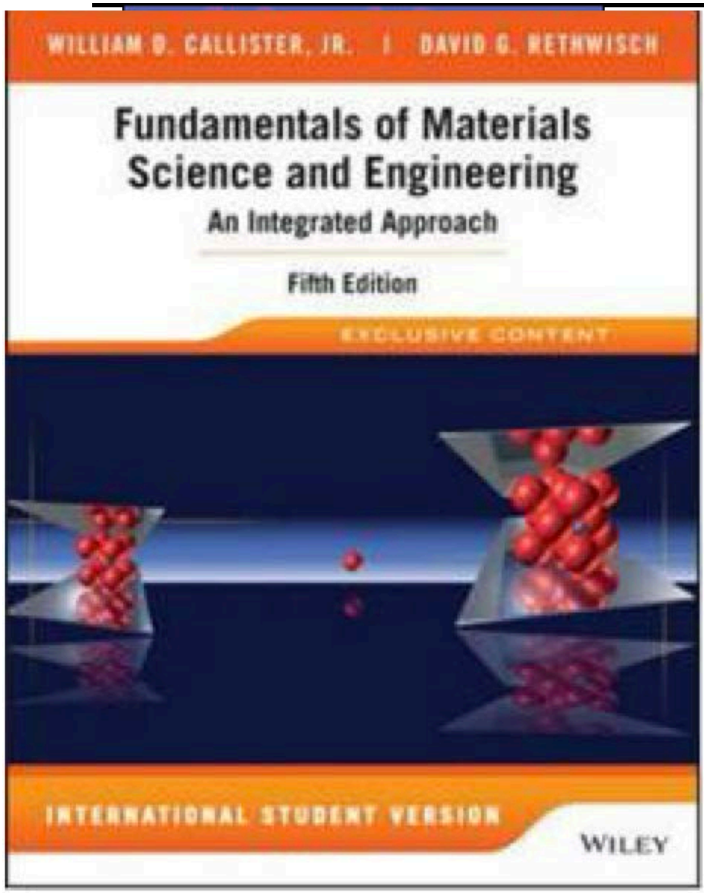
# 材料科學導論

# Introduction of materials science



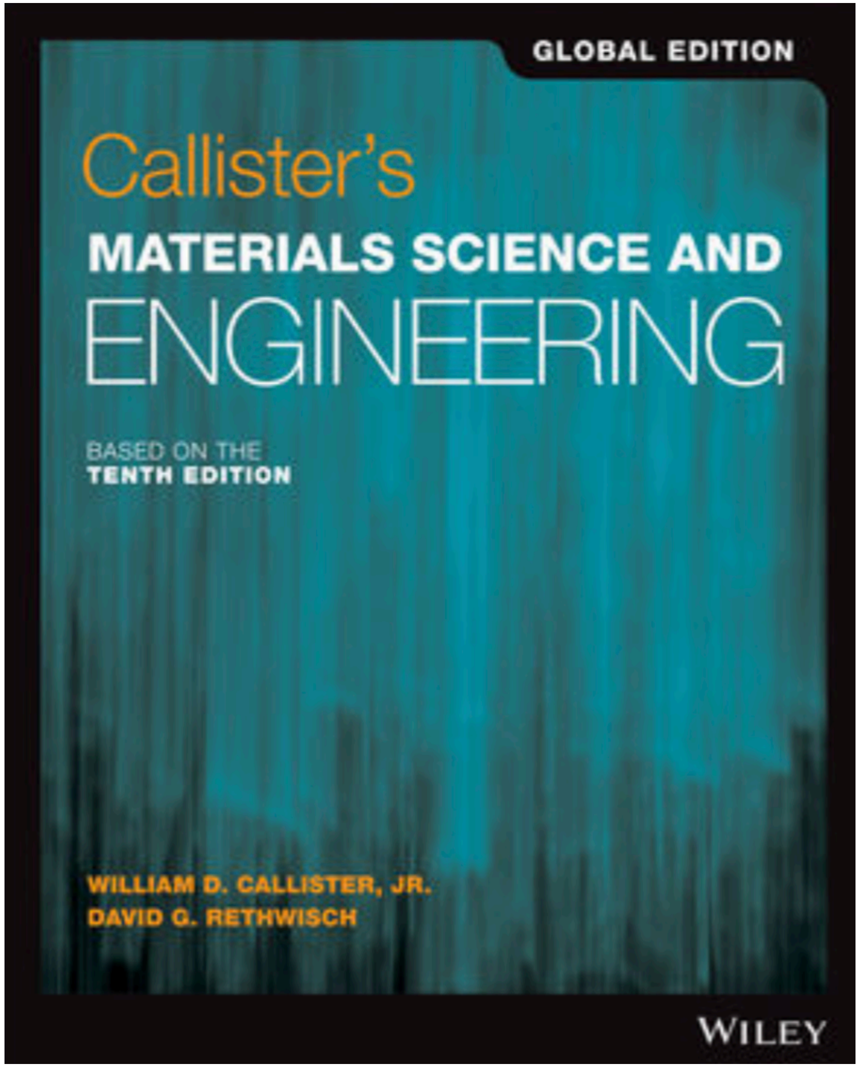

**Text Book**

## Fundamentals of Materials Science and Engineering: An Integrated Approach

**Fifth Edition**

**William D. Callister. JR • David G. Rethwisch**

# New edition




## Callister's Materials Science and Engineering, 10th Edition, Global Edition

William D. Callister Jr., David G. Rethwisch

https://www.wiley.com/enie/Callister's+Materials+Science+and+Engineering,+10th+Edition,+Global+Edition-p-9781119455202

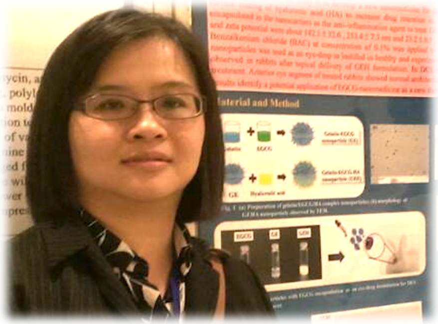
滄海圖書

# 曾靖孋 生醫材料暨組織工程所

## 臺灣大學 醫學工程博士

Ching-Li Tseng

Associate Professor



# Main Instructor

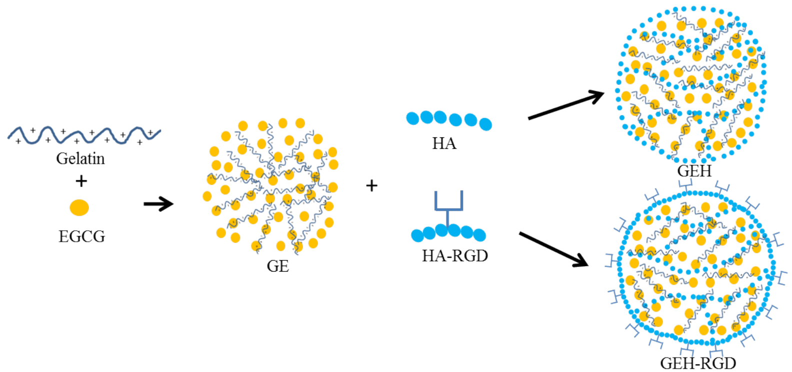
- Biomaterials
- Nanomedicine
- Ocular Drug Delivery
- Targeted therapy

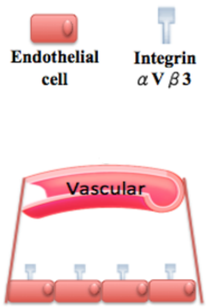
➢ **Eye drops with nanomedicine for effectively treating ocular diseases**

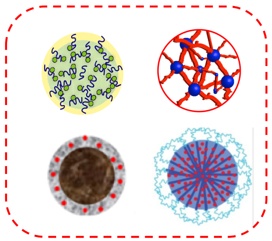
- **Good patient compliance, friendly use.**
- **Increase drug bioavailability in ocular tissue**
- **Controlled release of drug/gene**
- **Targetable therapy according to ligand modification on nanoparticles**

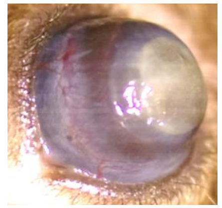
➢ **Proof therapy model**

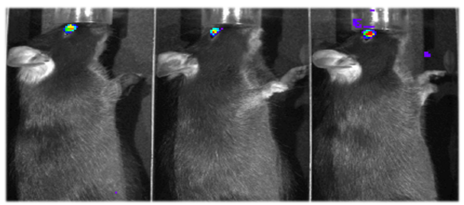
- **Dry eye syndrome**
- **Corneal neovascularization**
- **Anti-angiogenesis treatment in retina** (on going)

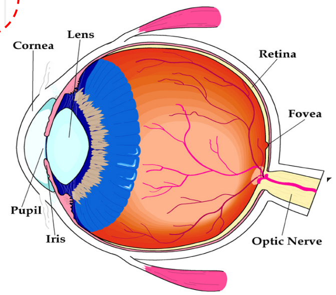


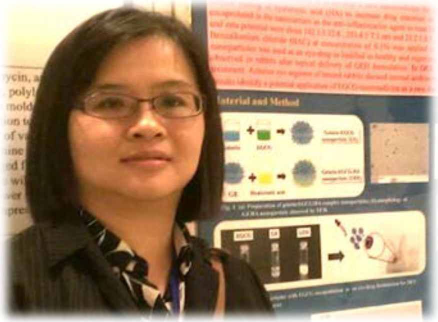









# Main Instructor



醫學綜合大樓 - 後棟六樓 K0677室

TEL: (02) 27361661# 5214

Email: chingli@tmu.edu.tw

Office hour: 週二早上

11:00-12:00

- Discuss homework, quizzes, exams
- Discuss lectures, book

# Teaching Assistants

| Name | Office | Tel. |
|---|---|---|
| 吳昱儀<br>潘亮辰 | 醫綜後棟六樓<br>生工所<br>學生休息室<br>K0660室 | Ext. 5204 |

## Teaching Assistants will

- Participate in examination sessions,
- Have office hours to help you with course material and problem sets.

# 莊爾元 生醫材料暨組織工程所

清華大學 化學工程博士

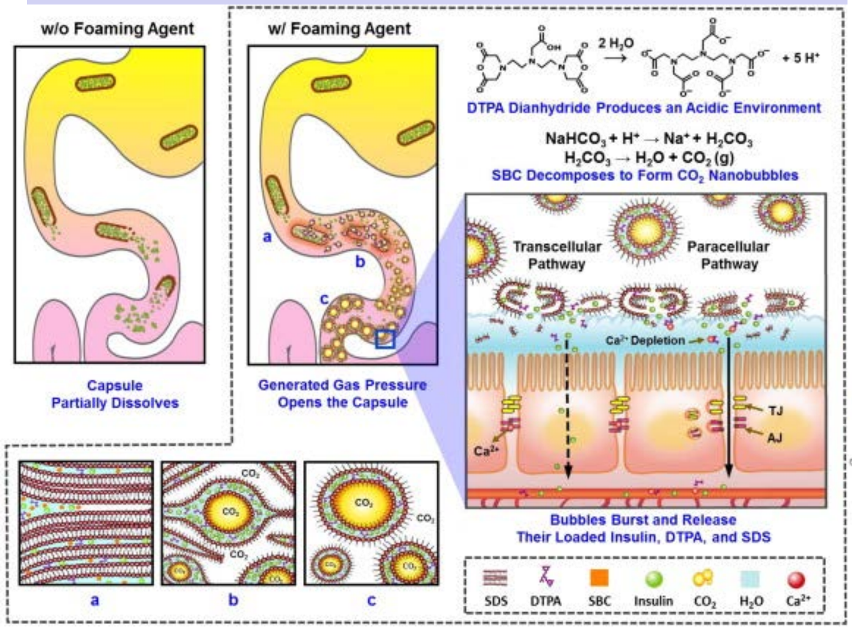
Er-Yuan Chuang, PhD

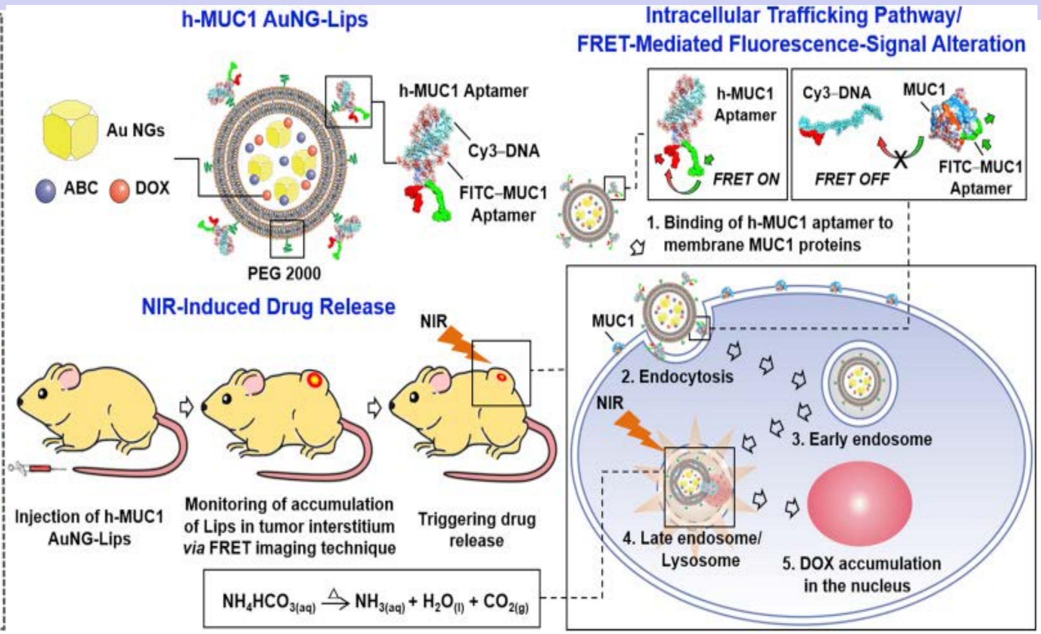
Assistant Professor

# Instructor:

- Nano-Biomaterials
- Oral route drug delivery
- Cancer drug delivery

- **Functional carrier systems for drug delivery in cancer and diseases, and for non-invasive photothermal anticancer therapy**
- **Nano-biomaterial for tissue engineering**



# Instructor:

李紹先

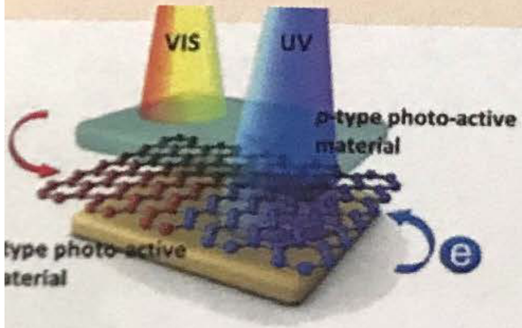
臺灣大學 材料科學博士

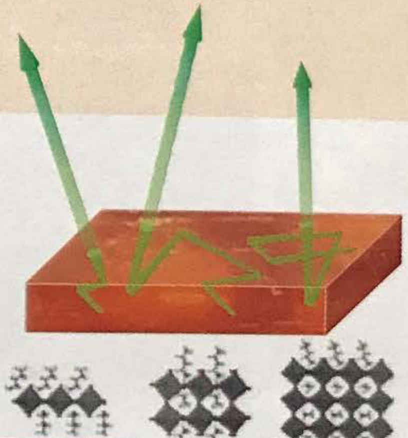
Shao-Sian Li, Ph. D

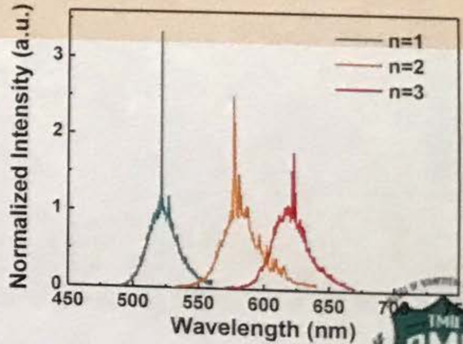
Assistant Professor

- 2 dimensional materials
- Photocarrier dynamics
- Biomedical device
- Surface modification
- Energy conversion

- High quality 2-dimensional materials for biomedical sensors and biomedical appliance.
- Growth of carbon-based 2D materials with large area.
- Fabrication of atomically thin film by solution process.
- Novel 2D materials for biomedical sensor and other optoelectronics, like energy conversion devices.
- Surface modification of medical appliance to improve the biomedical properties.





# GRADING

- Attendance : 10-15%

  - Questions/response in class

- **Midterm Exam.: 35%**

- **Final Exam.: 40%**

- Quiz or Home work: 10-15%

# Introduction to Materials Science & Engineering

**Course Objective...**

Introduce fundamental concepts in Materials Science & Engineering

**You will learn about:**

- Material structures
- How structure dictates properties
- How processing can change structure

**This course will help you to:**

- Use materials properly
- Rrealize new design opportunities with materials

# Chapter 1:

# Introduction to
# Materials Science & Engineering

## Issue to Address

- What is materials science and engineering?
- Why are materials important?
- Why is it important for engineers to understand materials ?

# What Are Materials?

- Substances out of which all things are composed or made.

We obtain materials from earth crust and atmosphere.

礦物 矽 鐵

- Silicon and Iron constitute 27.72 wt. % and 5.00 wt.% of **earths crust** respectively.-
- Nitrogen and Oxygen constitute 78.08 wt.% and 20.95 wt.% of **dry air** by volume respectively.

What materials are present in the classroom?

# What makes a material?

## Elements

- Consist of only one type of atom
- Cannot be broken down

標準

## Criteria for element classification

- Based on individual properties
- Grouped according to shared properties

# What makes a material?

## Compounds

- Most substances are compound.
- Compounds are created when **two** or **more elements** are chemically combined.
- **Properties are different** than the elements from which the compound was created.

$Cl_2$ $NaCl$

2


© iStockphoto/Mark Oleksiy

1

© iStockphoto/Jill Chen

3


© iStockphoto/Mark Oleksiy

1 → 2 → 3

© blickwinkel/Alamy

© blickwinkel/Alamy

# Why Are Materials Important?

- Materials drive advancements in our society

|  | 熔點 |
| --- | --- |
| 銅 | 1000 多 |
| 銅 + 錫 | 800 多 |

  - Stone Age 石器時代
  - Bronze Age 青銅器時代
  - Iron Age 鐵器時代

新浪旅游配图：疯狂原始人 郧县人 图片来源：@Realchi

Bronze: **Cupper**
**+**
**Tin** (~12%)

https://www.pixpo.net/post521822

https://imgur.com/g3G1hRS

# Automobile

Car body - steel plate

Electronic devices – semiconducting materials

Wheel – polymer/steel

# What is Materials Science & Engineering?

- Materials **science**
  - Investigate relationships between structures and properties of materials
  - Design/develop **new materials**

- Materials **engineering**
  - Create products from existing materials
  - Develop materials **processing techniques**

# 下町火箭-1/2

**Material Science**

**Material Engineering**



# Why is it Important for Engineers to Understand Materials?

- Products/devices/components that engineers design are all made of materials.
- To select appropriate materials and processing techniques for specific applications engineers.
  - have knowledge of material properties
  - understand the structure-property relationships

---

**Materials Science**

**Basic Knowledge of Materials**

**Materials Science & Engineering**

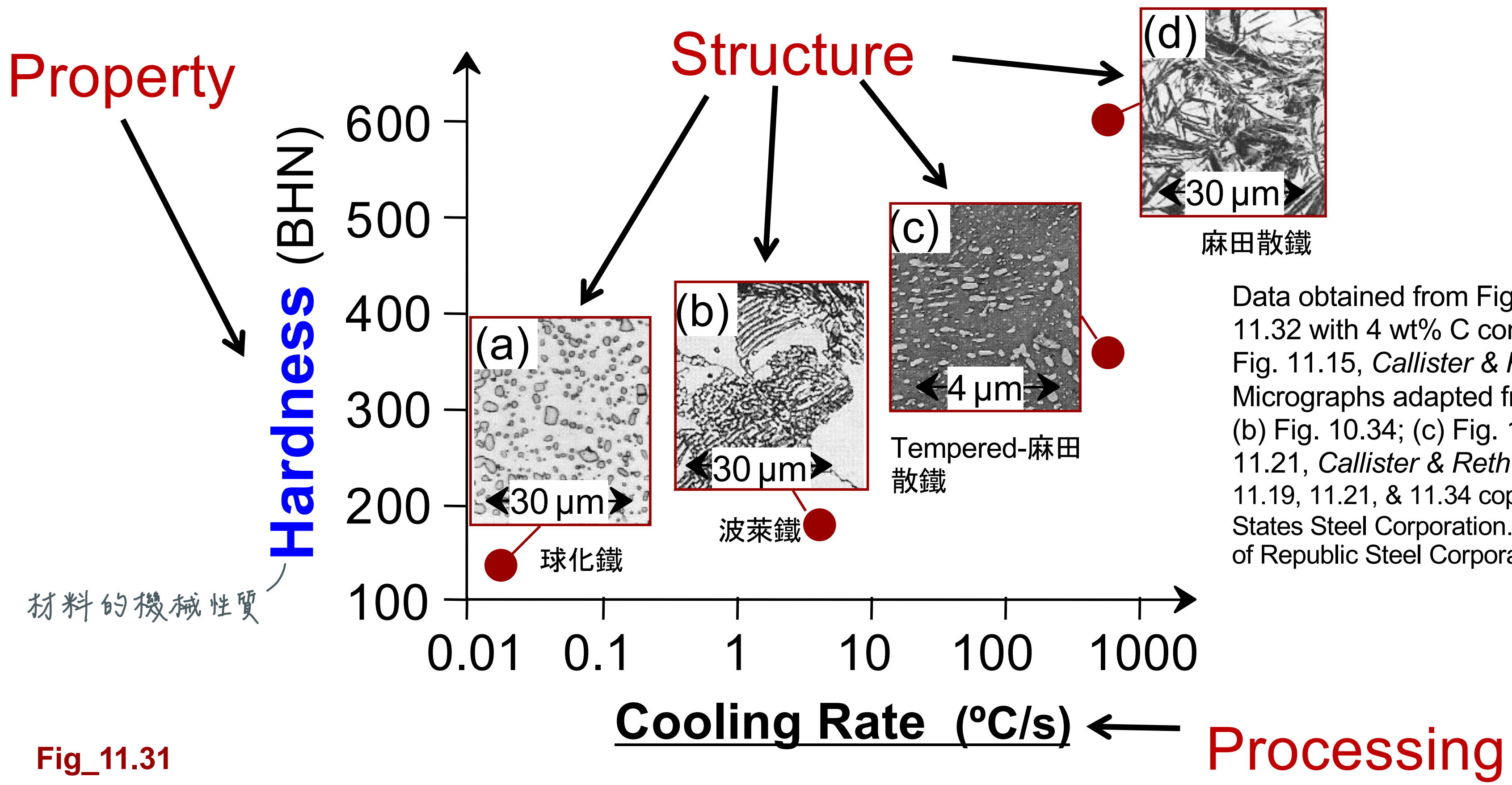
**Resultant Knowledge of Structure and Properties**

**Materials Engineering**

**Applied Knowledge of Materials**

# Relationships Among Processing, Structure, & Properties

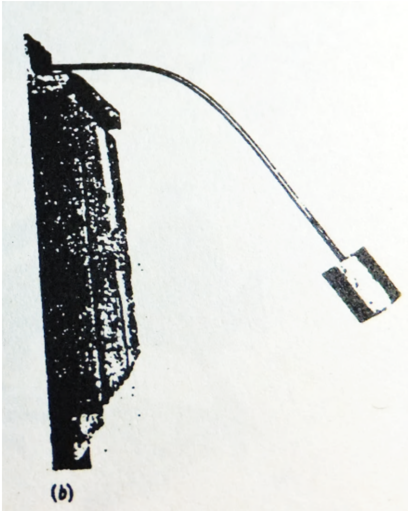
- **Processing** (e.g., cooling rate of steel from high temperature) ***affects* structure** (microstructure)
- **Structure** in turn effects **hardness**




Data obtained from Figs. 11.31(a) and 11.32 with 4 wt% C composition, and from Fig. 11.15, *Callister & Rethwisch 5e*. Micrographs adapted from (a) Fig. 11.19; (b) Fig. 10.34; (c) Fig. 11.34; and (d) Fig. 11.21, *Callister & Rethwisch 5e*. (Figures 11.19, 11.21, & 11.34 copyright 1971 by United States Steel Corporation. Figure 10.34 courtesy of Republic Steel Corporation.)

Fig_11.31

# Relationships Among Processing, Structure, & Properties




## Heat-treatment (熱處理) to obtain softer materials)

The controlled heating and cooling processes used to change the structure of a material and alter its physical and mechanical properties.

- Annealing (退火)
- Quench (淬火) ⟶ 急速的溫度變化

## Cold-working (冷加工) for greater strength and hardness)

The **shaping** of metal at temperatures substantially <u>below the point of recrystallization</u>. Cold working adds strength and hardness.

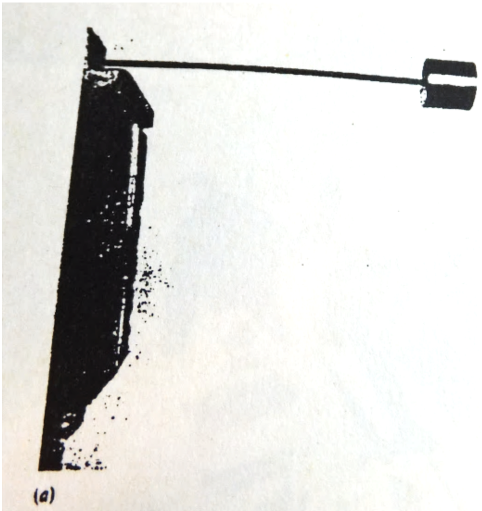



**TABLE 1.2** Mechanical Properties of 316L Stainless Steel for Implants

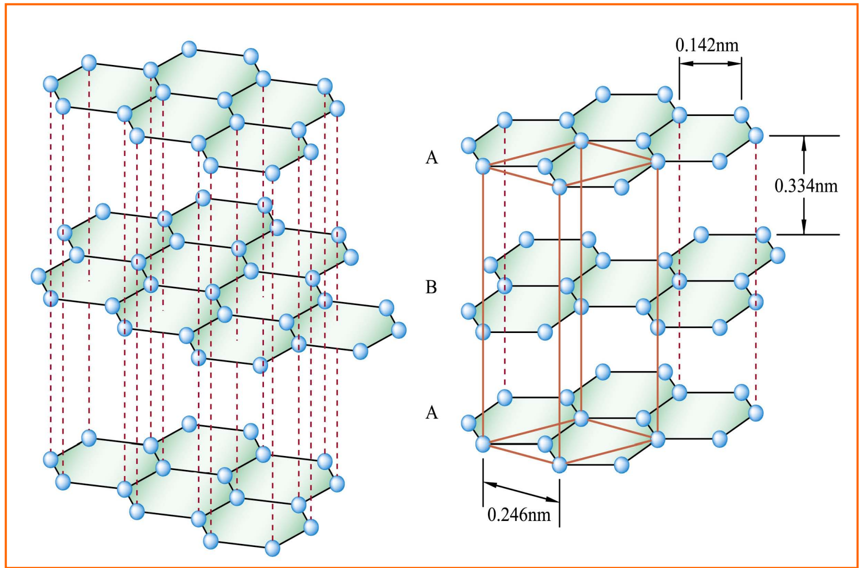
| Condition | Ultimate tensile strength, min. (MPa) | Yield strength (0.2% offset), min. (MPa) | Elongation 2 in. (50.8 mm) min. % | Rockwell hardness |
|---|---|---|---|---|
| Annealed | 485 | 172 | 40 | 95 HRB |
| Cold-worked | 860 | 690 | 12 | — |

*Source:* American Society for Testing and Materials, F139–86, p. 61, 1992.

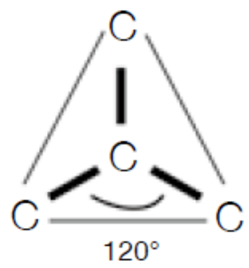
# Relationships Among Processing, Structure, & Properties

## Structures of Carbon Materials

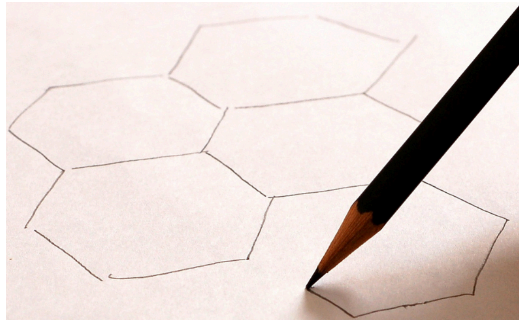
**Graphite石墨** **Graphene石墨烯**

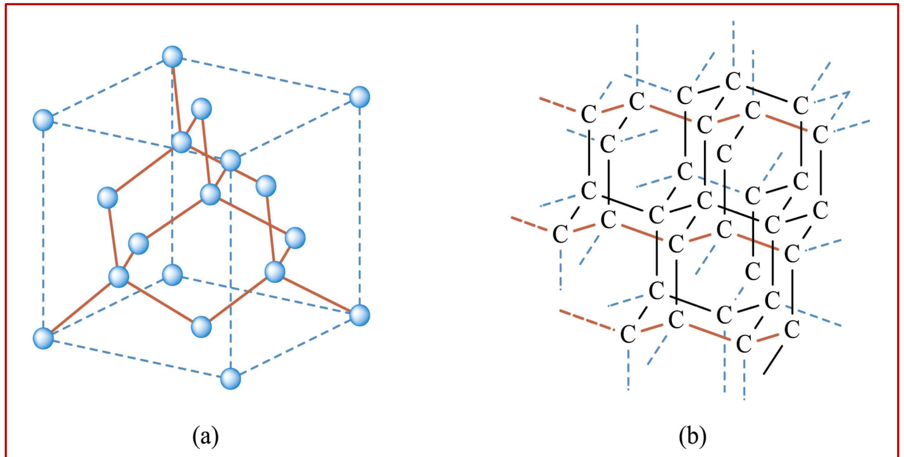



石墨
SP2混成軌域

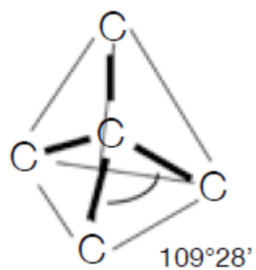



三角形






鑽石
SP3混成軌域




四面體

# Types of Materials

- **Metals:**
  - Composed of one or more **metallic elements**
  - **Aalloys** (>/= two metallic elements)
  - **Strong, ductile**
  - High **thermal** & **electrical conductivities**
  - Opaque (不透明), reflective (反光)



Fig_1-9

- **Iron**
- **Copper**
- **Aluminum**

- **Ceramics**:

  陶瓷

  – Compounds of **metallic** & **non-metallic** elements (oxides, carbides, nitrides, sulfides)

  – Hard, Brittle, wear resistance

  – Low thermal & electrical conductivities, insulator

  – Opaque, translucent , or transparent

© William D. Callister, Jr.

- **Glass**
- **$Al_2O_3$**
- **$Si_3N_4$**

Fig_1-10

- **Polymers/plastics**:
  - Compounds of non-metallic elements
  - Organic giant molecular and most noncrystalline
  - 延展性
  - Soft, ductile, low strengths, low densities
  - Low thermal & electrical conductivities
  - Opaque, translucent or transparent

© William D. Callister, Jr.

- **Poly vinyl Chloride (PVC)**
- **Polyester (PS)**

**Fig_1-11**

- **Composite materials**

  - Have been engineered that consist of **more than one material** type.
  - Fiberglass in which glass fibers are embedded within a polymeric material.
  - Fiberglass acquires strength from the glass and flexibility from the polymer.

Carbon fiber-reinforced polymer

(CFRP)

碳纖維強化聚合物）


http://road.cc/content/feature/211921-13-best-carbon-fibre-road-bikes-£799-£10000

# Why Are Materials Important?

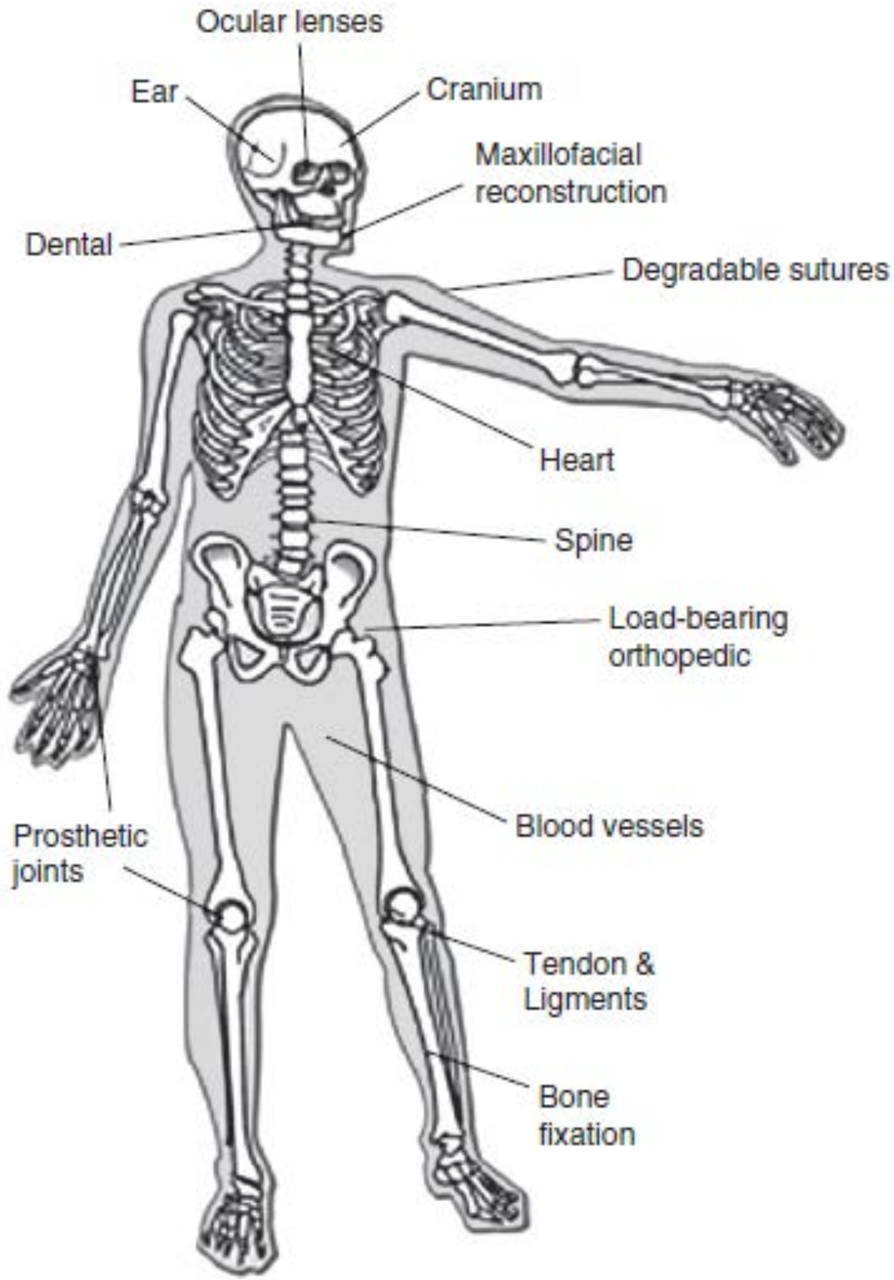
- What is today's material age?

Advanced materials

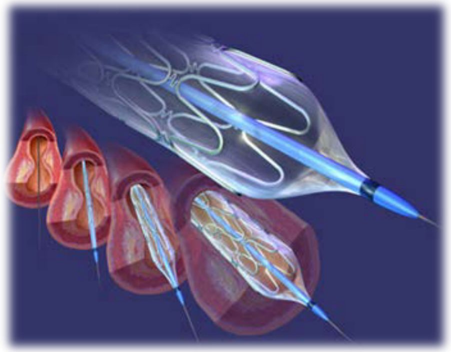
- Silicon (Electronic Materials) Age?
- Polymer Age?
- Biomaterials Age
- Nanomaterials Age?

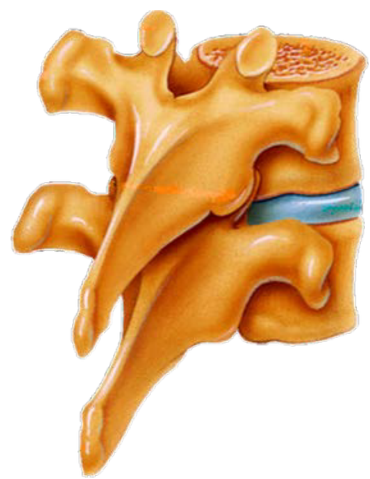
Too many new materials,
materials utilization was totally **a selection process**.

# Biomaterials




| USA | Expenditure (USD) |
|---|---|
| Health care | 14 billion |
| Biomaterials | 9 billion |

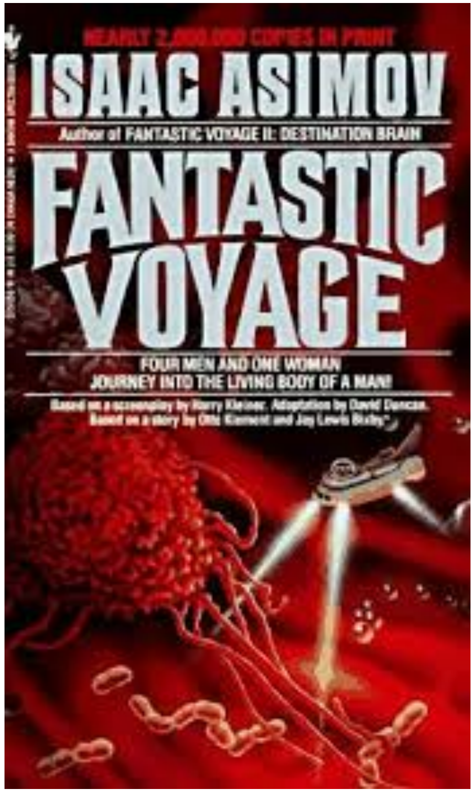




J Black, in chapter: Biocompatibility: Definition and Issues, Biological Performance of Materials: Fundamentals of Biocompatibility, CRC Press, US, 2006.

# Nanotechnology

1966 ***Fantastic Voyage*****聯合縮小軍**

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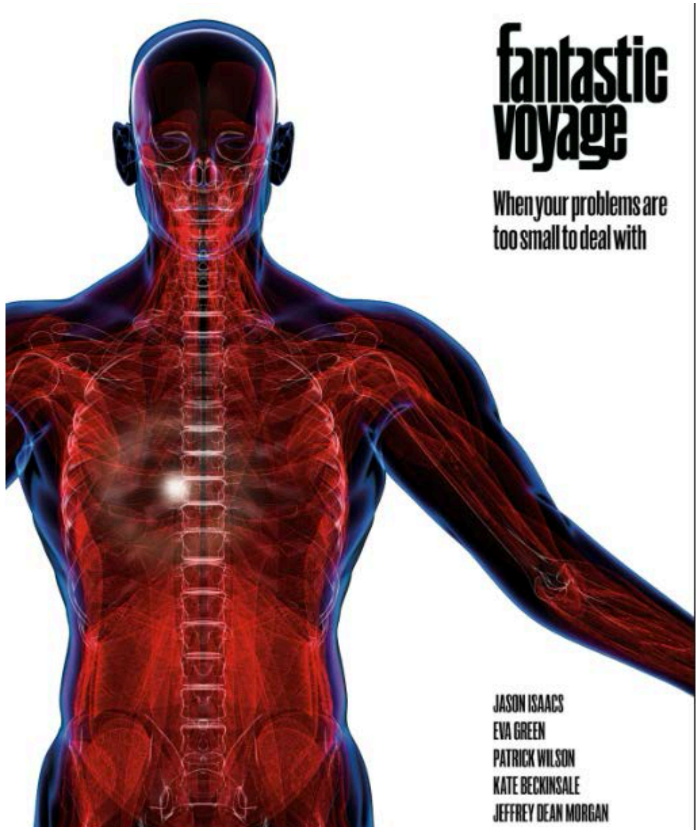
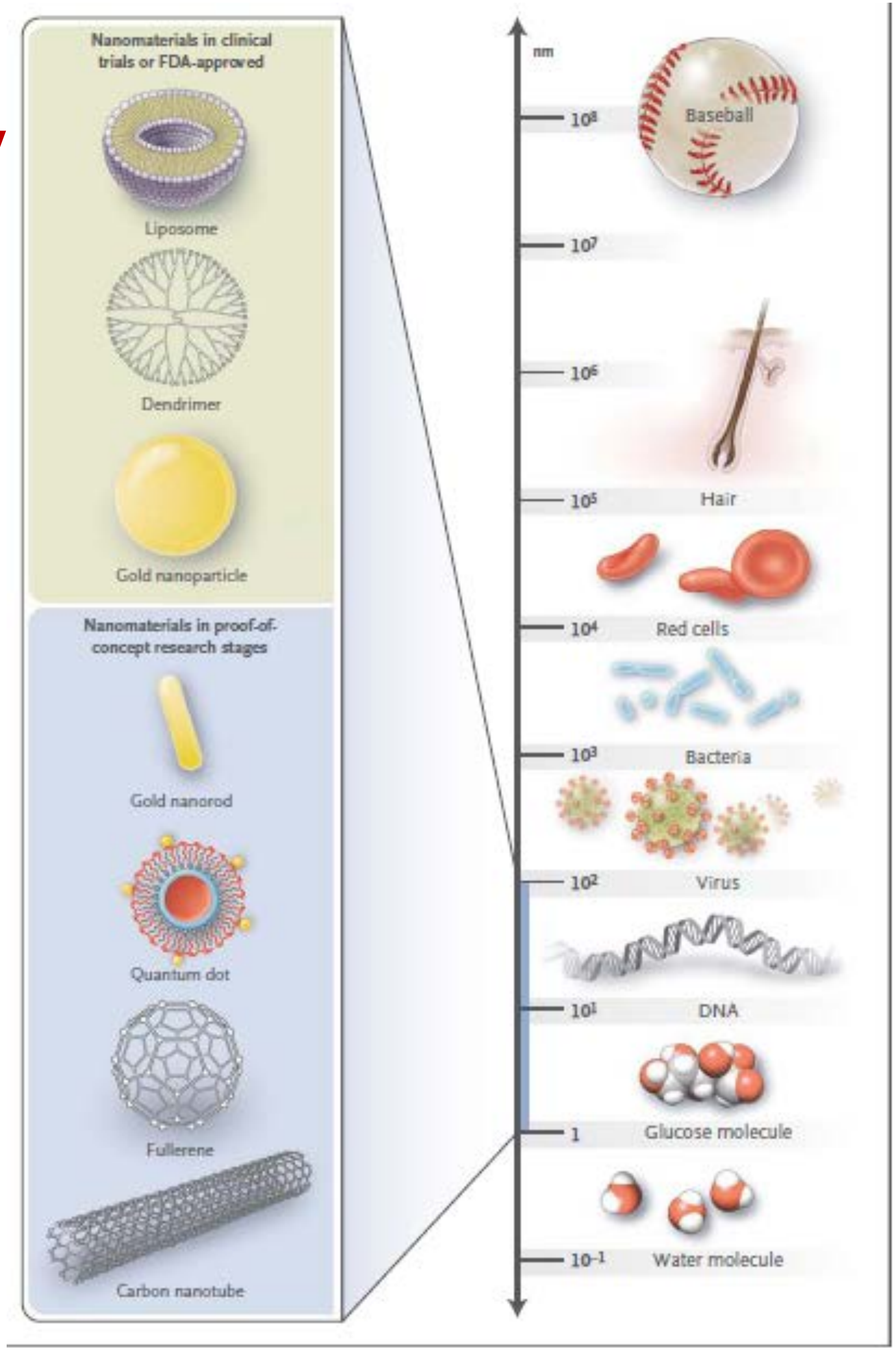



http://www.catspawdynamics.com/fantastic-voyage-posters-and-wallpaper/

# Nanomaterials Commonly Used in Medicine

- Liposomes
- C60
- Carbon  nanotube (CNT)
- Quantum dots




N Engl J Med 2010;363:2434-43

# Material Property Types

Properties of materials fall into six categories as follows:

- Mechanical
- Electrical
- Thermal
- Magnetic
- Optical
- Deteriorative

# Materials Selection

**Engineers** often **solve materials** selection problems.

**Procedure:**

1. For a Specific **Application** ⟶ Determine Required Properties
   - Properties: mechanical, electrical, thermal, magnetic, optical, deteriorative.

2. From List of **Properties** ⟶ Identify Candidate Material(s)

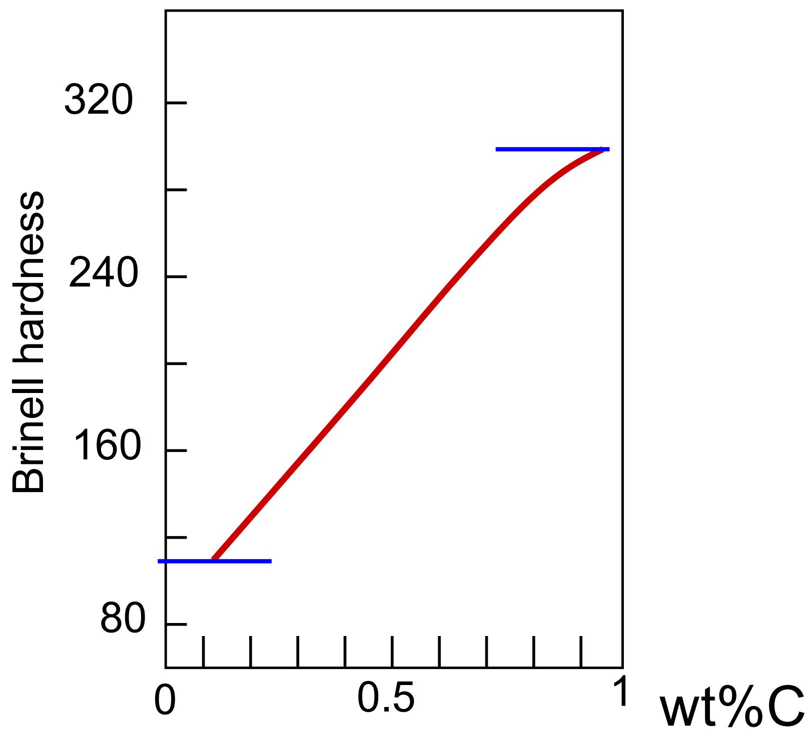
3. Best **Candidate Material** ⟶ Specify Processing technique(s)
   - To provide required set of properties
   - To produce component having desired shape and size
   - Example techniques: casting, mechanical forming, welding, heat treating

Processing → Structure → Properties → Performance

# Mechanical Properties

- **Strength**
- **Hardness**
- **Ductility**
- **Stiffness**

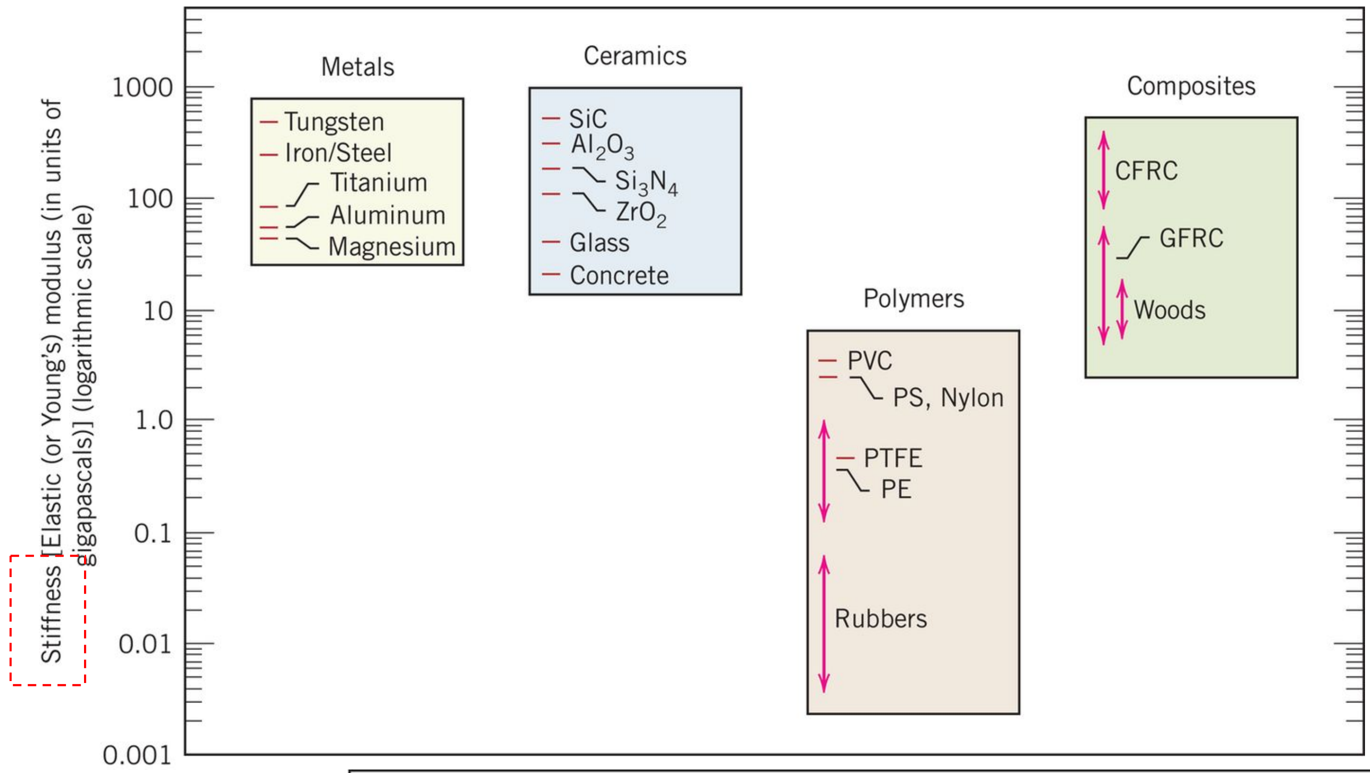
Affect of **carbon content** on the **hardness of a common steel:**

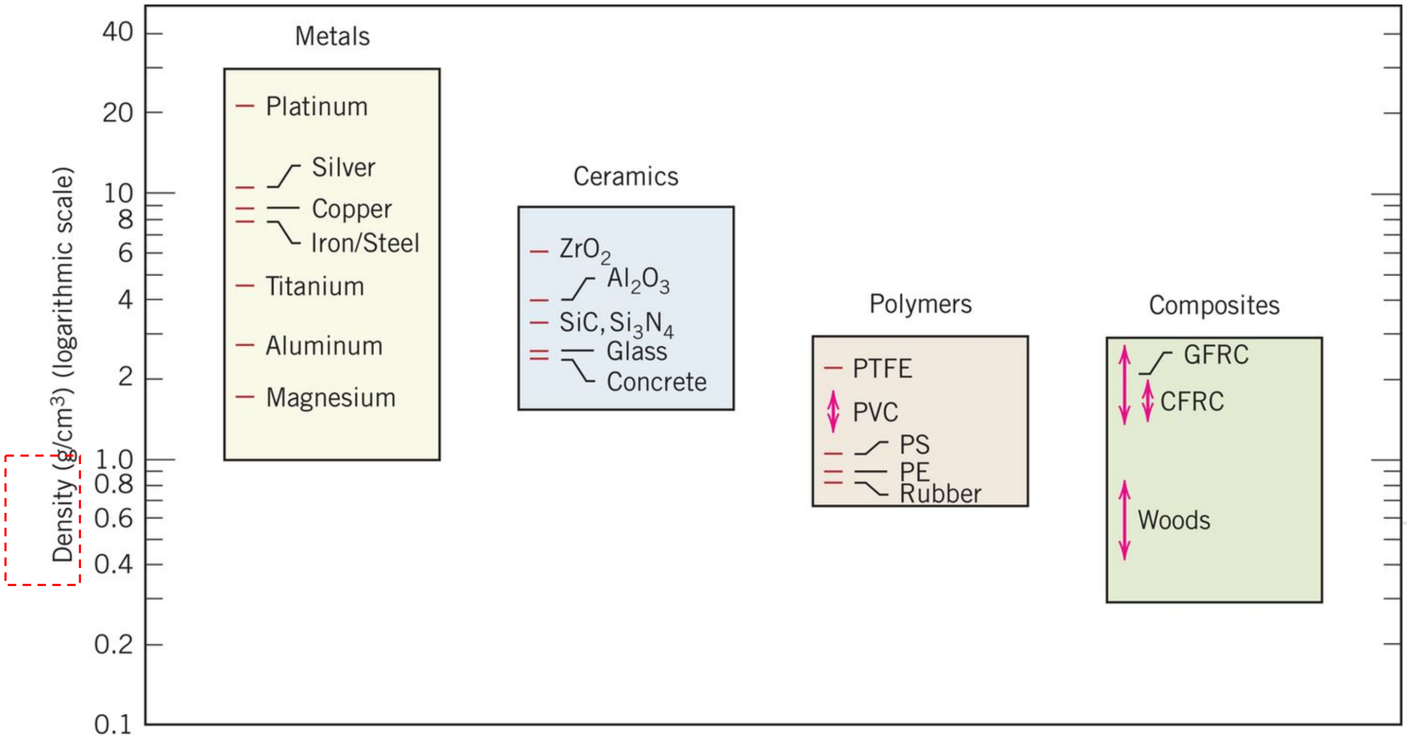



- Increasing carbon content increases **hardness of steel.**

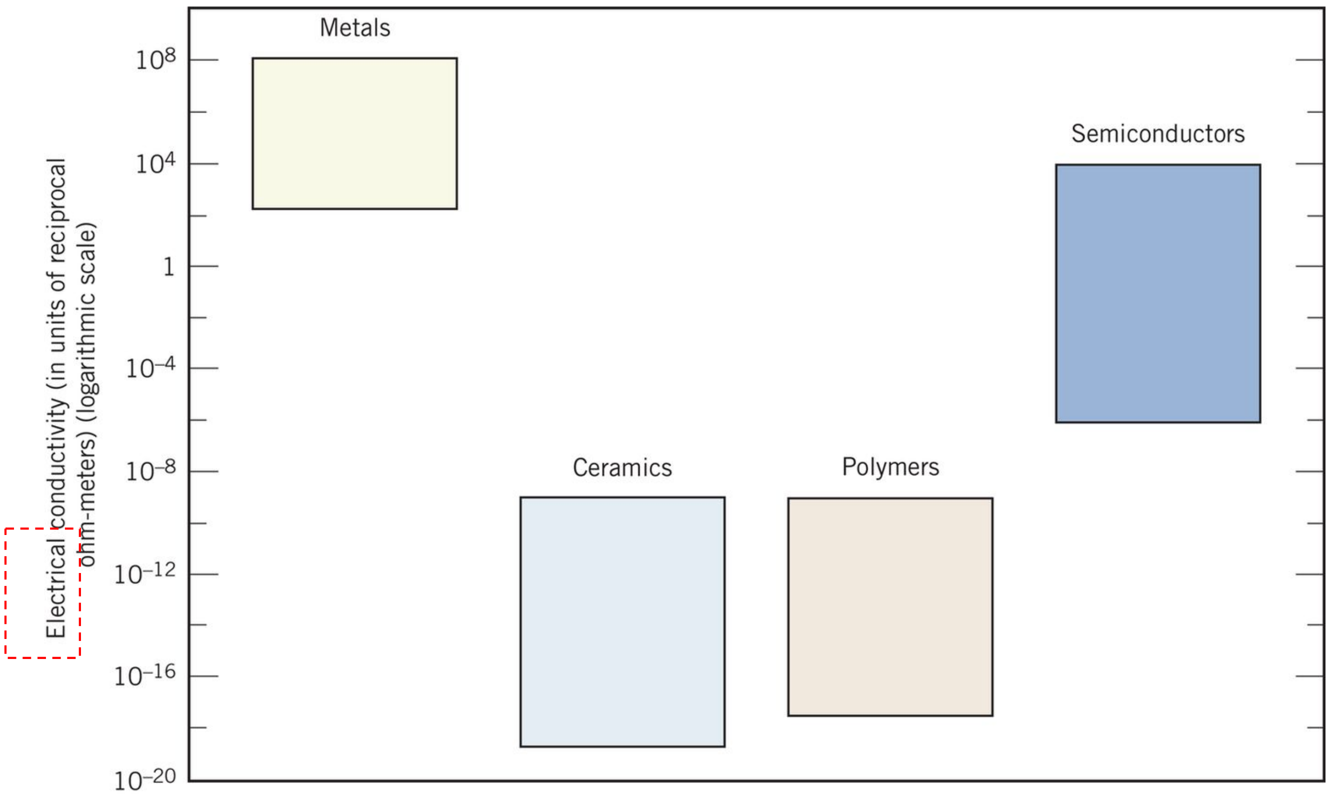
Fig. 11.31, *Callister & Rethwisch 5e.* [Data taken from *Metals Handbook: Heat Treating*, Vol. 4, 9th edition, V. Masseria (Managing Editor), 1981. Reproduced by permission of ASM International, Materials Park, OH.]

## Mechanical Properties



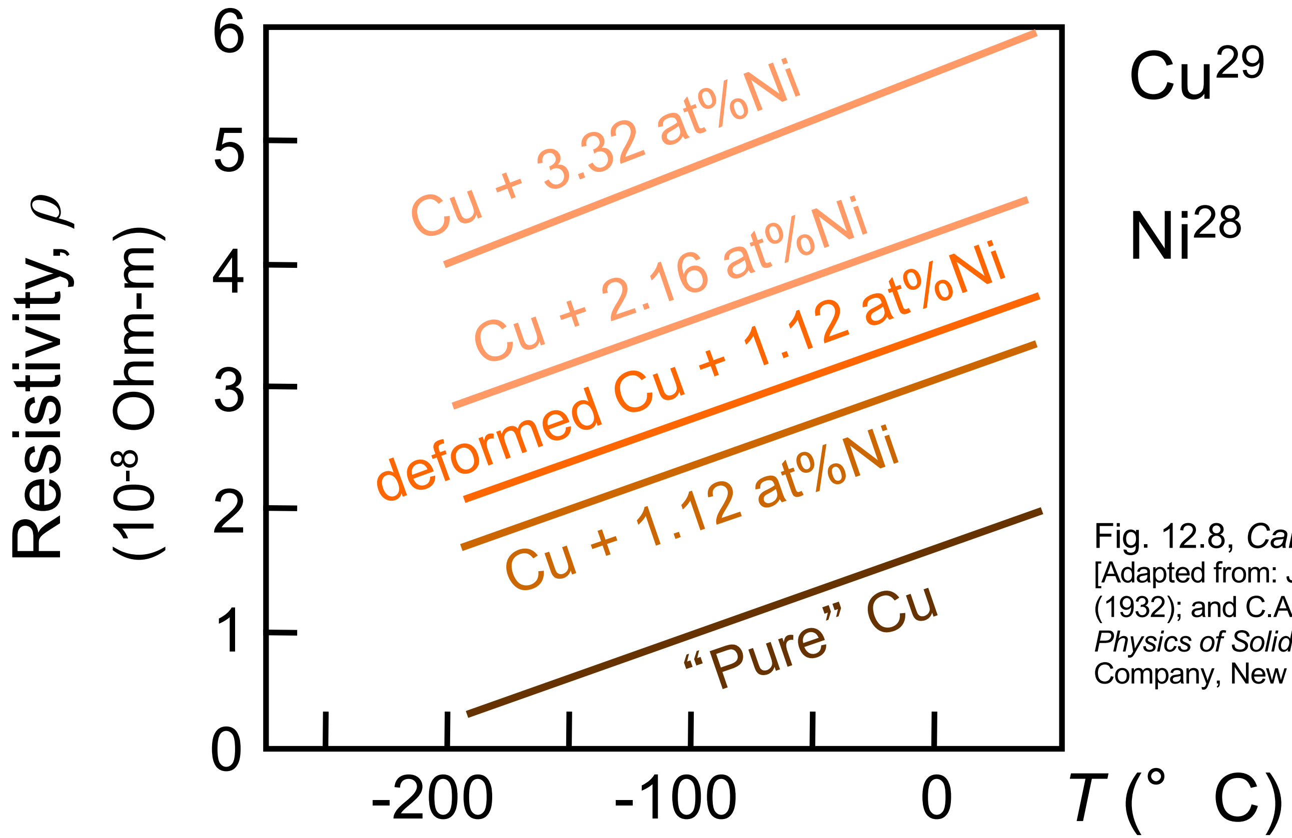



# Mechanical Properties



# Electrical Properties

Factors that affect **electrical resistivity** – for **copper (Cu)**:




$Cu^{29}$ $(3d^{10}4s^{1})$

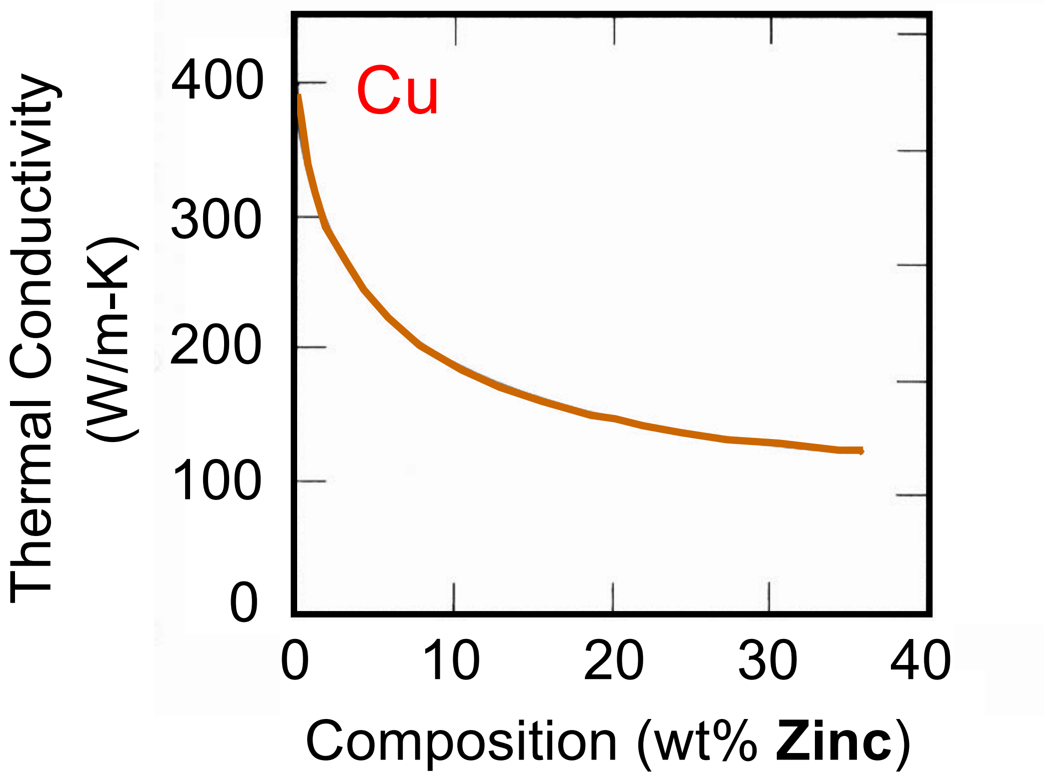
$Ni^{28}$ $(3d^{8}4s^{2})$

Fig. 12.8, *Callister & Rethwisch 5e.* [Adapted from: J.O. Linde, *Ann Physik* **5**, 219 (1932); and C.A. Wert and R.M. Thomson, *Physics of Solids*, 2nd edition, McGraw-Hill Company, New York, 1970.]

- Increasing temperature increases resistivity.
- Increasing impurity content (e.g., Ni) increases resistivity.
- Deformation increases resistivity.

# Thermal Properties

**Thermal Conductivity** – measure of a material's ability to ***conduct heat***




- Thermal Capacity
- Thermal Expansion

Cu 29 ($3d^{10}4s^1$)

Zn 30 ($3d^{10}4S^2$)

Fig. 17.4, *Callister & Rethwisch 5e.* [Adapted from *Metals Handbook: Properties and Selection: Nonferrous alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker, (Managing Editor), ASM International, 1979, p. 315.]

- Increasing impurity content (e.g., **Zn** in Cu) decreases thermal conductivity.

# Optical Properties

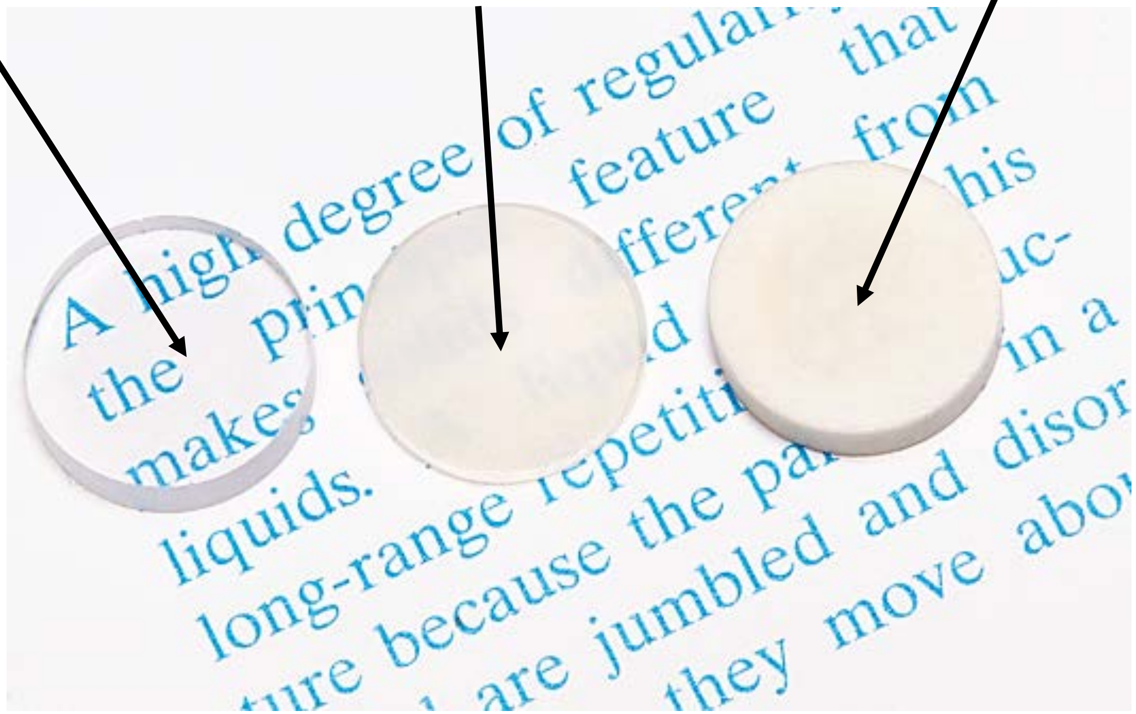
- The light transmittance of some materials depend on their structural characteristics:

**$Al_2O_3$**

Aluminum oxide single crystal (high degree of perfection)
— is optically **transparent**

Aluminum oxide polycrystalline material (having many small grains)
— is optically **translucent**

Aluminum oxide polycrystalline material having some porosity
— is optically **opaque**



Specimen preparation, P.A. Lessing

# Deteriorative Properties

- Small cracks formed in steel bar that was simultaneously stressed and immersed in sea water

  \- Form of stress-corrosion cracking

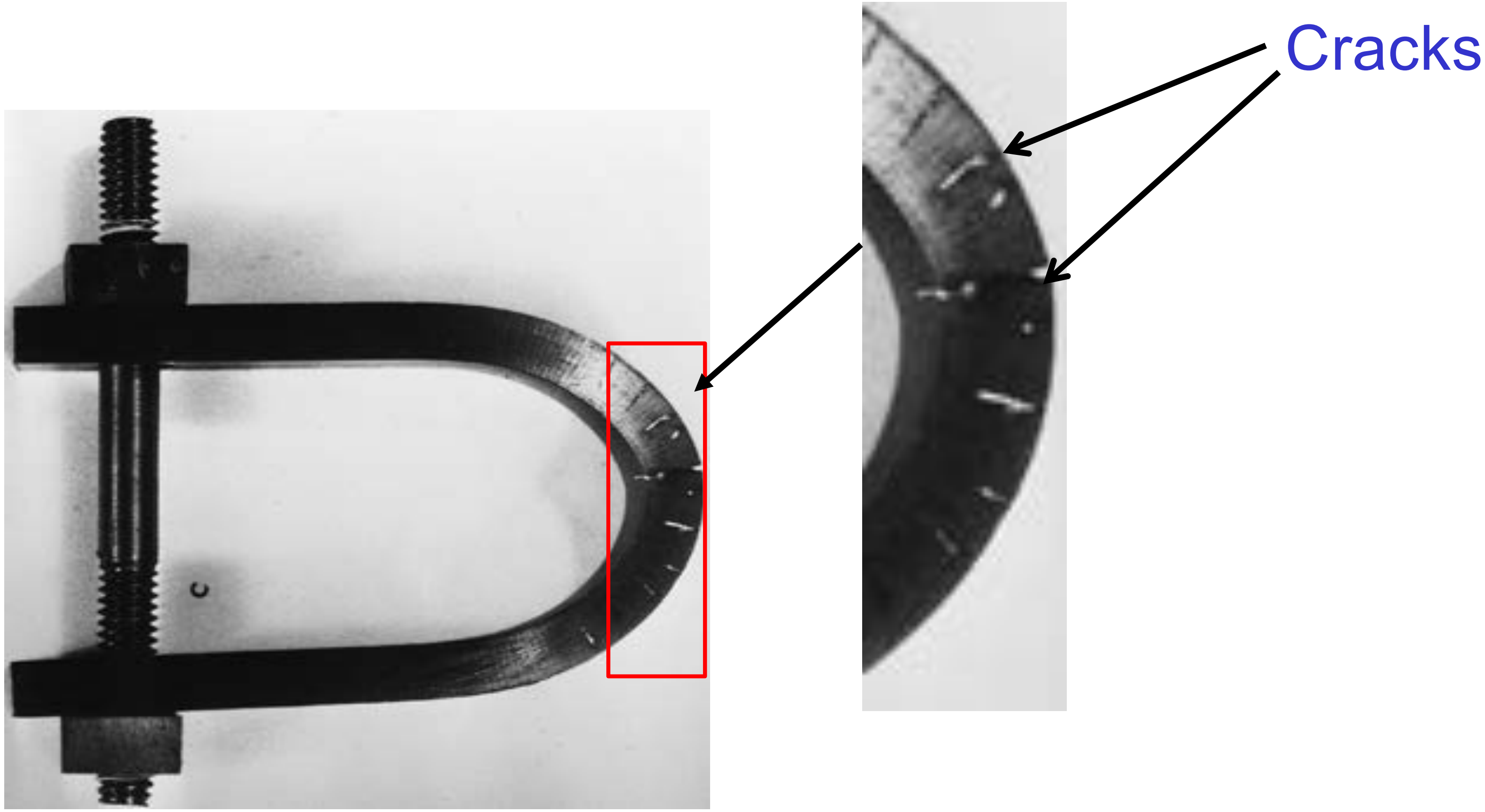
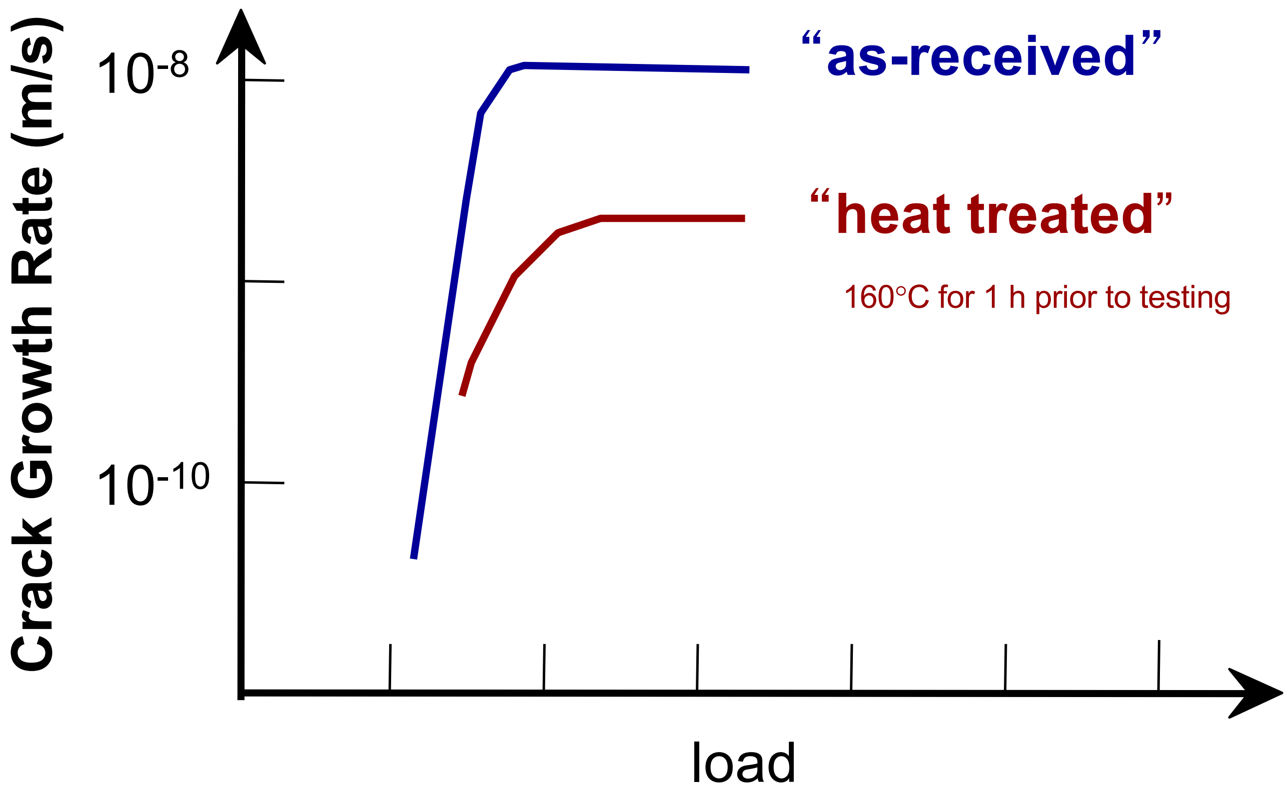



Fig. 16.21, *Callister & Rethwisch 5e.*
(from *Marine Corrosion, Causes, and Prevention*, John Wiley and Sons, Inc., 1975.)

# Deteriorative Properties (cont.)

- For stress-corrosion cracking, rate of crack growth is diminished by heat treating




Adapted from Fig. 11.20(b), R.W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials" (4th ed.), p. 505, John Wiley and Sons, 1996. (Original source: Markus O. Speidel, Brown Boveri Co.)

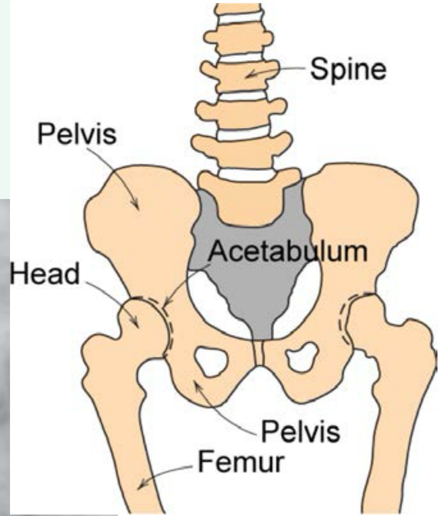
For Aluminum alloy 7178 that is stressed while immersed in a saturated aqueous NaCl solution, crack growth rate is reduced by heat treating (160°C for 1 h prior to testing).

# Example of Materials Selection:

## Artificial Hip Replacement

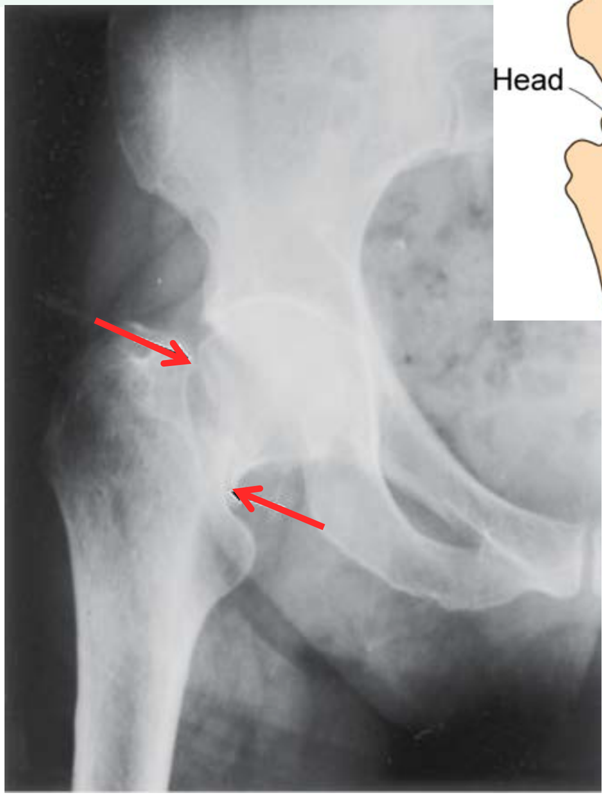
Hip joint problems can be painful and disabling

- Joint deterioration (loss of cartilage) as one ages
- Joint fracture




X-ray of normal hip joint

arrows point to ends of fracture line



X-ray of fractured hip joint

# Materials: Artificial Hip Replacement

- Damaged and diseased hip joints can be replaced with artificial ones
- Materials requirements for artificial joints
  - Biocompatible – minimum rejection by surrounding body tissues
  - Chemically inert to body fluids
  - Mechanical strength to support forces generated
  - Good lubricity and high wear resistance between articulating surfaces

# SUMMARY

- **Appropriate** materials and processing decisions require engineers to understand materials and their properties.
- Materials' **properties** depend on their **structures**; structures are determined by how materials are processed
- In terms of chemistry the three classifications of materials are ***metals***, ***ceramics***, and ***polymers***.
- Most properties of materials fall into the following six categories: *mechanical, electrical, thermal, magnetic, optical,* and *deteriorative.*
- An important role of engineers is that of *materials selection*.