Selection of Engineering Materials

IM 515E

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- Textbook:

  Budinski, K.G. and Budinski, M.K., “Engineering Materials: Properties and selection, 8th ed., Prentice Hall, 2005.

- Other References:

1) Ashby, M., Shercliff, H. and Cebon, D., “Materials: Engineering Science, Processing & Design”, 1st ed., Butterworth-Heineman, 2007.
2) Ashby, M.F., “Materials Selection in Mechanical Design”, Pergamon Press, 2005.

Aims & Objectives

- To provide the students with the basic knowledge about structure and properties of different engineering materials.
- To introduce the students to the different classes of engineering materials in addition to new materials.
- To enable the students to understand the concept of designing with materials and the important criteria used in selecting materials for a particular application.

Outlines

W1:	General Introduction
	Classification of Engineering Materials
W2:	The Design Process
W3:	Mechanical System Design Concepts
W4:	Material Properties summarized on Materials
	Selection Charts
W5:	Developing a systematic strategy for material
	Selection in a given component Case 1
W6:	Developing a systematic strategy for material
	Selection in a given component Case 2
W7:	Exam
W8:	Formal procedures and main principles of materials selection using state-of-the art selection charts

Outlines

W9: Formal procedures and main principles of materials selection using state-of-the art selection charts

W10: Material selection for multi-constraint and compound objective problems

W11: Optimal material selection factoring cross-sectional shape of the component

W12: Exam

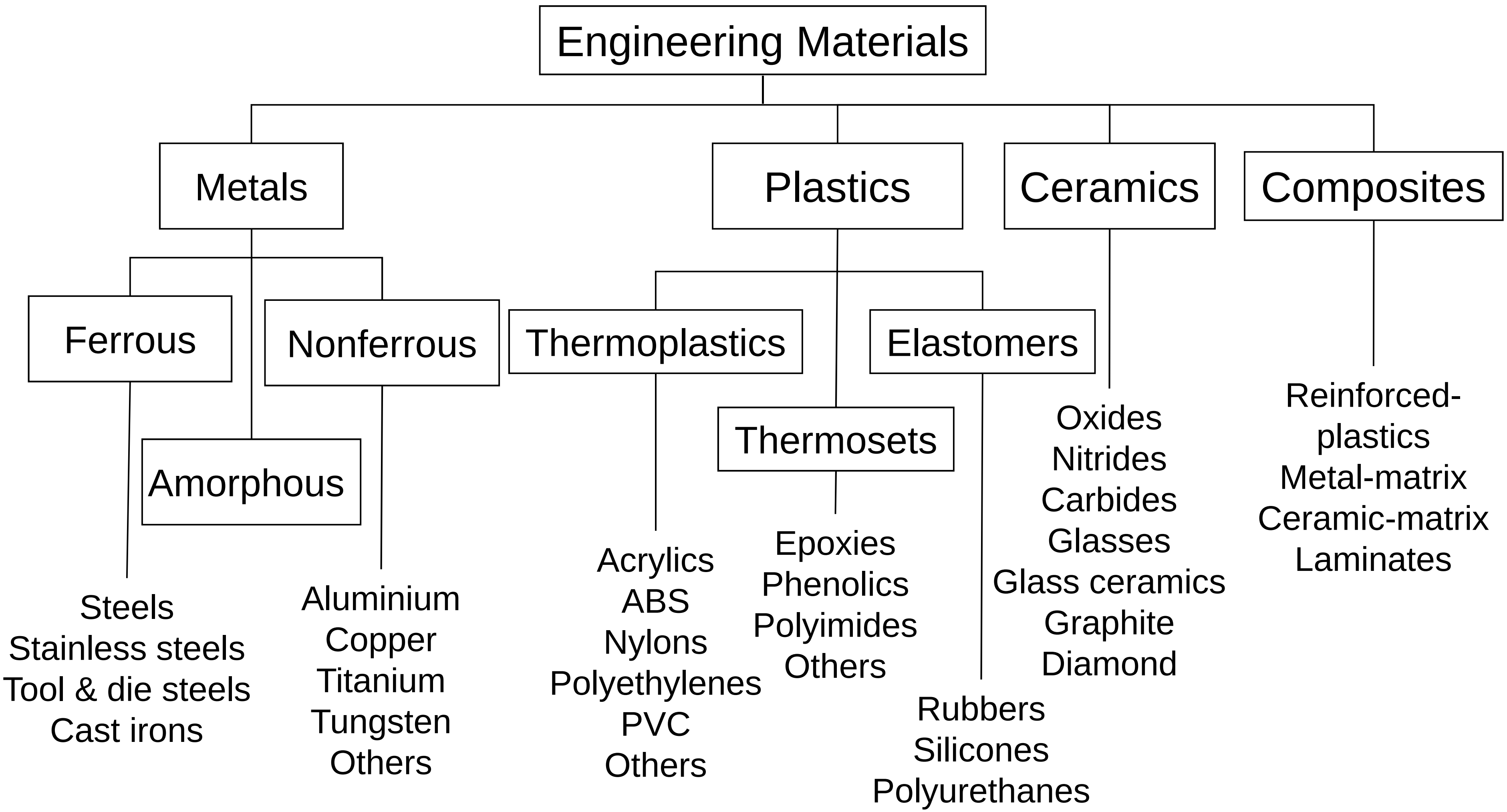
W13: Case studies in material selection for various practical engineering applications

W14: Case studies in material selection for various practical engineering applications

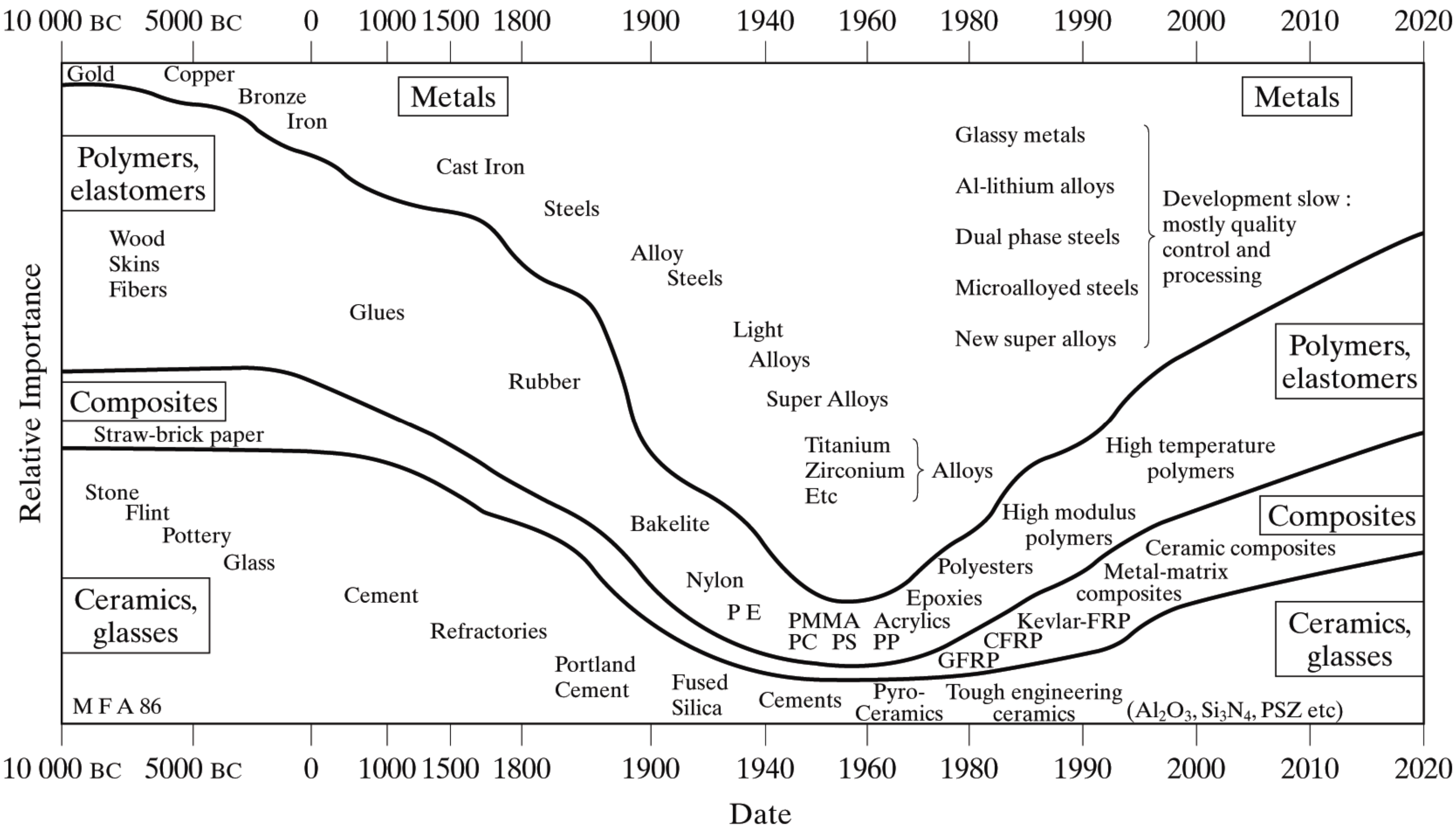
W15: Review

W16: Final Exam

Classification of Engineering Materials



Evolution of Engineering Materials with Time



Different Classes of Engineering Materials

The different classes of materials include:

Metals:

- They have relatively high stiffness, measured by the modulus, E.
- Most when pure are soft and easily deformed, meaning that σ_y is low.
- They can be made strong by alloying and by mechanical and heat treatment, increasing σ_y , but they remain ductile, allowing them to be formed by deformation processes.
- They are tough, with a usefully high fracture toughness K_{1C}.
- They have good thermal and electrical conductivity, but they are reactive and most corrode rapidly if not protected.

Different Classes of Engineering Materials

- Metals include the following families;
  - Irons and Steels (based on Fe),
  - Aluminium alloys (based on Al),
  - Magnesium alloys (based on Mg),
  - Titanium alloys (based on Ti),
  - Nickel alloys (based on Ni),
  - Zinc alloys (based on Zn), and
  - Copper alloys (based on Cu), including brasses.

Different Classes of Engineering Materials

Ceramics:

- They are non-metallic, inorganic solids, like porcelain or alumina.
- They have many attractive features. They are stiff, hard and abrasion resistant, they retain their strength to high temperatures, and they have good corrosion resistance.
- Most are good electrical insulators. However, unlike metals, they are brittle, with low K_{1C}.
- This gives ceramics low tolerance for stress-concentration. Therefore, it is more difficult to design with ceramics than with metals. Examples include;
  - Aluminas,
  - Silicon carbides,
  - Silicon nitrides, and
  - Zirconias.

Different Classes of Engineering Materials

Glasses:

- They are non-crystalline (amorphous) solids.
- The most common are the soda-lime and borosilicate glasses familiar as bottles and Pyrex ovenware.
- The lack of crystalline structure suppresses plasticity, so like ceramics, they are hard and remarkably corrosion resistant.
- They are excellent electrical insulator, and, of course, they are transparent to light.
- But like ceramics they are brittle and vulnerable to stress concentration.

Different Classes of Engineering Materials

Different types of glasses:

Glass	Typical composition wt%	Typical uses
Soda-lime glass	$70SiO_2$,10CaO,$15Na_2O$	Windows, bottles, etc Easily formed and shaped
Borosilicate glass	$80SiO_2$, $15B_2O_3$, $5Na_2O$	Pyrex; cooking and chemical glassware; high temperature strength, low coefficient of expansion, good thermal shock resistance

Different Classes of Engineering Materials

Polymers:

- They are organic solids based on long chains of carbon (or, in a few, silicon) atoms.
- Polymers are light – their densities ρ are less than those of metals.
- Compared with other families they are floppy, with moduli E that are roughly 50 times less than those of metals.
- But they can be strong, and because of their low density, their strength per unit weight is comparable to that of metals.
- Their properties depend on temperature, a polymer that is tough and flexible at room temp. may be brittle at -4ºC and may turn rubbery at 100ºC of boiling water. Few have useful strength above 150ºC.

Different Classes of Engineering Materials

- If these aspects are allowed for in the design, the advantages of polymers can be exploited.
- They are easy to shape; complicated parts performing several functions can be moulded from a polymer in a single operation.
- Their properties are suited for components that snap together, making assembly fast and cheap.
- A good design in which sizing the mould is done accurately and with precoloring the polymer, no finishing operations are required. Examples include:
  - PE, PP, PET, PC, PS, PEEK, PA (Nylons),
  - Polyesters,
  - Phenolics, and
  - Epoxies.

Different Classes of Engineering Materials

Elastomers:

- They are polymers with unique property that their stiffness, measured by E, is extremely low (500 – 5000 times less than those of metals) and their ability to be stretched to many times their starting length yet recover their initial shape when released.
- Despite their low stiffness, they can be strong and tough.
- Examples include:
  - Isoprene,
  - Neoprene,
  - Butyl rubber,
  - Natural rubber,
  - Silicones, and EVA

Different Classes of Engineering Materials

Hybrids:

- They are combinations of two or more materials in an attempt to get the best of both.
- Glass and Carbon-Fiber-Reinforced polymers (GFRP and CFRP) are examples, so too are sandwich structures, foams and laminates.
- Almost all natural materials are hybrids (wood, bone, skin, …etc).
- Hybrid components are expensive and they are relatively difficult to form and join. So, despite their attractive properties, the designer will use them only when the added performance justifies the added cost.

The Design Process

Scope

- The starting point: **Good Mechanical Design** including the role of materials.
- Mechanical Design deals with the following characteristics of mechanical systems:
  - The physical properties
  - The proper functioning
  - The production
- Industrial Design "the aesthetics" involves:
  - Pattern
  - Form
  - Colour
  - Texture
  - Other aspects such as customer appeal

The Design Process

- There are three types of mechanical design:
  - **Original** – a completely new idea
  - **Adaptive** – the evolution of a product
  - **Variant** – the change of size or shape without changing the function
- Our intention is to develop a **methodology** for materials selection in mechanical design.
- We briefly review the **design process** and encounter a new vocabulary (special jargon) involving abstract concepts.

Types of Design

- **Original Design**
  - Involves a new working principle, e.g. a compact disk, a flash disk
  - In searching for original designs, the designer must range his thinking as widely as possible
  - He must consider all possible solutions and then choose (by some sensible procedure) between them
- New Materials – which offer new, unique combinations of properties enable original designs
- Examples:
  - High purity silicon enabled the development of transistors
  - High purity glass → the optical fiber
  - High coercive force magnets → the miniature earphone
  - High temperature alloys → the gas turbine

Types of Design

- Sometimes the **new material** suggests a new product.
- More often, the **new product** requires the development of a new material.
- Gas turbine/Nuclear technologies:
  - Have required the development of new metallic alloys
  - Provide the driving force behind the current developments of ceramics and composites
- **Adaptive Design**
  - Searches for incremental advance in performance via a refinement of the working principle
  - This is often made possible by developments in materials
  - Examples:
    - Polymers replacing metals in household goods
    - Carbon fibers replacing wood in sports goods

Types of Design

- Market share can be won or lost according to whether the manufacturer exploits new materials in developing his product.
- **Variant Design**
  - Involves a change in scale or dimension or design detail without changing function
  - Change of scale may require change of material
  - Examples:
    - Model aeroplane made of balsa wood’ full scale plane made of Al alloys.
    - Model boiler made of copper, full scale boiler made of steel.
- Technical Systems
  - A technical system consists of assemblies and components put together in a way that performs a function.

Types of Design

– Example

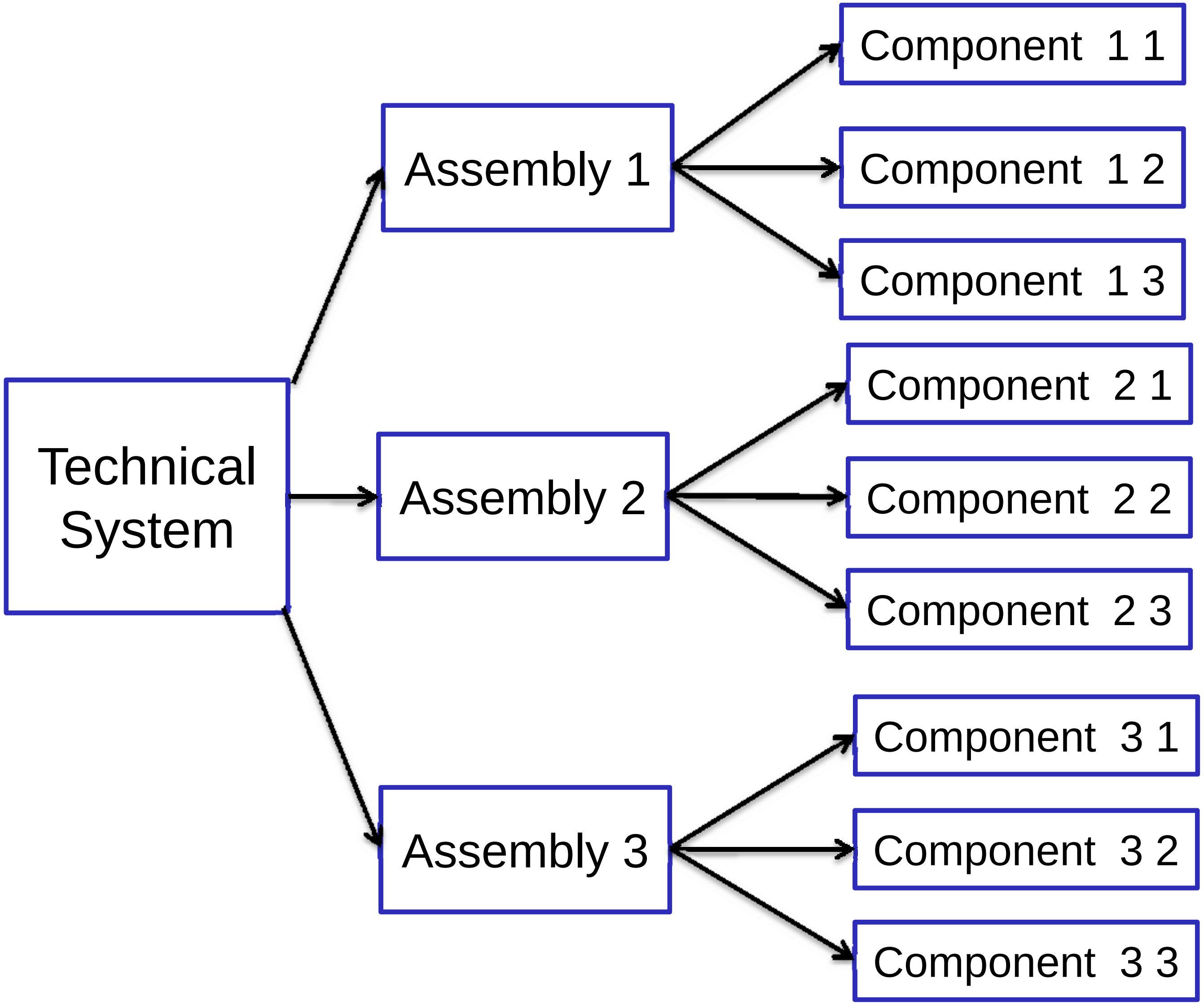
A **bicycle** is a **technical** system

- A wheel is an assembly made up of components such as rim, spokes, hub, etc.
- Each component is made of different material.

– The analysis of a technical system involves a breakdown into assemblies and components.

– Material selection is at the component level.

Types of Design



Types of Design

- Materials selection is at the component level:
  - Some components are standard, common to many designs, e.g. a wood screw
  - Even among standards there is a choice of material, e.g. a screw can be made of brass, mild steel or stainless steel.
- The designer must select:
  1. The material,
  2. The shape, and
  3. The processing route

- Function, material, shape and processing route **all interact**.