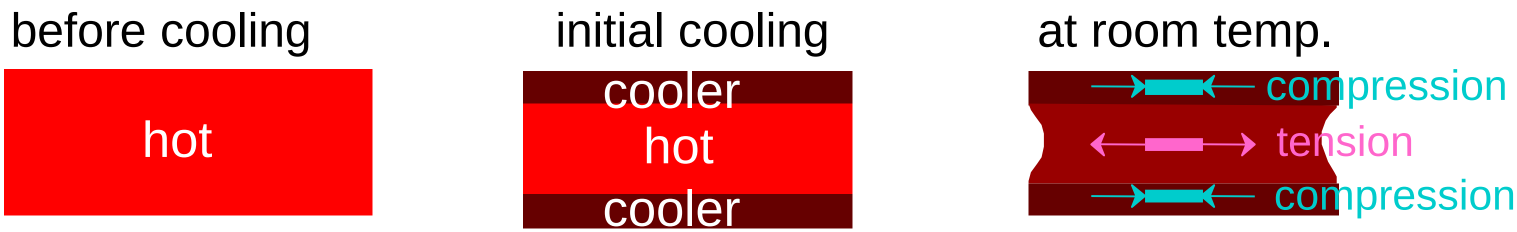
  -- removes internal stresses caused by uneven cooling.

- Tempering:

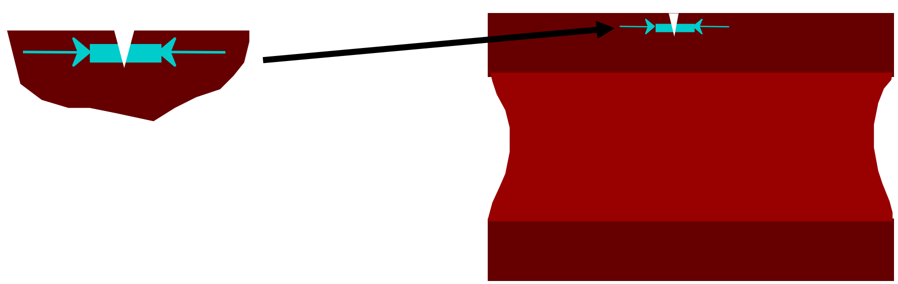
  -- puts surface of glass part into compression

  -- suppresses growth of cracks from surface scratches.

  -- sequence:



-- Result: surface crack growth is suppressed.



Ceramic Fabrication Methods (iia)

GLASS FORMING | **PARTICULATE FORMING** | CEMENTATION

Hydroplastic forming:

- Mill (grind) and screen constituents: desired particle size
- Extrude this mass (e.g., into a brick)

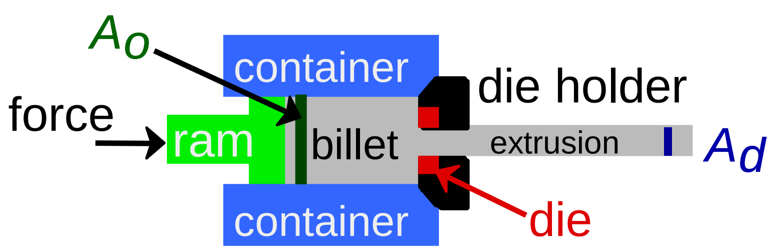


Fig. 17.2 (c), *Callister & Rethwisch 9e*.

- Dry and fire the formed piece

Ceramic Fabrication Methods (iia)

GLASS FORMING | **PARTICULATE FORMING** | CEMENTATION

Slip casting:

- Mill (grind) and screen constituents: desired particle size
- Mix with water and other constituents to form slip
- Slip casting operation

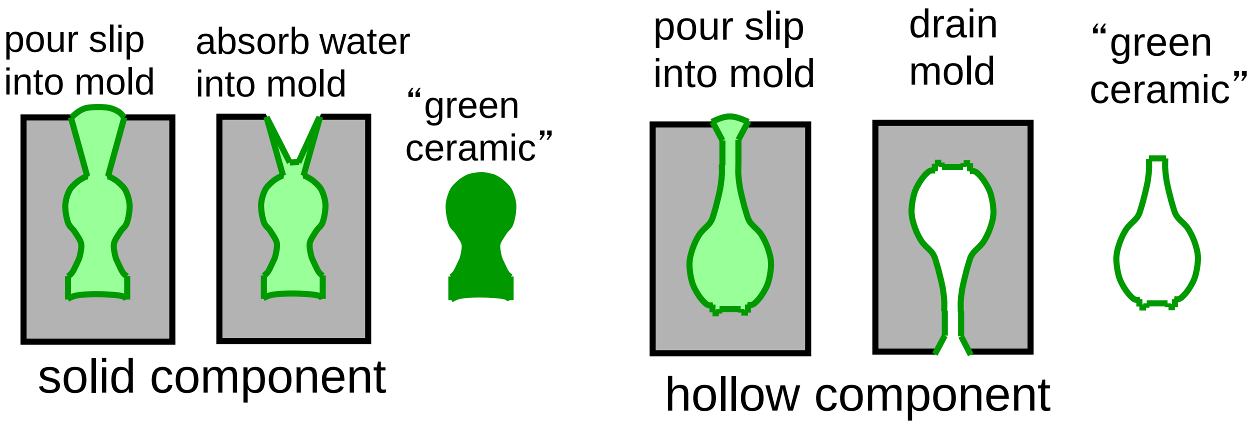


Fig. 17.29, *Callister & Rethwisch 9e*.
(From W.D. Kingery, *Introduction to Ceramics*, Copyright © 1960 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

- Dry and fire the cast piece

Typical Porcelain Composition

(50%) 1. Clay

(25%) 2. Filler – e.g. quartz (finely ground)

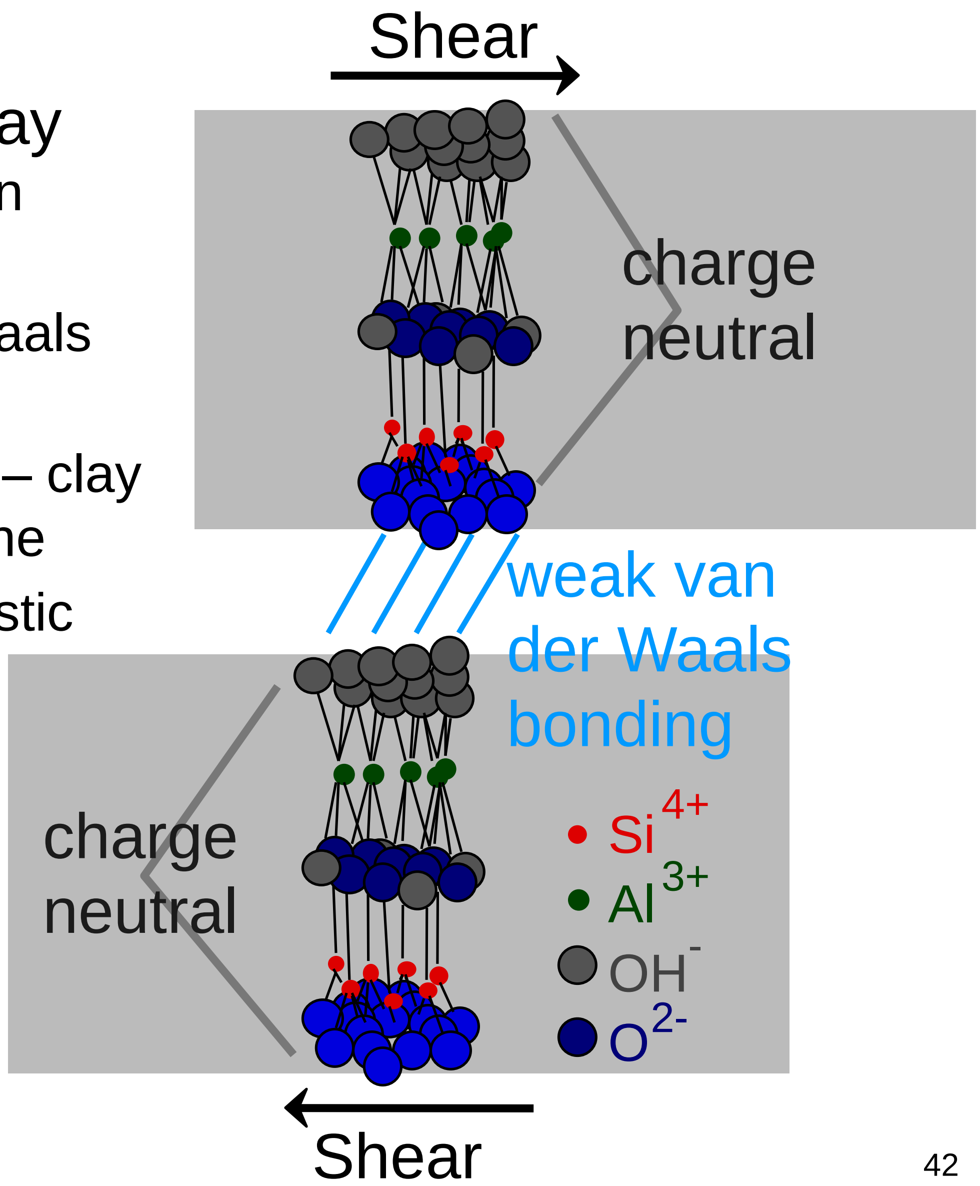
(25%) 3. Fluxing agent (Feldspar)

-- aluminosilicates plus K^+, Na^+, Ca^+

-- upon firing - forms low-melting-temp. glass

Hydroplasticity of Clay

- Clay is inexpensive
- When water is added to clay
  - -- water molecules fit in between layered sheets
  - -- reduces degree of van der Waals bonding
  - -- when external forces applied – clay particles free to move past one another – becomes hydroplastic



- Structure of Kaolinite Clay:

Fig. 4.15, *Callister & Rethwisch 9e*.
[Adapted from W.E. Hauth, "Crystal Chemistry of Ceramics", *American Ceramic Society Bulletin*, Vol. 30 (4), 1951, p. 140.]

Drying and Firing

- **Drying**: as water is removed - interparticle spacings decrease – shrinkage .

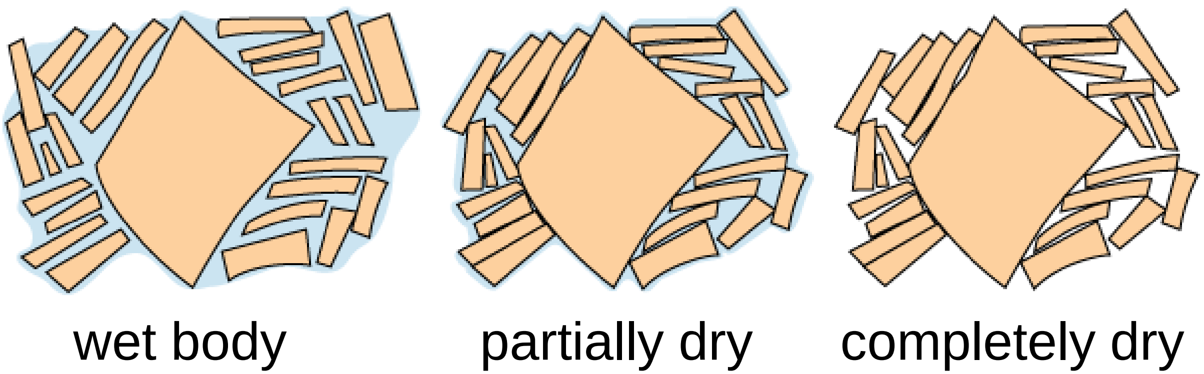


Fig. 17.30, *Callister & Rethwisch 9e*. (From W.D. Kingery, *Introduction to Ceramics*, Copyright © 1960 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

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

- **Firing**:
  -- heat treatment between 900-1400° C
  -- vitrification: liquid glass forms from clay and flux – flows between SiO_2 particles. (Flux lowers melting temperature).

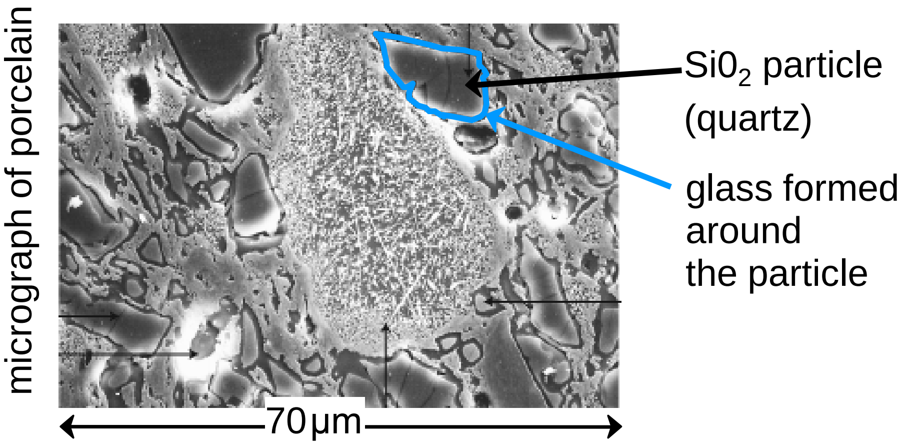


Fig. 17.31, *Callister & Rethwisch 9e*. (Courtesy H.G. Brinkies, Swinburne University of Technology, Hawthorn Campus, Hawthorn, Victoria, Australia.)

Ceramic Fabrication Methods (iib)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

Powder Pressing: used for both clay and non-clay compositions.

- Powder (plus binder) compacted by pressure in a mold
  -- Uniaxial compression - compacted in single direction
  -- Isostatic (hydrostatic) compression - pressure applied by fluid - powder in rubber envelope
  -- Hot pressing - pressure + heat

Sintering

Sintering occurs during firing of a piece that has been powder pressed

-- powder particles coalesce and reduction of pore size

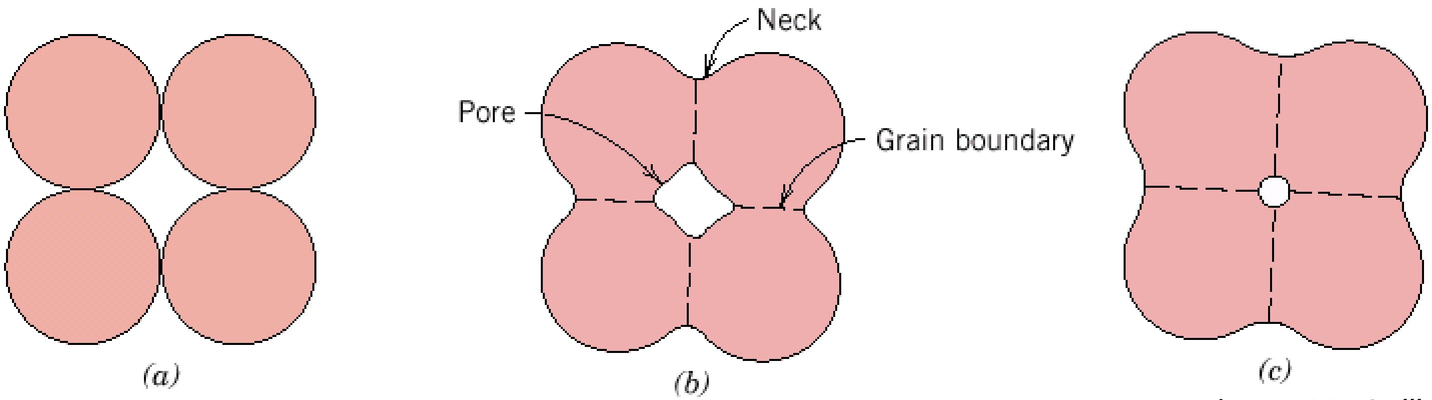


Fig. 17.33, *Callister & Rethwisch 9e*.

Aluminum oxide powder:

-- sintered at 1700° C for 6 minutes.

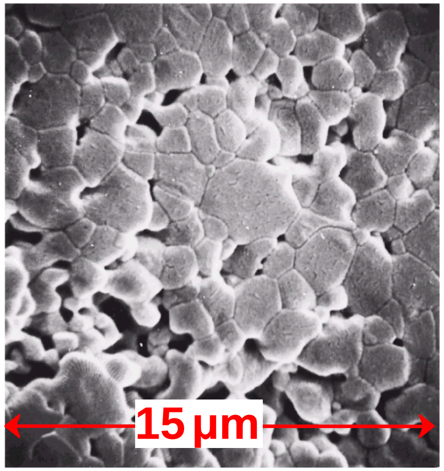


Fig. 17.34, *Callister & Rethwisch 9e*. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, Introduction to Ceramics, 2nd edition, p. 483. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

Tape Casting

- Thin sheets of green ceramic cast as flexible tape
- Used for integrated circuits and capacitors
- Slip = suspended ceramic particles + organic liquid (contains binders, plasticizers)

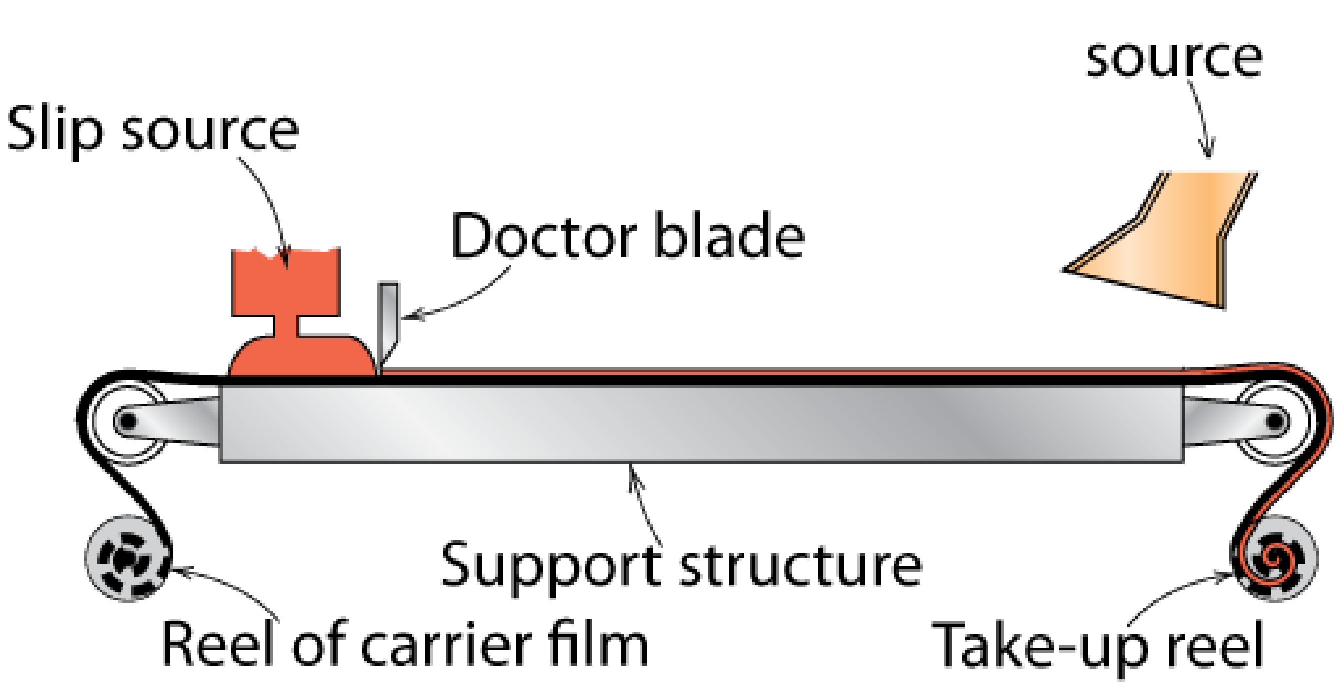


Fig. 17.35, *Callister & Rethwisch 9e*.

Ceramic Fabrication Methods (iii)

GLASS FORMING | PARTICULATE FORMING | CEMENTATION

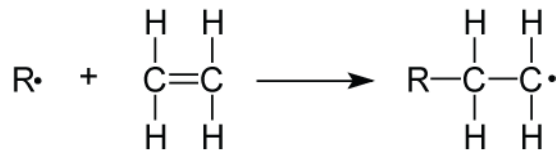
- Hardening of a paste – paste formed by mixing cement material with water
- Formation of rigid structures having varied and complex shapes
- Hardening process – hydration (complex chemical reactions involving water and cement particles)
- Portland cement – production of:
  -- mix clay and lime-bearing minerals
  -- calcine (heat to 1400°C)
  -- grind into fine powder

Polymer Formation

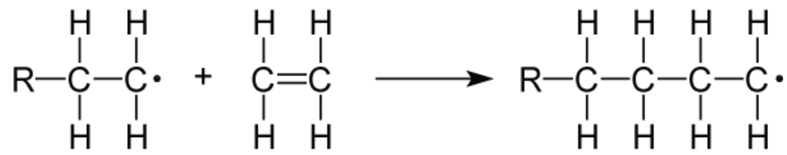
- There are two types of polymerization
  - Addition (or chain) polymerization
  - Condensation (step) polymerization

Addition (Chain) Polymerization

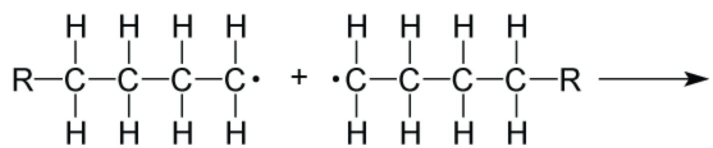
– **Initiation**

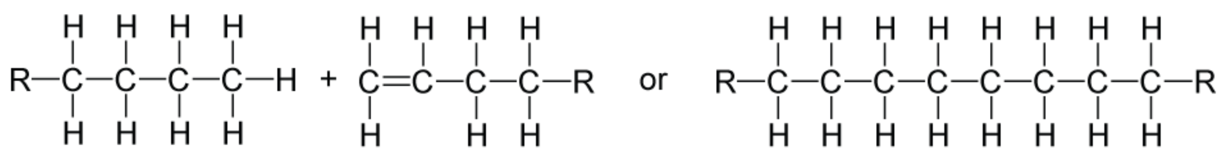


– **Propagation**



– **Termination**

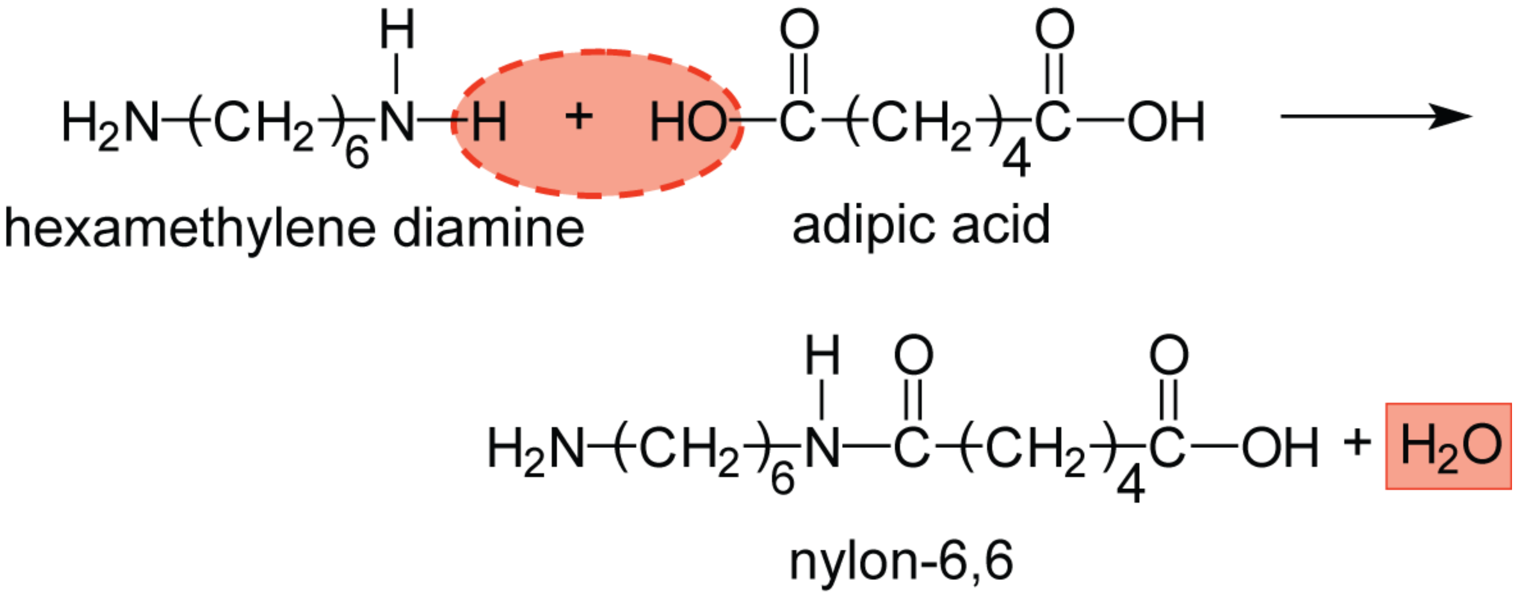




Disproportionation

Combination

Condensation (Step) Polymerization



Polymer Additives

Improve mechanical properties, processability, durability, etc.

- Fillers
  - Added to improve tensile strength & abrasion resistance, toughness & decrease cost
  - ex: carbon black, silica gel, wood flour, glass, limestone, talc, etc.
- Plasticizers
  - Added to reduce the glass transition temperature T_g below room temperature
  - Presence of plasticizer transforms brittle polymer to a ductile one
  - Commonly added to PVC - otherwise it is brittle

Polymer Additives (cont.)

- Stabilizers
  - Antioxidants
  - UV protectants
- Lubricants
  - Added to allow easier processing
  - polymer “slides” through dies easier
  - ex: sodium stearate
- Colorants
  - Dyes and pigments
- Flame Retardants
  - Substances containing chlorine, fluorine, and boron

Processing of Plastics

- Thermoplastic
  - can be reversibly cooled & reheated, i.e. recycled
  - heat until soft, shape as desired, then cool
  - ex: polyethylene, polypropylene, polystyrene.
- Thermoset
  - when heated forms a molecular network (chemical reaction)
  - degrades (doesn't melt) when heated
  - a prepolymer molded into desired shape, then chemical reaction occurs
  - ex: urethane, epoxy

Processing Plastics – Compression Molding

Thermoplastics and thermosets

- polymer and additives placed in mold cavity
- mold heated and pressure applied
- fluid polymer assumes shape of mold

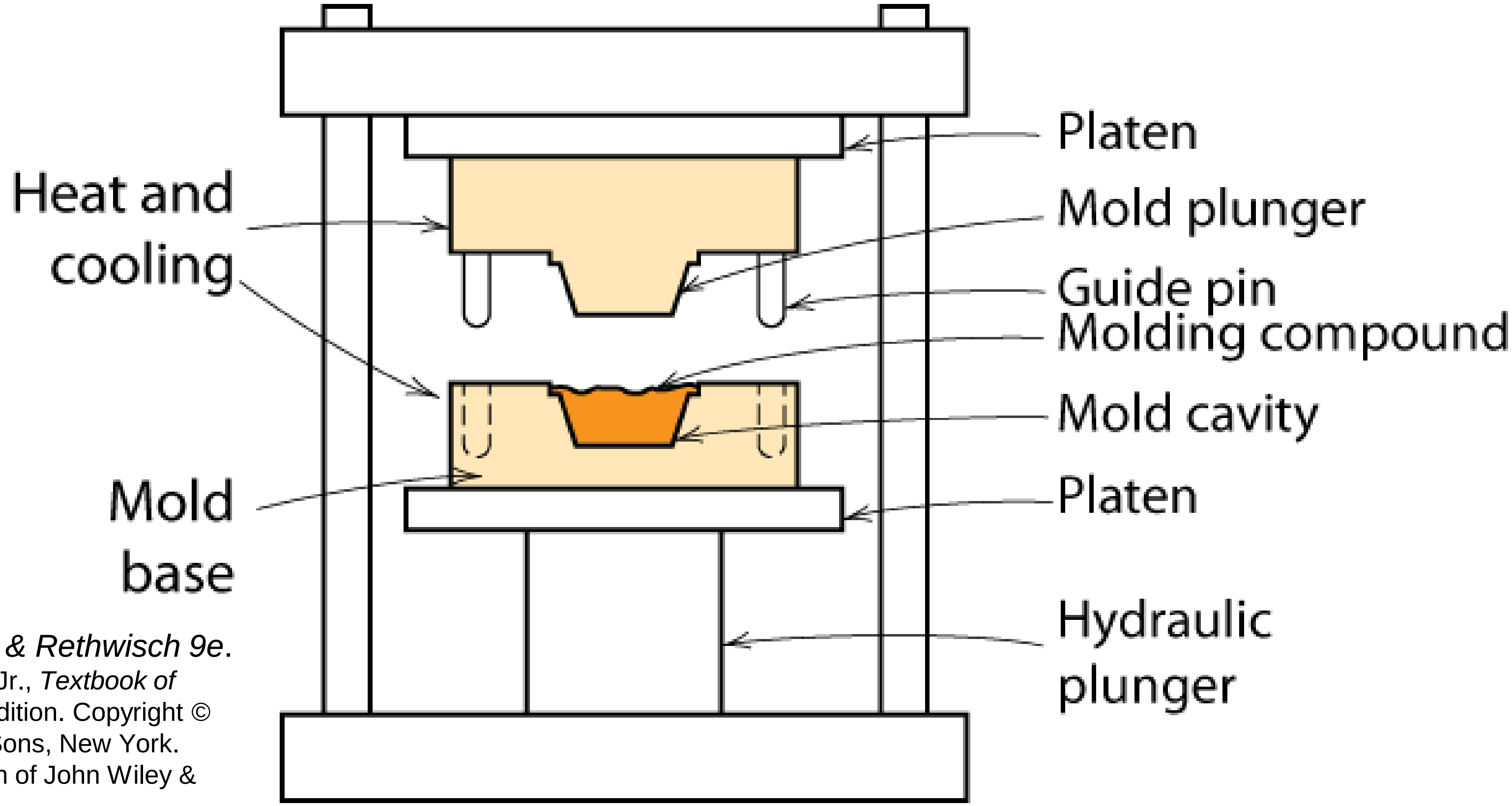


Fig. 17.36, *Callister & Rethwisch 9e*. (From F. W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd edition. Copyright © 1984 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

Processing Plastics – Injection Molding

Thermoplastics and some thermosets

- when ram retracts, plastic pellets drop from hopper into barrel
- ram forces plastic into the heating chamber (around the spreader) where the plastic melts as it moves forward
- molten plastic is forced under pressure (injected) into the mold cavity where it assumes the shape of the mold

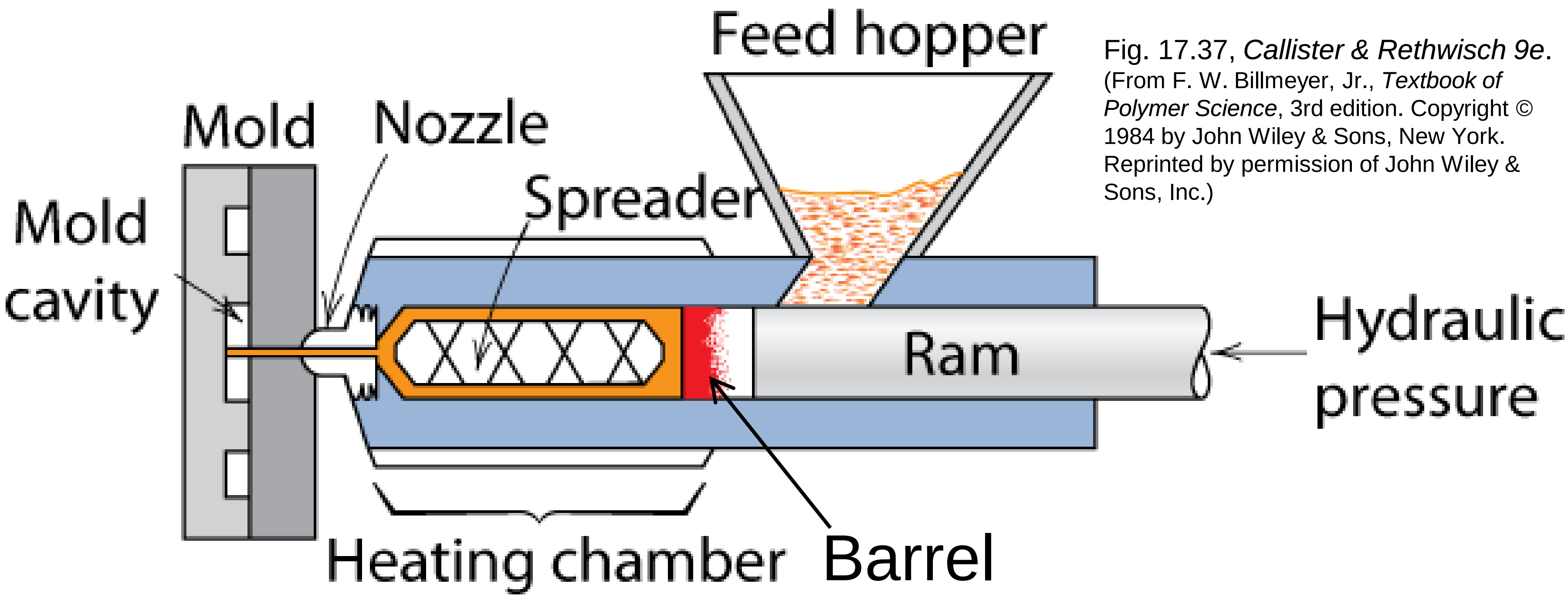


Fig. 17.37, *Callister & Rethwisch 9e*. (From F. W. Billmeyer, Jr., *Textbook of Polymer Science*, 3rd edition. Copyright © 1984 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

Processing Plastics – Extrusion

thermoplastics

- plastic pellets drop from hopper onto the turning screw
- plastic pellets melt as the turning screw pushes them forward by the heaters
- molten polymer is forced under pressure through the shaping die to form the final product (extrudate)

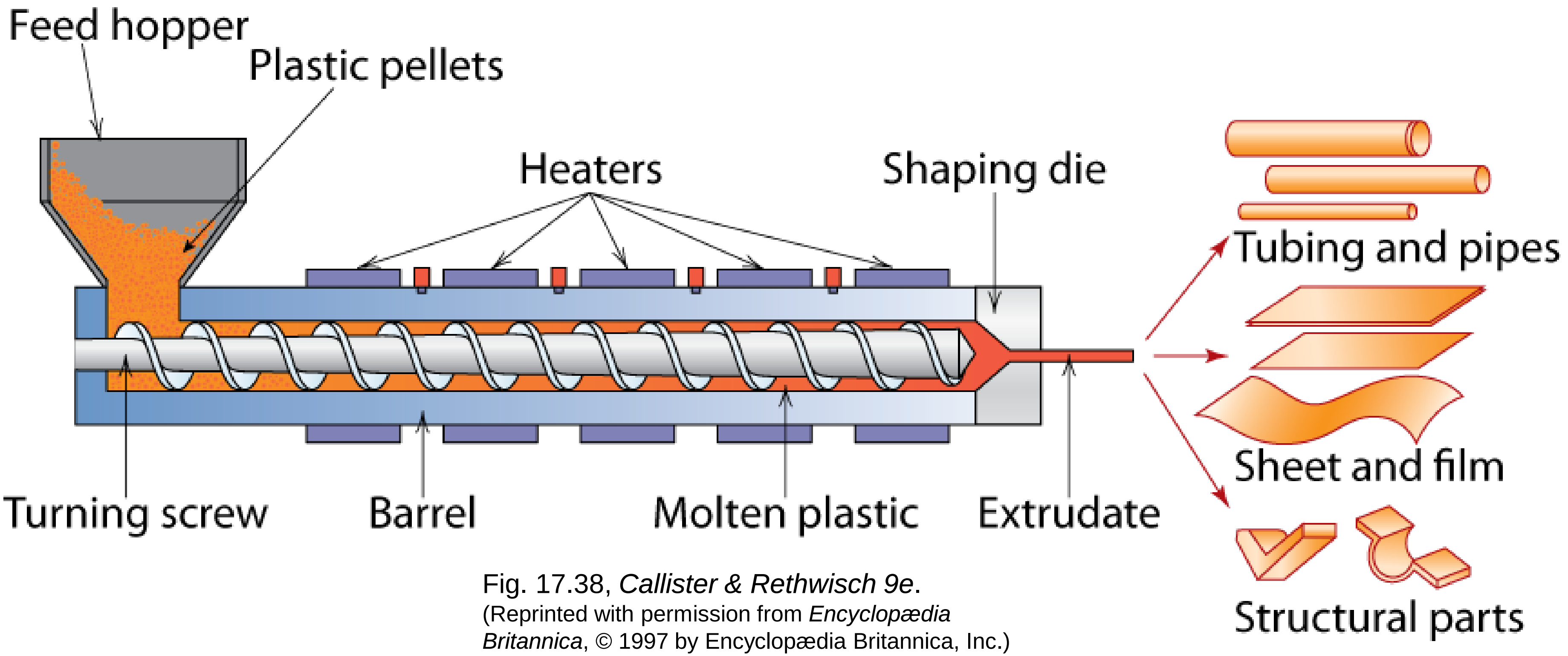


Fig. 17.38, *Callister & Rethwisch 9e*.
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Processing Plastics – Blown-Film Extrusion

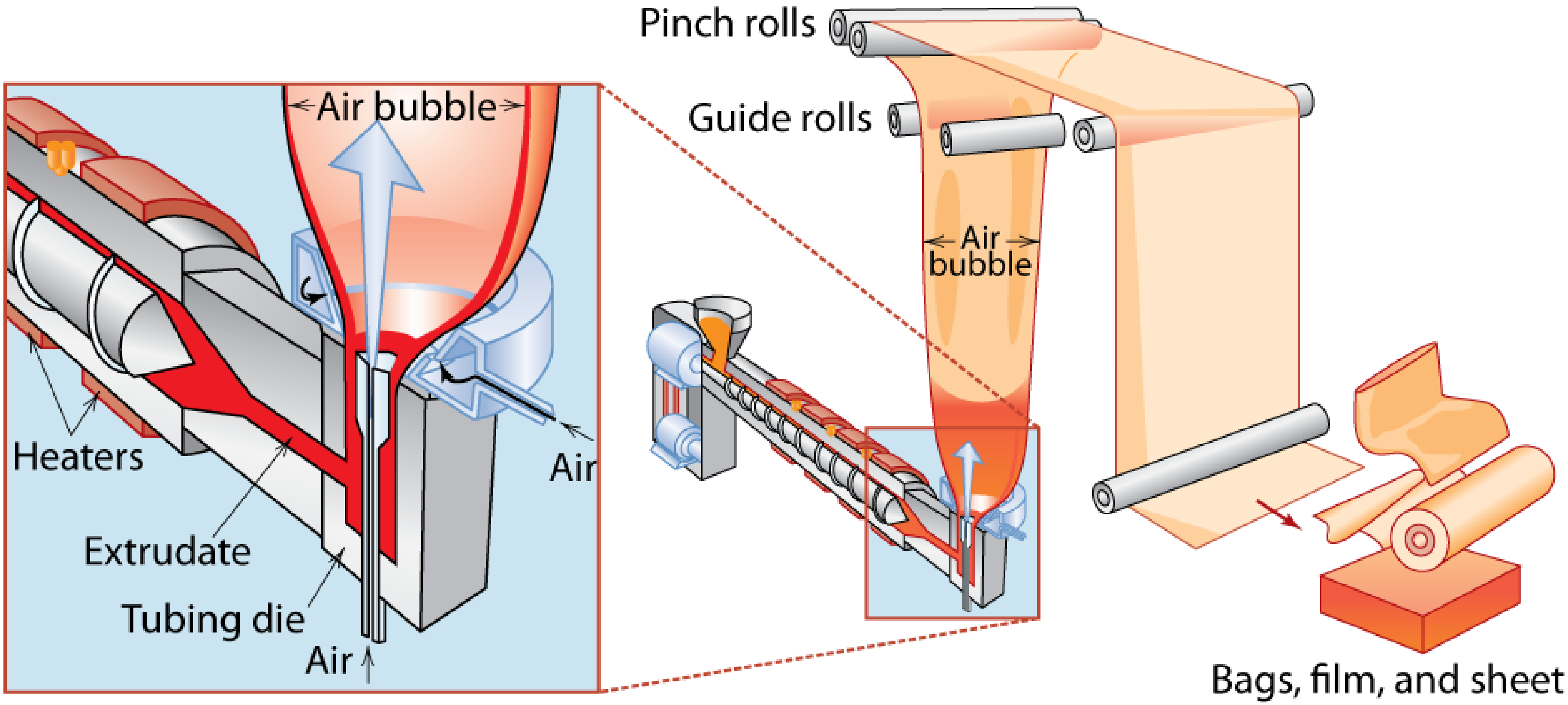

Fig. 17.39, *Callister & Rethwisch 9e*.
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Summary

- Metal fabrication techniques:
  -- forming, casting, miscellaneous.

- Hardenability of metals
  -- measure of ability of a steel to be heat treated.
  -- increases with alloy content.

- Precipitation hardening
  --hardening, strengthening due to formation of precipitate particles.
  --Al, Mg alloys precipitation hardenable.

Summary (Cont.)

- Ceramic Fabrication techniques:
  -- glass forming (pressing, blowing, fiber drawing).
  -- particulate forming (hydroplastic forming, slip casting, powder pressing, tape casting)
  -- cementation

- Heat treating procedures for ceramics
  -- glasses—annealing, tempering
  -- particulate formed pieces—drying, firing (sintering)

- Polymer Processing
  -- compression and injection molding, extrusion, blown film extrusion

- Polymer melting and glass transition temperatures

Materials Science and Engineering

Chapter 1 Introduction

Chapter 2 Atomic Structure and Interatomic Bonding
Chapter 3 Fundamentals of Crystallography
Chapter 4 The Structure of Crystalline Solids
Chapter 5 Structure of Polymers
Chapter 6 Imperfections in Solids

Chapter 7 Diffusion

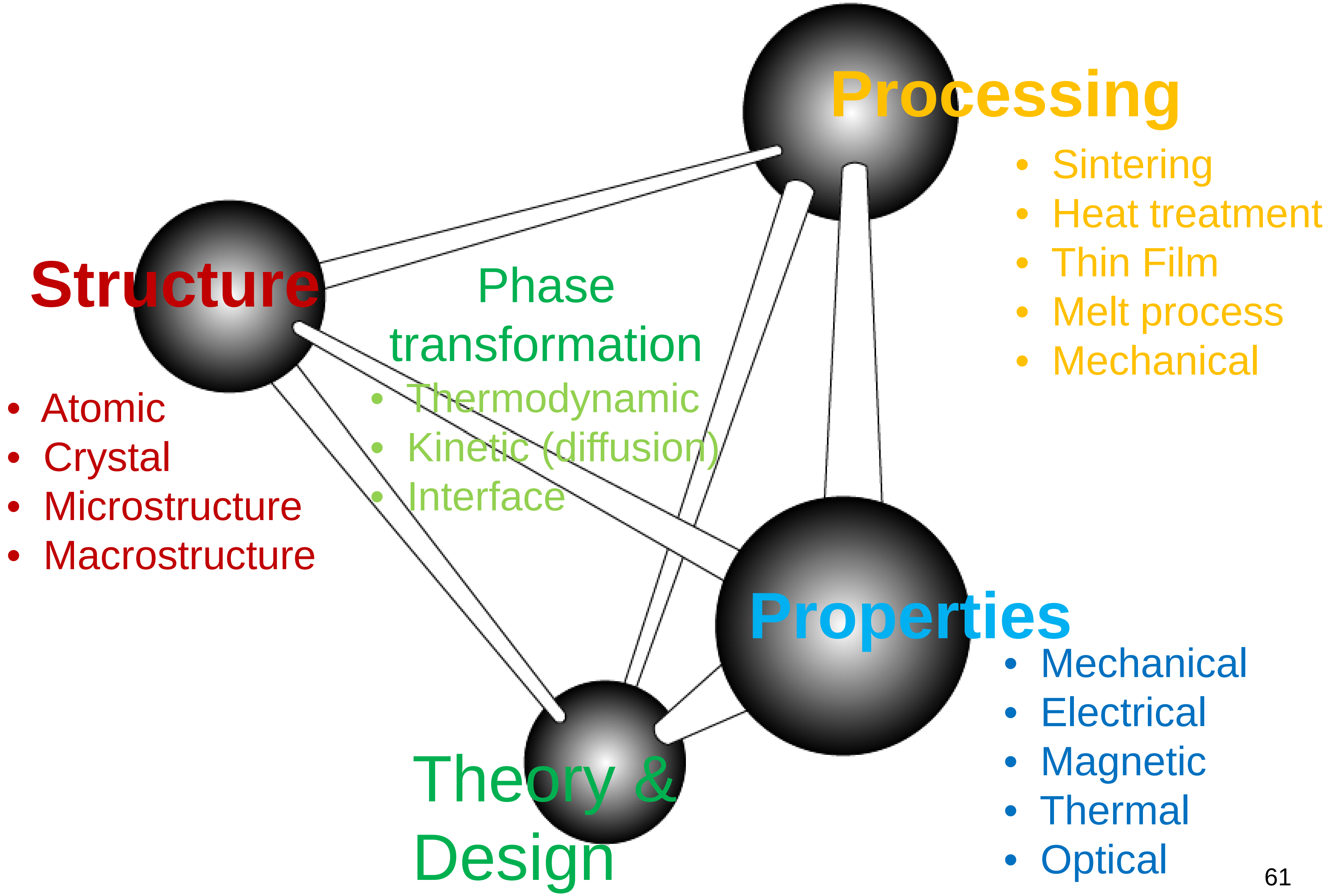
Chapter 8 Mechanical properties of Metals
Chapter 9 Dislocations and Strengthening Mechanism
Chapter 10 Failure

Chapter 11 Phase Diagrams
Chapter 12 Phase Transformations

Chapter 13 Properties and Applications of Metals
Chapter 14 Properties and Applications of Ceramics
Chapter 15 Properties and Applications of Polymers
Chapter 16 Composites Materials

Chapter 17 Fabrication and Processing of Engineering Materials

Materials Science and Engineering



기말고사 : 14일 (토) 오후 6시-9시

시험범위: Chapter 8 장 – Chapter 17 장
Text, 수업자료, Homework

장 소 : 33동 225 호 (Class number 01-26)
33동 226 호 (Class number 27-52)