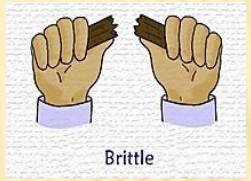
ME 215

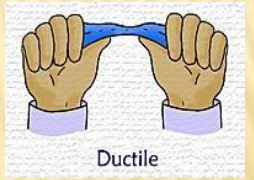
Chapter I

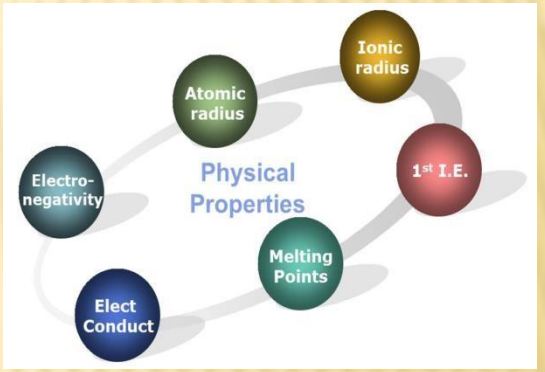
Introduction

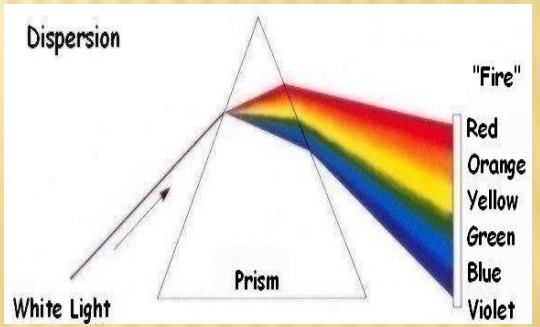
What is the meaning of?

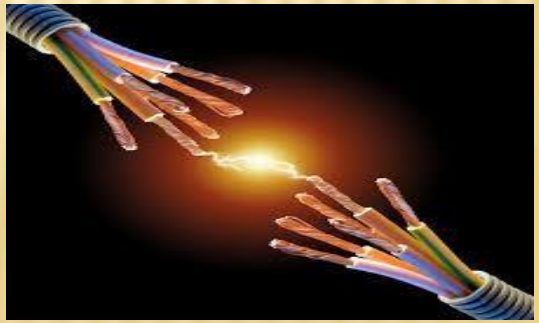
- Material Science
- Materials Engineering
- Mechanical Properties ← الخواص الميكانيكية
  سلوك المادة تحت تأثير الأحمال
- Physical Properties → خواص فيزيائية
- Thermal properties → خواص حرارية
- Electrical Properties → خواص كهربية
- Magnetic Properties → خواص مغناطيسية
- Optical Properties → خواص بصرية

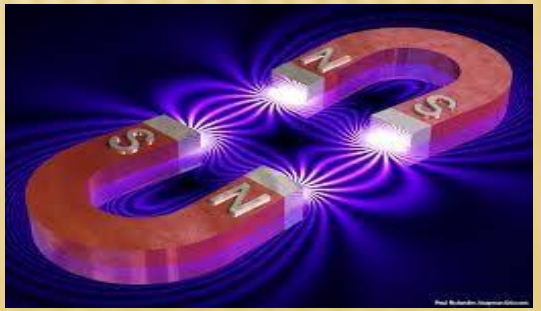


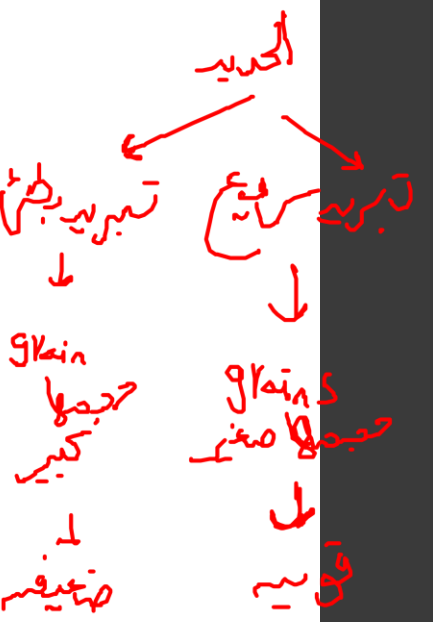












الفرق بين ال Material Science و ال Material Engineering

Material Science:

Studying the relationships between the structure and the properties of the material

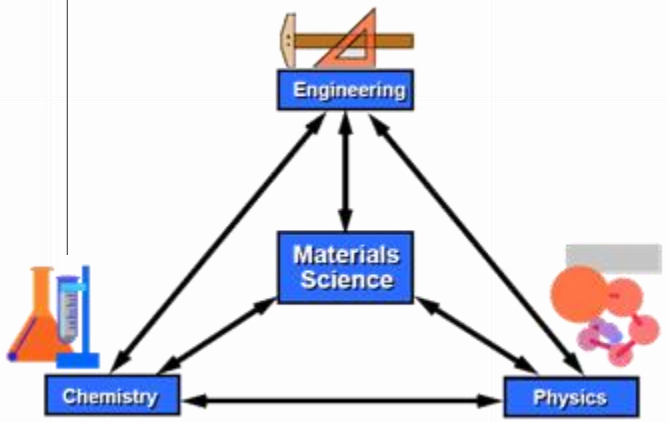
يدرس العلاقة بين التركيب و الخصائص للمادة.

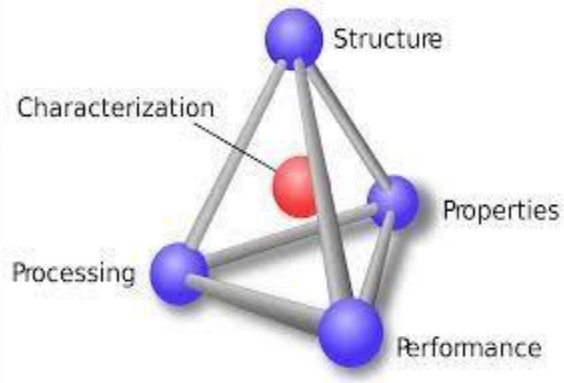
Materials Engineering:

designing the structure of materials based on the original structure and properties to produce a predetermined properties

تصميم التركيب اللازم للمادة للحصول على خواص محددة

Materials Science & Engineering





In materials science, a comprehensive understanding is gained by linking processing techniques to material structure, which then dictates the material's properties and ultimately its performance, requiring careful characterization to optimize the entire design process

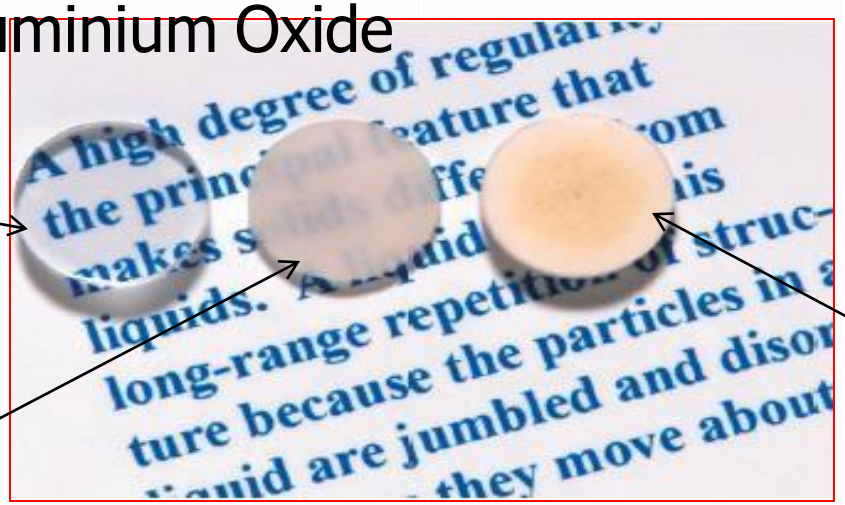
Processing
↓
Structure
↓
Properties
↓
Performance

Aluminium Oxide

Single Crystal
(no porosity)

Porosity refers to the void or empty spaces within the material.

Polycrystal
Low porosity



Polycrystal
High porosity

Highly porous polycrystalline alumina will appear opaque or translucent because light is absorbed or reflected by the internal pore structure, while a single-crystal, non-porous form of alumina is transparent.

What are the Materials?

- **Materials may be defined as substance of which something is composed or made.**
- **We obtain materials from earth crust and atmosphere.**
- **Historically, early civilizations have been designated by the level of their materials development;**

  (Stone Age, Bronze Age, Iron Age)

- **Examples :-**
  - **Silicon and Iron constitute 27.72 and 5.00 percentage of weight of earths crust respectively.**
  - **Nitrogen and Oxygen constitute 78.08 and 20.95 percentage of dry air by volume respectively.**

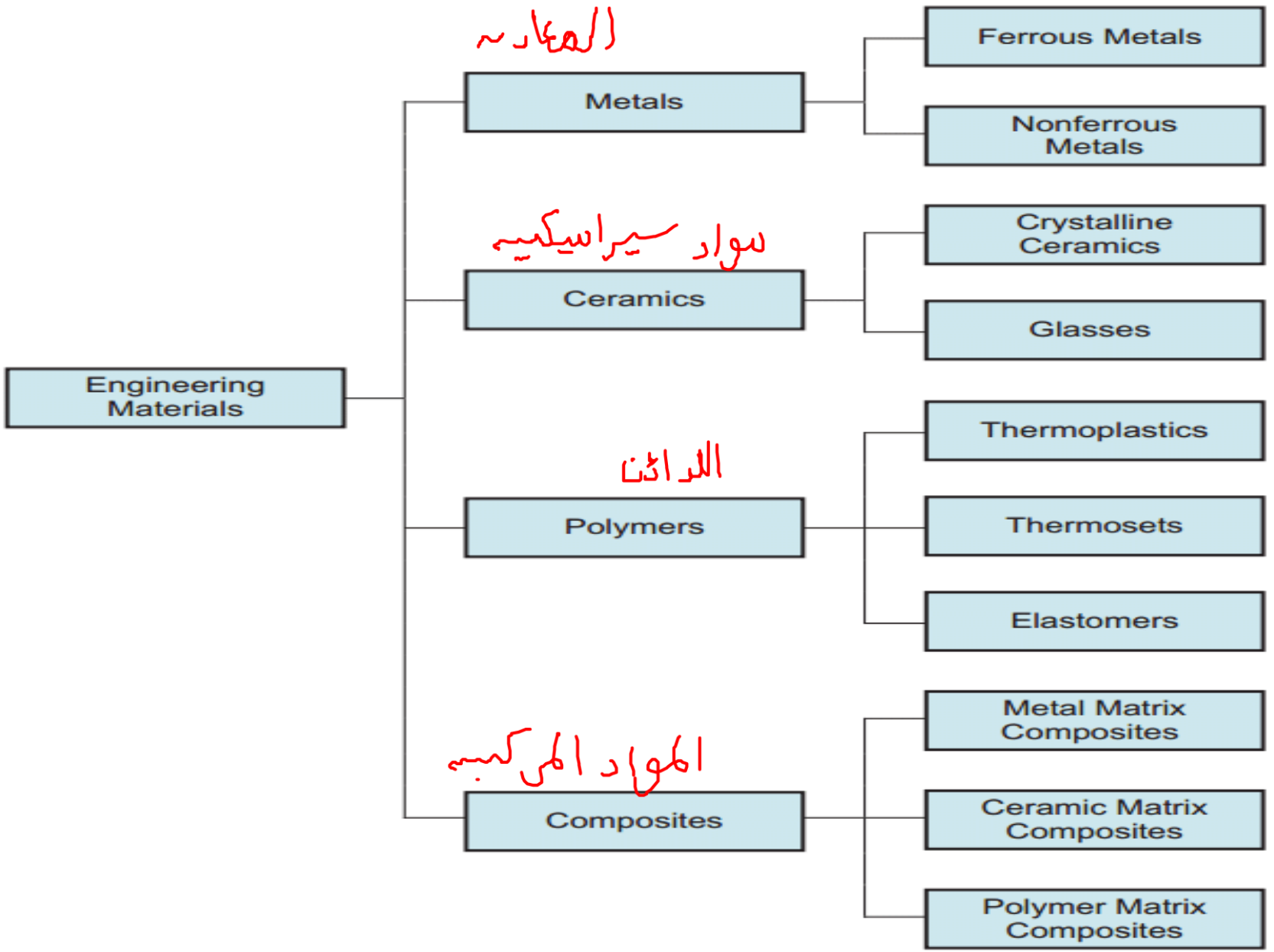
Why the Study of Materials is Important?

- Production and processing of materials constitute a large part of our economy.

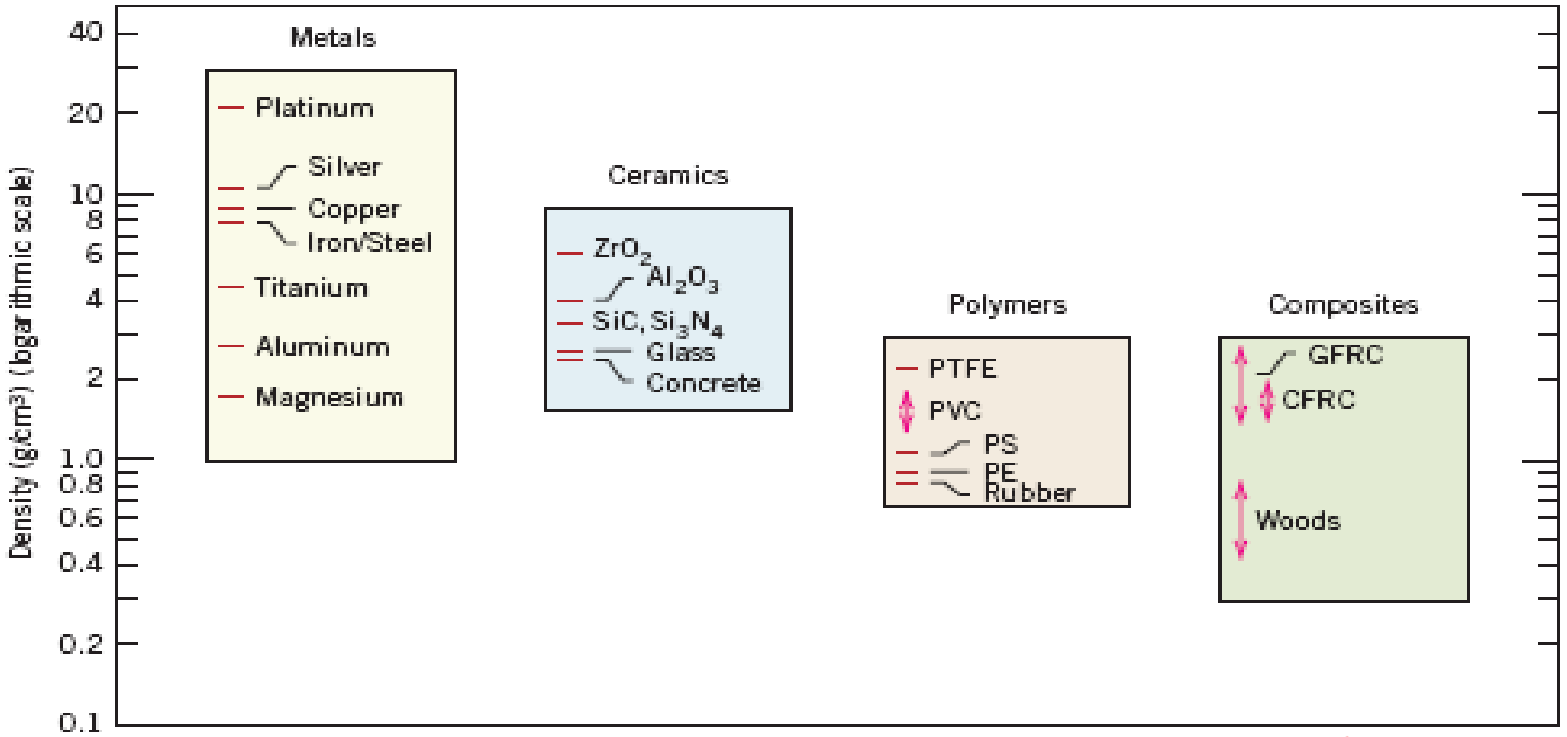
- **Engineers choose materials to suite design. New materials might be needed for some new applications.**

- Modification of properties might be needed for some applications.

Classification of Engineering Materials



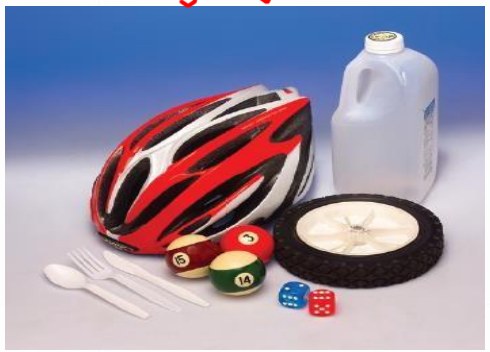
Classification of Engineering Materials

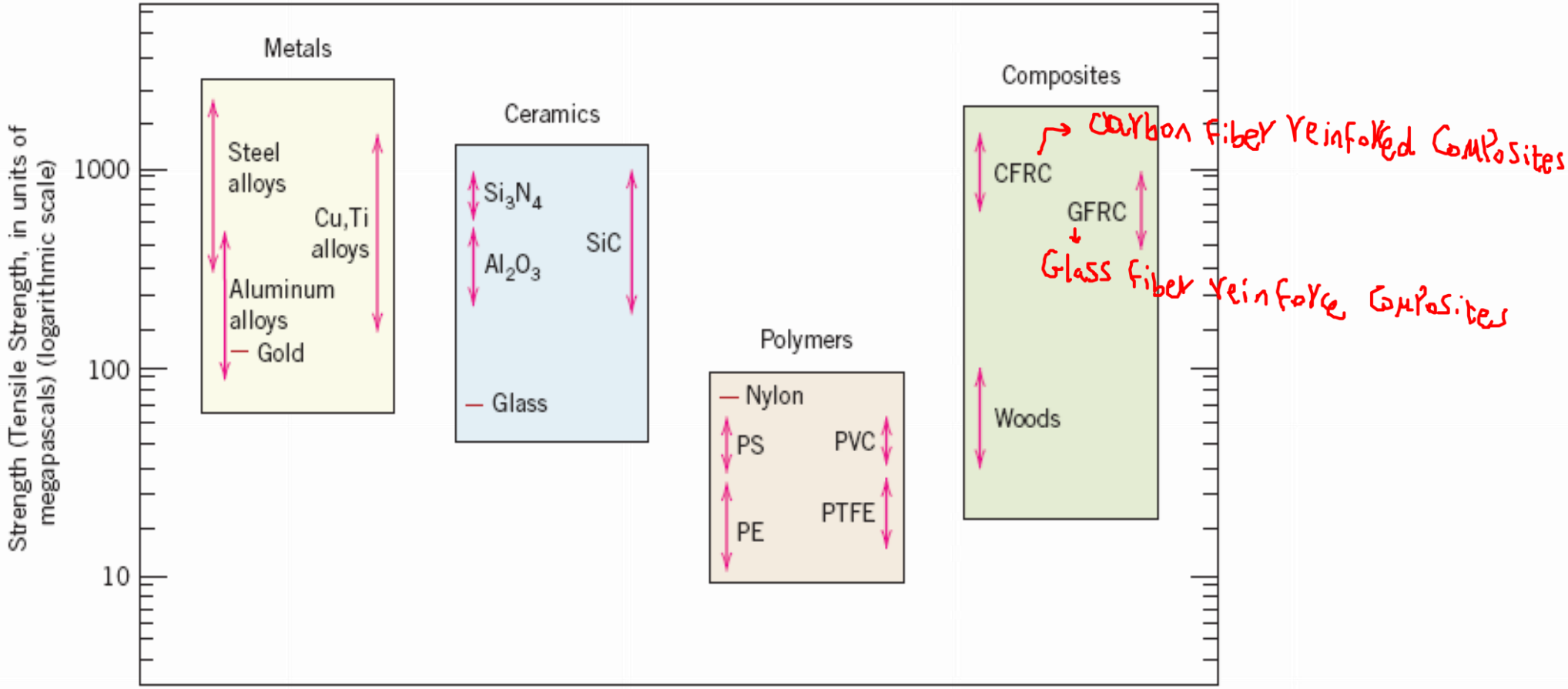


Metals

Ceramics

Polymers





Bar-chart of room temperature strength(i.e., tensile strength) values for various metals, ceramics, polymers, and composite materials.

METALS

Advantage of using metals

- High Stiffness and strength
- Toughness
- Good electrical conductivity
- Good thermal conductivity
- (Low cost)
- (Availability)

Characterization:

- Atoms arranged in a regular repeating manner.
- Relatively High Strength.
- High Density.
- Ductile.
- Excellent conductors of Electricity and Heat.
- Opaque to visible light.
- Shiny (glossy) appearance.

APPLICATIONS OF METALS

- Electrical wiring
- Buildings, Structures, Bridges etc.
- Automobiles: body, chassis, engine block, springs, etc.
- Air planes: engines, fuselage (airplane body), landing gears, etc.
- Trains: rails, engines, body, wheels
- Machines
- Machine tools: drills, hammers, saw blades, nuts, bolts, etc.
- Industrial Plant components, structures
- Magnets

Metals

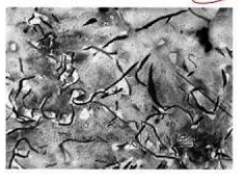
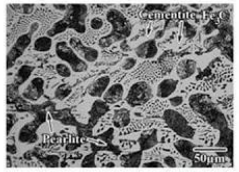
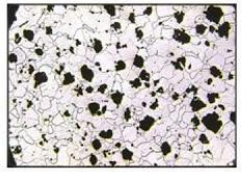
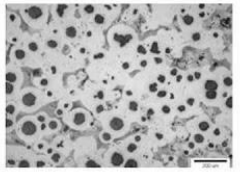
- Ferrous (حديدية)
  - Steel (حديد صلب) — $0,02\% < \%C < 2,11\%$
    - Plain Carbon Steel (حديد + كربون)
      - Low Carbon — $\%C < 0,3\%$
      - Medium Carbon — $0,3\% < C\% < 0,6\%$
      - High Carbon — $0,6\% < C\% < 0,95\%$
    - alloy steel (حديد + كربون + عناصر أخرى)
      - Low — less than 5% of alloying element
      - High — More than 5% of alloying elements → Stainless Steel
        - **Austenitic (18% Cr, 8%Ni) (with high corrosion resistance)**
        - **Ferritic (15-20% Cr, low carbon and no nickel) (moderate strength and corrosion resistance)**
        - **Martensitic (18% Cr, high carbon) (highly strong and suitable for applications requiring hardness and wear resistance)**
        - **Duplex – a mixture of austenite and ferrite.**
  - Cast Iron (حديد زهر) — $2\% < \%C < 4\%$
- Non-Ferrous (غير حديدية)

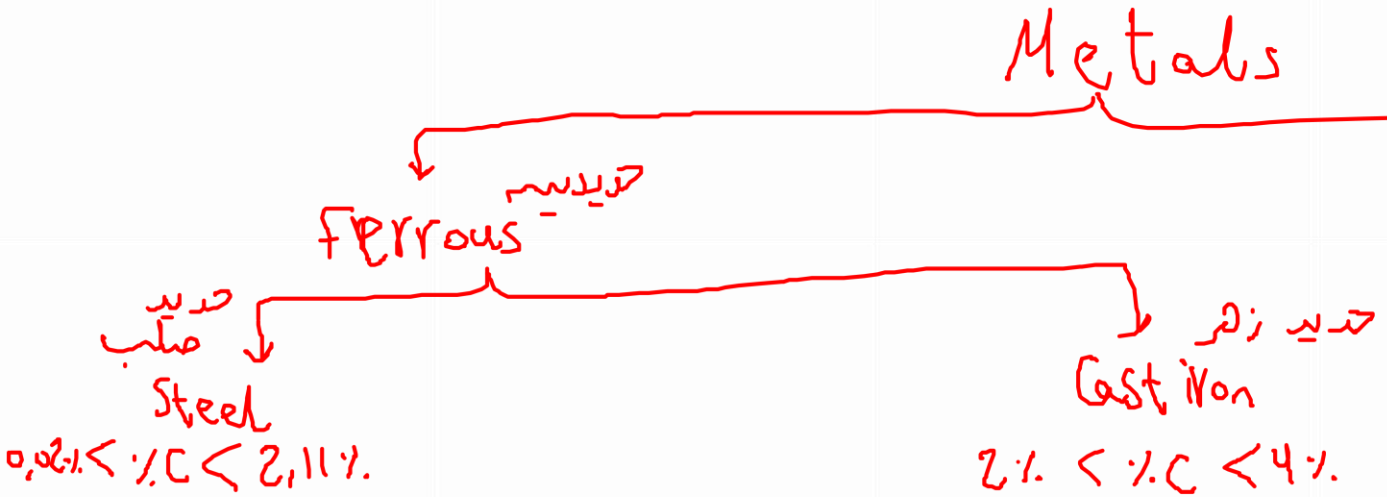
Metals

- Ferrous (حديدية)
  - Steel (حديد صلب) — $0.2\% < \%C < 2.11\%$
  - Cast Iron (حديد زهر) — $2\% < \%C < 4\%$
- Non-Ferrous (غير حديدية)

Cast Iron

طبقاً لصورة تواجد الكربون داخل الحديد

Gray Cast Iron	White Cast Iron	Malleable Cast iron	Ductile Cast iron
			
يتواجد الكربون في صورة تشكل جرافيتيه	يتواجد الكربون في صورة مركب Fe_3C	عالجت حراريه للـ White C.I لتحلل الـ Fe_3C	في صورة Nodules
Gray White flakes			Gray white



Al and its alloys - lighter, thermal conductor

Mg and its alloys – the lightest metal

Cu and its alloys – electric conductor

Ni and its alloys -

Ti and its alloys -

Zn and its alloys – low melting point

Lead and Tin – lower low melting points

Refractory metals

Precious metals

Precious metals

Gold – the second heaviest metal.

Platinum – the heaviest metal.

Silver – the highest electric conductivity.

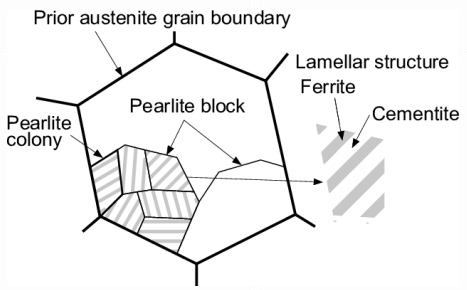
Types of metals

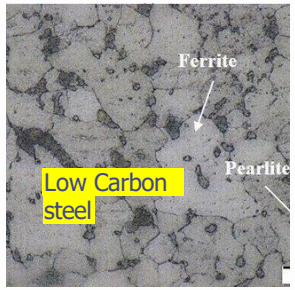
Ferrous Materials

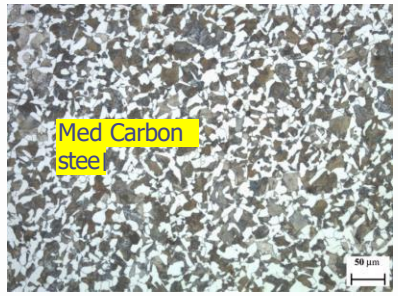
Steels (Iron Fe and carbon C)(0.02-2.11% of carbon): Plain carbon steels: Low Carbon steel (less than 0.3 carbon) Med Carbon steel (0.3 to 0.6) High Carbon steel (0.6 to 0.95)

Cementite (Fe_3C), or iron carbide, is a hard, brittle chemical compound of iron and carbon that forms in iron-carbon alloys, enhancing their strength

Ferrite is a soft, ductile, and body-centered cubic crystalline phase of iron that forms the major constituent of the alloy. It contains only a very small amount of dissolved carbon, making it similar in properties to pure iron.







Low alloy steels (Contains less than 5% of alloying elements like :chromium, nickel, molybdenum, and vanadium.), high alloy steels (Contains less than 5% of alloying elements)

Stainless steels

- **Austenitic (18% Cr, 8%Ni) (with high corrosion resistance)**
- **Ferritic (15-20% Cr, low carbon and no nickel) (moderate strength and corrosion resistance)**
- **Martensitic (18% Cr, high carbon) (highly strong and suitable for applications requiring hardness and wear resistance)**
- **Duplex – a mixture of austenite and ferrite.**

Chemical Composition (%)		Austenitic 316L Stainless Steel
Carbon	C	0.020
Nickel	Ni	11.21
Chromium	Cr	17.38
Manganese	Mn	1.860
Phosphorus	P	0.027
Sulphur	S	0.0054
Silicon	Si	0.510
Molybdenum	Mo	2.360
Nitrogen	N	0.038

Chemical composition of AISI 4140.

Element	C	Si	Mn	Cr	S	P	Mo	Fe
%	0.380	0.231	0.932	0.901	0.005	0.004	0.216	Rest

Cast Iron (Cast iron is broadly defined as an iron-carbon alloy with a carbon content typically above of 2.0% to 4.0%)

Cast irons are classified into types like Gray, White, Ductile, and Malleable based on the form the carbon takes (graphite flakes, iron carbide, graphite spheres, or graphite temper).

This structural difference in how the carbon is present determines the material's unique properties and applications.

Gray Cast Iron: Gray cast iron's structure consists of flake graphite (Graphite's composition is primarily carbon (C)) dispersed within a metal matrix of ferrite and/or pearlite Contains carbon in the form of graphite flakes making it relatively soft, machinable, and good at damping vibrations.

White Cast Iron:

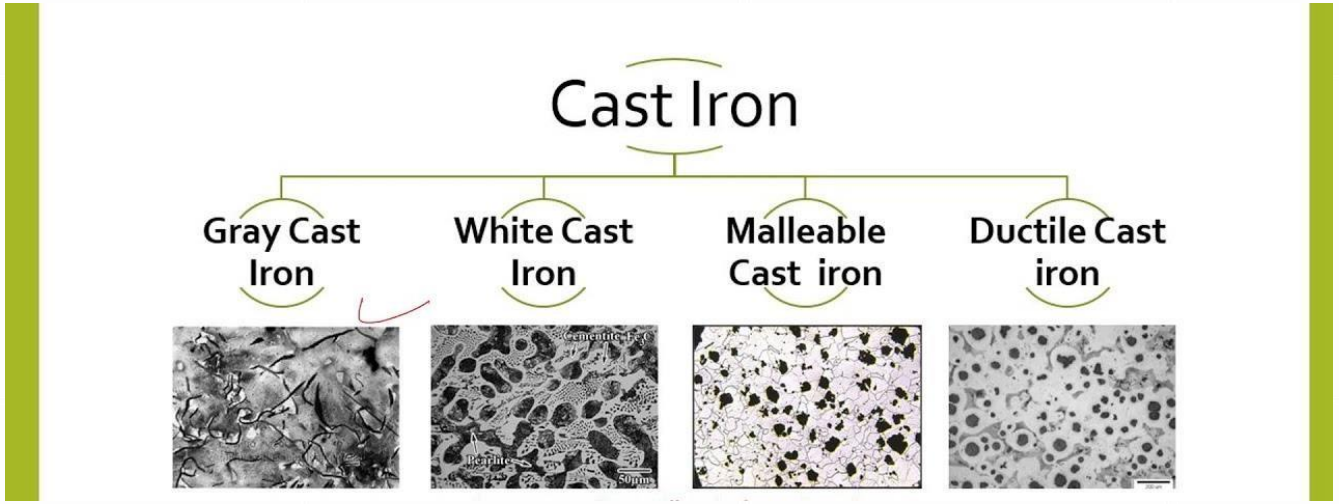
The structure consists primarily of hard, brittle cementite (iron carbide, Fe3C), which forms when carbon is rapidly cooled from the melt, along with phases like pearlite making it extremely hard, brittle, and not readily weldable.

Ductile Cast Iron (Nodular/Spheroidal Graphite):

Features carbon as spherical graphite nodules, providing ductility and malleability, which allows it to be used in more demanding structural applications.

Malleable Cast Iron:

Produced by annealing white cast iron to convert the iron carbide (Fe3C) into graphite temper (decomposed Fe3C), resulting in a more ductile and shock-resistant material.



Nonferrous Metals

- Al and its alloys - lighter, thermal conductor
- Mg and its alloys – the lightest metal
- Cu and its alloys – electric conductor
- Ni and its alloys -
- Ti and its alloys -
- Zn and its alloys – low melting point
- Lead and Tin – lower low melting points
- Refractory metals
- Precious metals

Differences between resilience and toughness

Resilience	Toughness
Resilience is defined as the ability of the solid material to absorb energy when it is elastically deformed.	Toughness is defined as the ability of the solid material to absorb energy until fracture occurs.
Modulus of resilience is the indication of resilience property of solid material. By definition, modulus of resilience is the energy, per unit volume, required to deform a particular solid material up to its elastic limit under tensile testing.	Modulus of toughness is the indication of toughness property of solid material. By definition, modulus of toughness is the energy, per unit volume, required for breaking a particular solid material under tensile testing.
Modulus of resilience is the area below engineering stress-strain curve up to elastic point.	Modulus of toughness is the total area below engineering stress-strain curve.
Value of modulus of resilience is smaller.	Value of modulus of toughness is much larger than modulus of resilience.
Resilience is important property to consider when high elastic deformation is desired, such as in springs.	Toughness is important consideration for metal forming processes (forging, bending, sheet metal operations, etc.).

Precious metals

- Gold – the second heaviest metal.
- Platinum – the heaviest metal.
- Silver – the highest electric conductivity.

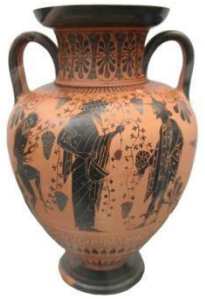
Ceramics

عبارة عن مادة معدنية ترتبط مع مادة غير معدنية برابطة أيونية لها بعض خصائص الرابطة التساهمية

- تحتفظ بخواصها في درجات الحرارة العالية.
- مقاومة عالية لظروف البيئة المحيطة.
- قوية وقصفة ↓ brittle
- رديئة التوصيل للحرارة والكهرباء.

Ceramic materials are compounds of metallic and nonmetallic elements with ionic or covalent bonds, mostly oxides, nitrides, and carbides. They have excellent high temperature properties and high resistance to harsh environments. They are generally hard and brittle, electrically insulative. Ceramic materials can be divided into three main categories:

Traditional Ceramics




Clayware, pottery, porcelain, mosaic, glass, stone, bricks and tiles, sand, earth……

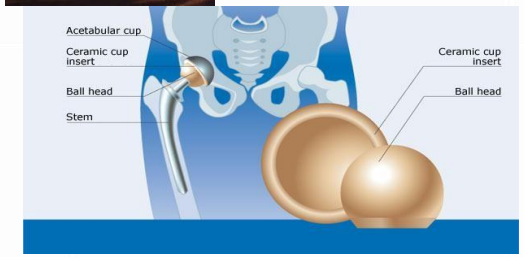
Engineering Ceramics




Cement, concrete, refractories, engineering glasses, ceramic tiles, ceramic coatings …..

Advanced Ceramics





cutting tools, bioceramics, components in capacitors, resistors, insulators, piezoceramics, magnets, superconductors, catalysts, electrolytes, semiconductors

Polymers

مركبات عضوية - تتكون من سلاسل من عناصر أساسها الكربون والهيدروجين -

A compound of long chain molecules containing carbon atoms such as polyethylene (PE), polyvinyl chloride, polystyrene.

Biological polymer – natural rubber - Synthetic polymer

- **Plastic – Thermoplastic (70%) and Thermosetting**
- **Elastomer (E) – rubber**

Positive characterization:

- **Net shaped, attractive properties (except strength), cost effective, less energy required to produce, translucent/transparent, composites**

Negative characterization:

- **Low strength & modulus, low temperature applications, degradation in properties**

Thermoplastic Polymers

Thermosetting Polymers

Elastomers

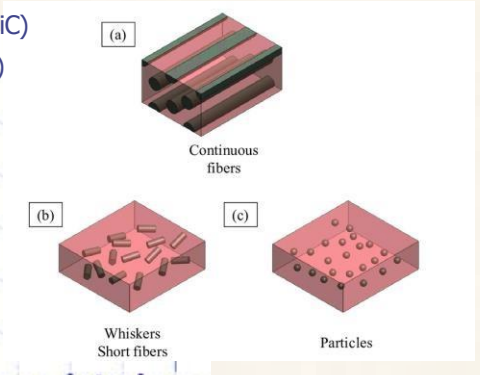
Matrix
الأساس

Reinforcement
مادة التقوية

Composite Materials

خليط غيرمتجانس من مادتين أو أكثر

Fiber: Silicon Carbide (SiC)
Aluminum Oxide (Al_2O_3)
Carbon Fibers…



- **Metal Matrix Composites (MMC)**
  - Mixture of ceramics and metals reinforced by strong, high-stiffness fibers

MMCs consist of a metallic matrix, such as aluminum or titanium, reinforced with ceramic fibers or particle

- **Ceramic Matrix Composites (CMC)**
  - Ceramics such as aluminum oxide and silicon carbide embedded with fibers for improved properties, especially high temperature applications.

In Ceramic Matrix Composites (CMCs), a ceramic is the matrix, which is a continuous phase, and the reinforcement is made of ceramic fibers.

- **Polymer Matrix Composites (PMC)**
  - Thermosets or thermoplastics mixed with fiber reinforcement or powder.

Carbon Fibre Reinforced Plastic

Fibreglass

Advanced Engineering Materials

"Materials of the future"

Semiconductors: computer industry

Biomaterials: Artificial hip replacements

Smart Materials: Shape memory alloys, Piezoelectric ceramics, magnetostrictive materials. Used for actuators, sensors.

Nanoengineered Materials: Catalysts, Carbon nanotubes,

Modern Materials Needs

- The development of more sophisticated and specialized materials, as well as consideration of the environmental impact of material production.
  - Nuclear energy: many problem remain in materials, from fuel to containment structures to facilities to the disposal of radioactive waste.
  - Transportation: facing low operating temperature engine etc.
  - Fuel cell energy: facing low operating temperature for high energy output.
  - Manufacturing process: facing toxic as a product of the process

Try to think: ?

What is the suitable type of material can be used for manufacturing carbonated beverages?!

PET (Polymers) or Aluminum (Metals)

Requirements:

1. **Nontoxic material, unreactive with the beverage, recyclable and light weight**
2. **Relatively strong, drop from a height of several feet**
3. **Inexpensive**
4. **Can be produced in different colours and able to be decorated.**