THE UNIVERSITY OF ZAMBIA

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

MEC 2309 – PROPERTIES OF ENGINEERING MATERIALS I

LECTURE 1

GMM/FKC 2022

GENERAL INTRODUCTION

GMM/FKC 2022

WHAT IS ENGINEERING ?

The Accreditation Board for Engineering and Technology (ABET) defines engineering as:

"The profession in which knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgement to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind."

Source:1985 Annual Report, Accreditation Board for Engineering and Technology, New York (1986)

GENERAL INTRODUCTION

- **Mechanical engineers** search for high temp materials so that gas turbines, engines etc can operate more efficiently; or wear resistance materials to manufacture bearings and shafts; or even hard materials for the manufacture of cutting tools.
- **Electrical engineers** search for materials that are good conductors of electricity by which electrical devices or machines can be operated at a faster rate with minimum power losses.
- **Aerospace & automobile engineers** search for materials having high strength-to weight ratio.
- **Electronic engineers** search for materials that are useful in the fabrication &miniaturization of electronic devices
- **Civil engineers** search for high strength materials for use in construction of roads, bridges and buildings

GENERAL INTRODUCTION

- **All these requirements can be met when the internal structure and engineering properties of materials are known to an engineer or technologist.**

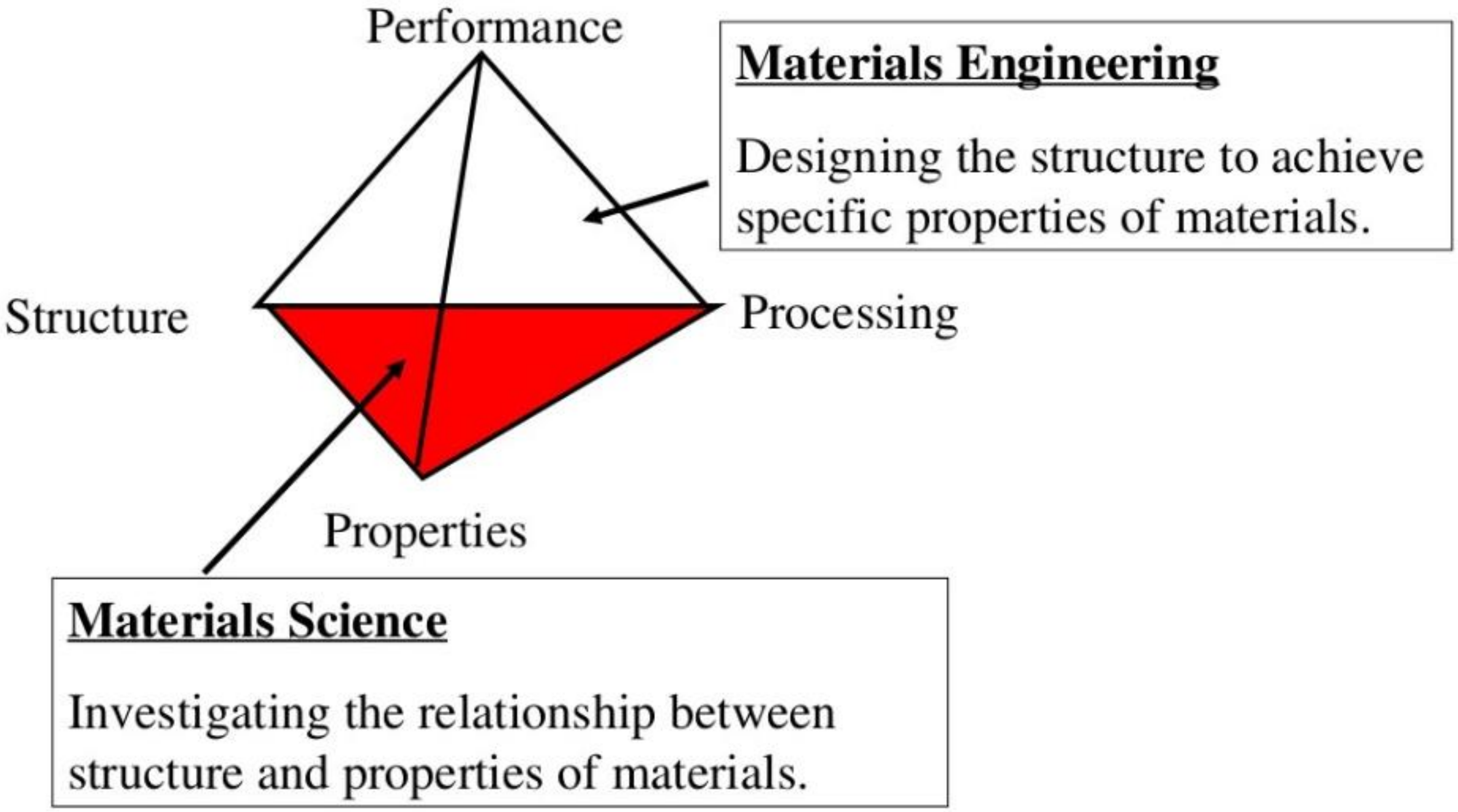
GENERAL INTRODUCTION

- **Without materials there is no Engineering!!!**

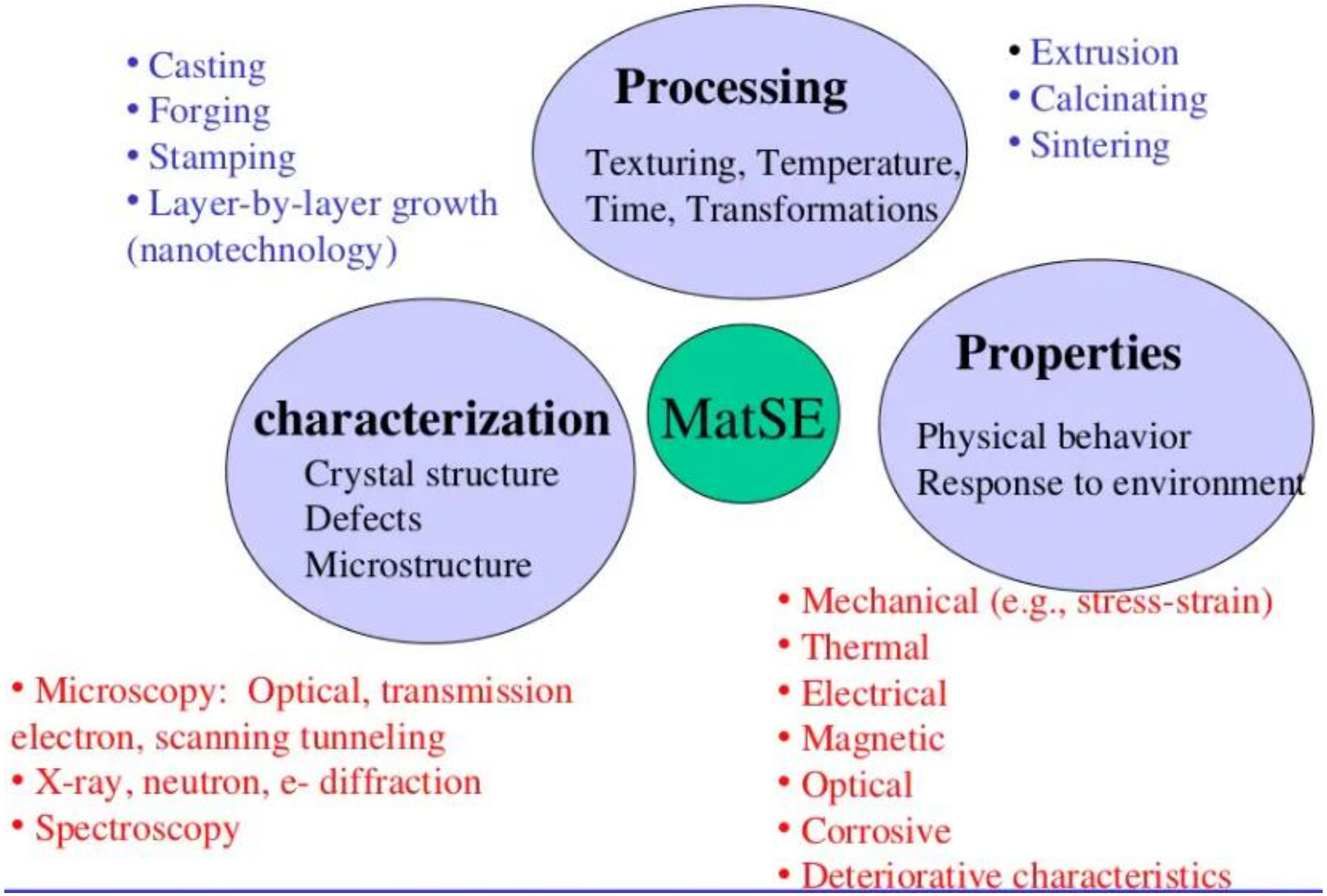
MATERIALS SCIENCE AND ENGINEERING

- **Materials Science**
  - The discipline of investigating the relationships that exist between the structures and properties of materials.
- **Materials Engineering**
  - The discipline of designing or engineering the structure of a material to produce a predetermined set of properties based on established structure-property correlation.
- **Four Major Components of Material Science and Engineering:**
  - **Structure of Materials**
  - **Properties of Materials**
  - **Processing of Materials**
  - **Performance of Materials**

MATERIALS SCIENCE AND ENGINEERING



MATERIALS SCIENCE AND ENGINEERING



Types of Materials

- Materials can be divided into the following categories
  - Crystalline
  - Amorphous

CLASSIFICATION OF MATERIALS

Crystalline Materials

- These are materials containing one or many crystals. In each crystal, atoms or ions show a long range periodic arrangement.
- All metals and alloys are crystalline materials.
- These include iron, steel, copper, brass, bronze, aluminum, duralumin , uranium, thorium etc.

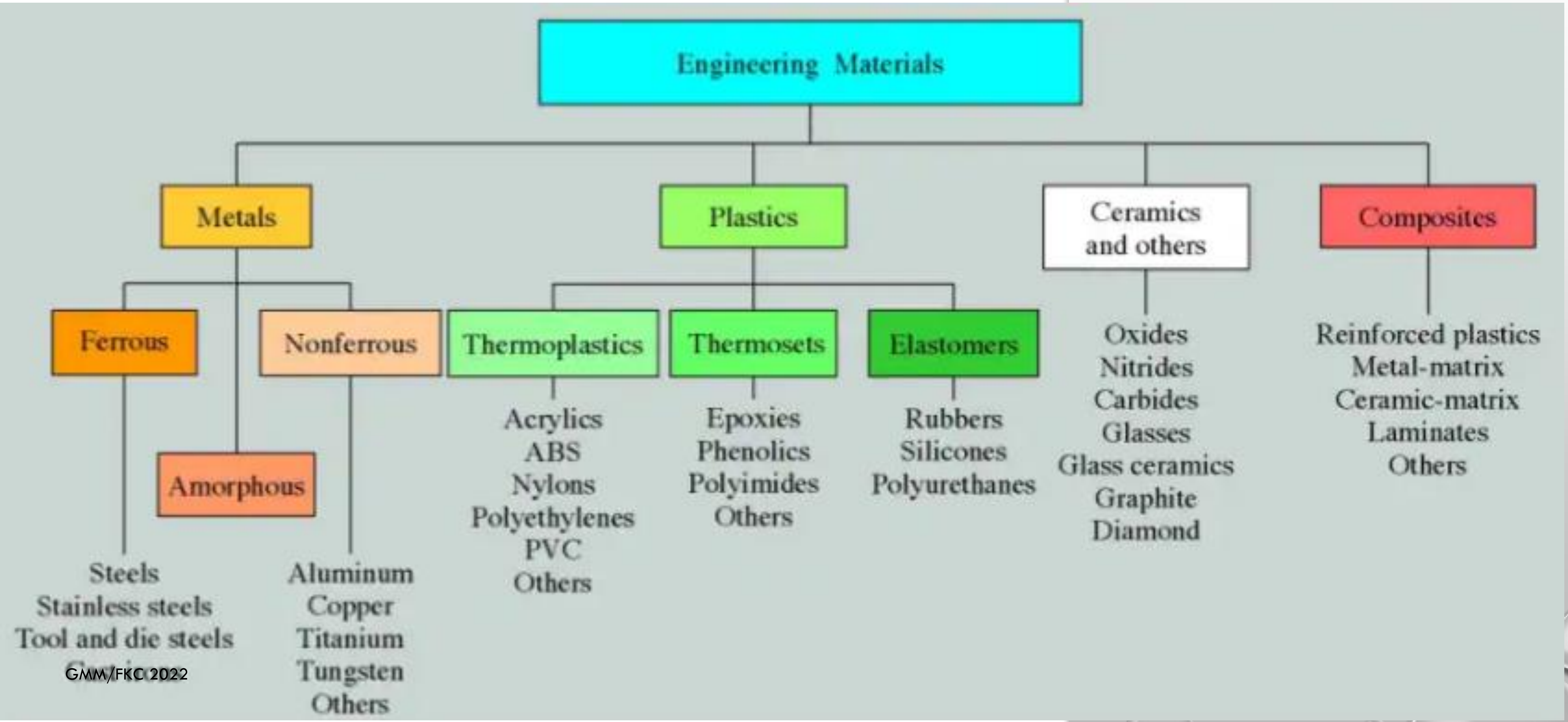
Amorphous Material

- The term amorphous refers to materials that do not have regular, periodic arrangement of atoms
- Glass is an amorphous material

CLASSIFICATION OF MATERIALS

Another useful classification of materials is
- Metals
- Ceramics
- Polymers
- Composites

CLASSIFICATION OF MATERIALS



SELECTION OF MATERIALS

- It is obvious that the choices of materials for various applications are numerous. In fact, more than 50,000 materials available to the engineer in design

- Choice not easy from this vast menu which material best suits the purpose.

- Therefore, systematic material selection based on the required properties and other related factors is needed

CONSEQUENCES OF INCORRECT MATERIALS SELECTION

- Mistakes can cause disasters.
  - During World War II, one class of welded merchant ships suffered heavy losses, by breaking in half at sea: low ***fracture toughness*** of the steel welds.
  - Aircraft lost due to use of materials with lower ***fatigue strength***
  - Bridges collapse due to resonance with matching soldiers.
  - Appliances made of plastic: usually fail because of low ***modulus (of Elasticity)*** of the polymer.

CLASSES OF PROPERTIES OF MATERIALS

- These bulk properties of materials that will be considered are listed in Table 1 on the following slide, along with other common classes of properties that the designer must consider when choosing a material.

- Many properties will be unfamiliar and will be introduced through examples

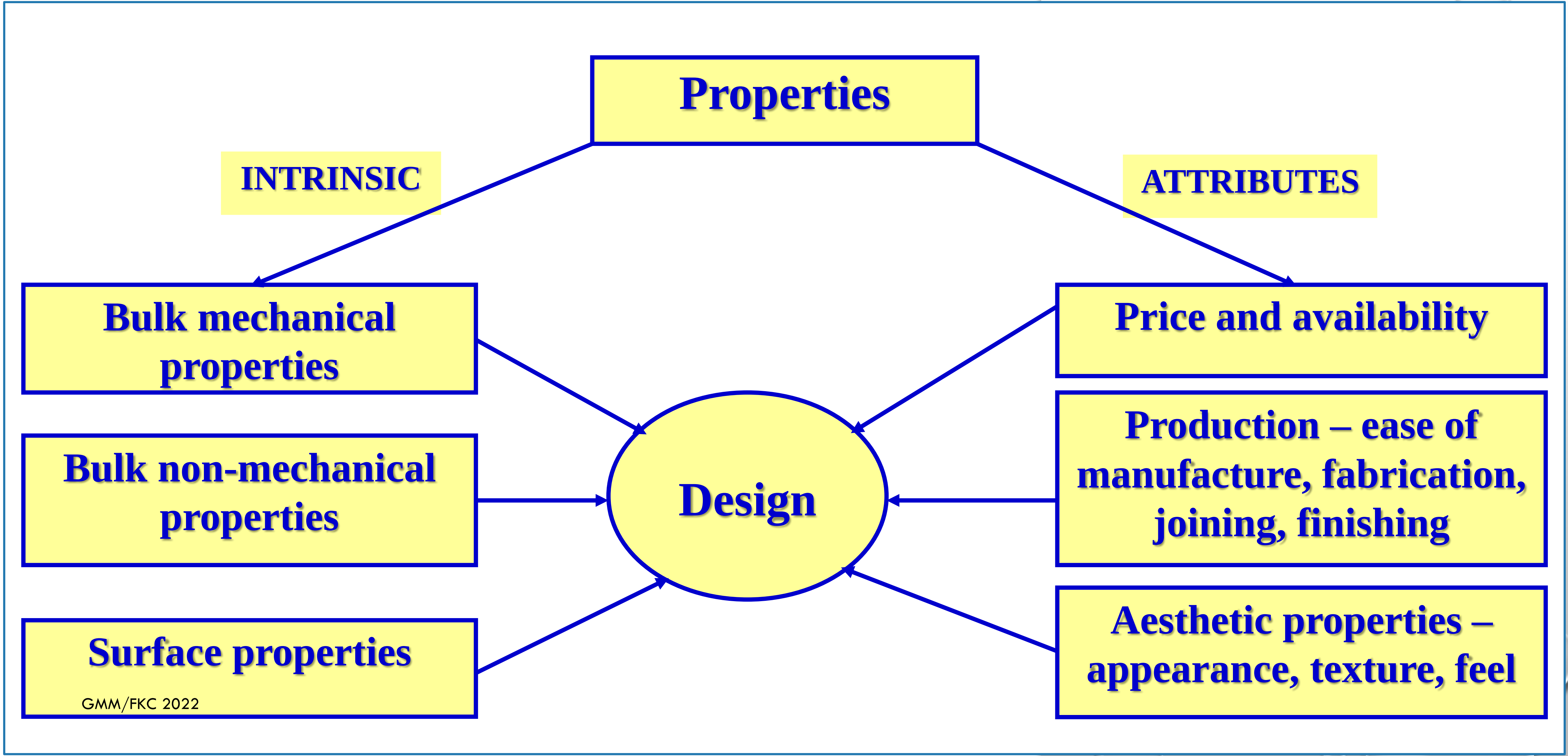
CLASSES OF PROPERTIES OF MATERIALS

ECONOMC	GENERAL PHYSICAL	MECHANICAL	THERMAL	ELECTRICAL
• Price • Availability • Recyclability	• Density	• Modulus • Yield strength • Tensile strength • Hardness • Fracture toughness • Fatigue strength • Creep strength • Damping	• Thermal conductivity • Specific heat • Thermal expansion coefficient	• Conductivity • Resistivity

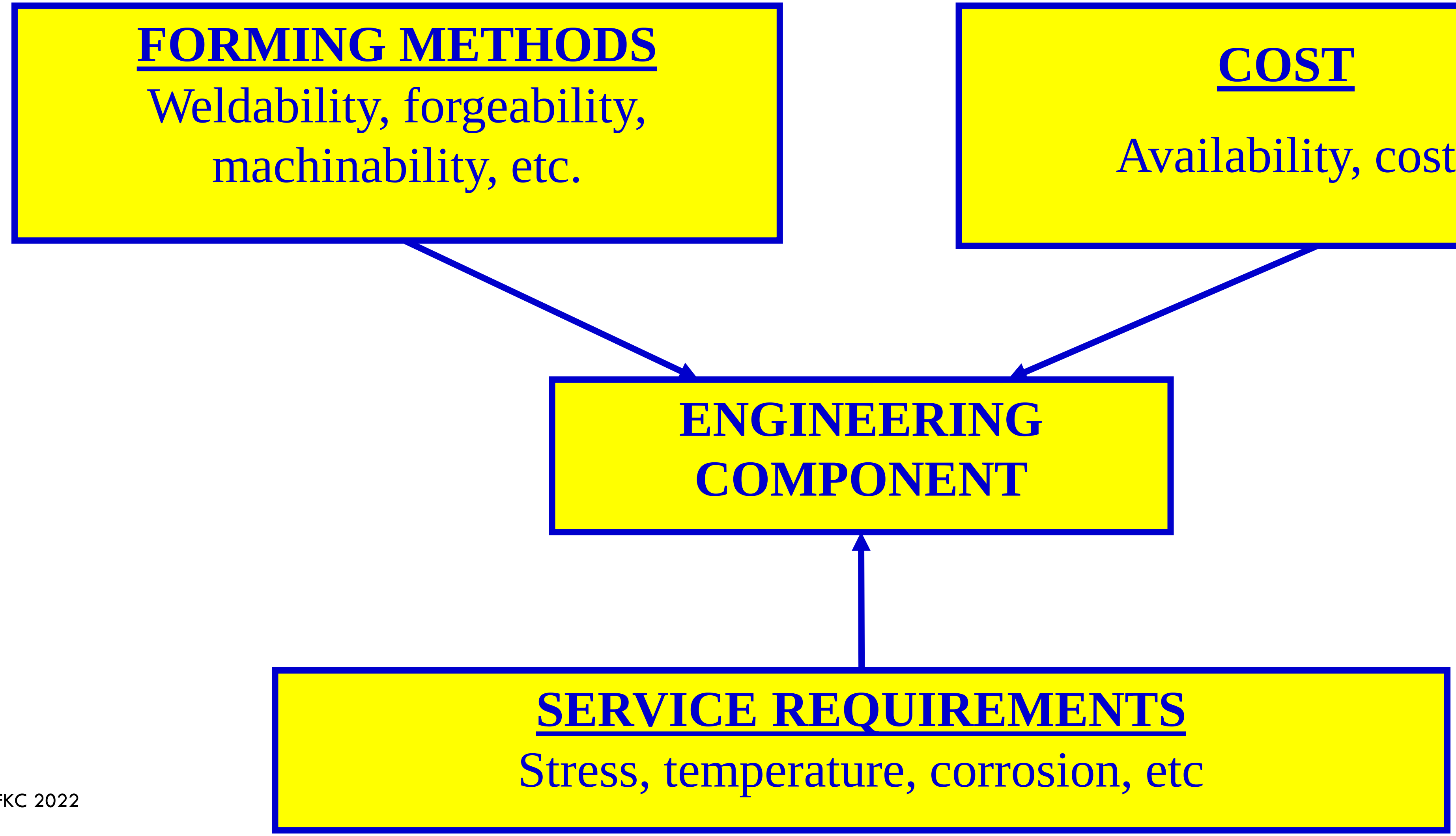
CLASSES OF PROPERTIES OF MATERIALS CONT'D

MAGNETIC	ENVIRONMENTAL	PRODUCTION	AESTHETIC/ ERGONOMIC
• Dielectric constant • Magnetic permeability	• Oxidation Interaction • Corrosion • Wear	• Ease of manufacture • Joining • Finishing	• Colour • Texture • Feel

EFFECTS OF MATERIAL PROPERTIES ON DESIGN



MATERIALS SELECTION CRITERIA



EXAMPLES OF HOW DESIGNERS SELECT MATERIALS

The following examples of how designers select materials will be discussed:

1. Plastic-handheld screwdriver
2. The turbofan blades
3. The spark plug of an internal combustion engine

1. Plastic-handheld screwdriver

Shaft and blade - ***high-carbon steel*** - a metal.

- ***modulus*** is high.
- ***modulus = resistance to elastic deflection or bending.***
- Shaft needs high ***yield strength*** to resist bending & twisting
- Blade needs high ***hardness***, to resist damage
- The material of the shaft and blade must have high ***fracture toughness*** so that it does not break easily.

The handle of the screwdriver - ***polymer*** or ***plastic***, (polymethylmethacrylate (PMMA), plexiglass or perspex).

- Larger section than shaft – so twisting $\Rightarrow$ less important.
- For soft ***rubber*** (another polymer) - modulus is very low, but a thin skin of rubber might be useful because its ***friction coefficient*** is high, for easy grip.
- ***Wood*** – still important but being replaced by PMMA for ***ease of fabrication.***
- Aesthetic reasons: ***appearance*** and ***feel*** or ***texture***, are right; ***density*** low, so screwdriver can be light.
- ***PMMA*** = cheap thus product can be of reasonable ***price***.

- ***Wood*** – still important but being replaced by PMMA for ***ease of fabrication***.

- Aesthetic reasons: ***appearance*** and ***feel*** or ***texture***, are right; ***density*** low, so screwdriver can be light.

- ***PMMA*** = cheap thus product can be of reasonable ***price***.

2. The turbofan blades

- Air is propelled past (and into) the engine to provide aerodynamic thrust.
- The air is further compressed by the compressor blades, and is then mixed with fuel and burnt in the combustion chamber.
- Expanding gases drive the turbine blades, to provide power to the turbofan and the compressor blades, and
- Finally pass out of the rear of engine, adding to the thrust.

Made from a ***titanium alloy***, a metal.

- Good ***modulus***, ***yield strength***, ***fracture toughness*** and ***light***.
- Resists ***fatigue*** (failure due rapidly fluctuating or reversing loads), ***surface wear*** (striking everything from water droplets to large birds) and ***corrosion*** (important at seaside takeoffs).
- ***Density*** $\Rightarrow$ very important - the heavier the engine, the less the payload.

- To reduce weight further, ***composite blades*** (made of ***carbon-fibre reinforced polymers – CFRP***) used. $\rho_{\mathbf{CFRP}}$ **< 0.5**$\rho_{\mathbf{Titanium}}$

- $\rho_{\mathbf{Titanium}}$ **=** 4.5 kg/m^3

- ***Cladding*** with metallic leading edges used to improve ***toughness***.

- **<u>The turbine blades</u>** (in the hottest part of the engine, e.g. the first row of blades, the 'HP1' blades) run at metal temperatures of about 950^{o}C,

- They require high resistance to ***creep***.

- They also require high resistance to ***oxidation***.

- Nickel-based alloys used for this application.

3. The spark plug of an internal combustion engine

Spark electrodes must resist ***thermal fatigue*** (rapidly fluctuating temps), ***wear*** (spark erosion) and ***oxidation and corrosion*** from hot upper-cylinder gases containing compounds of S, and Pb (from anti-knock additives)

- ***Tungsten alloys*** used for the electrodes

Insulation around the central electrode is non-metallic

- ***Alumina*** (a ceramic) is used.
- It has high ***electrical insulation, good thermal fatigue resistance*** and ***resistance to corrosion and oxidation*** (it is an oxide already).

END OF LECTURE 1