CHEMISTRY

64th Class, 03-12-2021

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Last class

- Mechanical properties
- Stress – strain curve, various materials

In this class

- Composite materials

Advanced engineering materials

- Mechanical properties of solid – stress-strain relationship
- Tensile strength, Hardness, Fatigue, Impact strength, Creep
- Composite materials - introduction and types (FRC, MMC, CMC) – Applications
- Surface characterisation techniques - XRD and XPS

Mechanical properties

- Sub group of physical properties
- Knowledge of mechanical properties is paramount to finalize the material for an engineering product
- The mechanical properties of a material are those properties that **involve a reaction to an applied load**
- The mechanical properties of a material are not constants and often change as a **function of temperature, rate of loading and other conditions**

Mechanical properties

Common mechanical properties are

- Stress
- Strain
- Strength
- Hardness
- Malleability, Ductility
- Elasticity , Plasticity
- Toughness
- Thermal stability

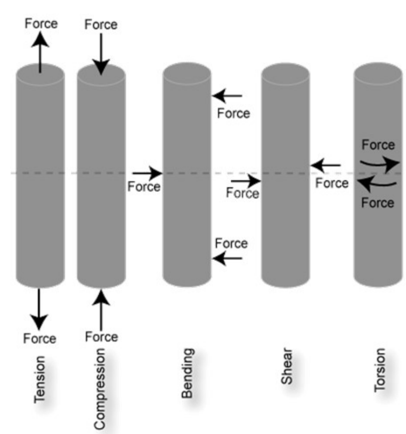
Effect of loading

- Properties of a material that involve a reaction to an applied load
- The application of a force to an object is known as loading
- Can be subjected to many different loading scenarios and a material's performance is dependant on the loading conditions
- Five fundamental loading conditions - tension, compression, bending, shear, and torsion

Effect of loading, conditions

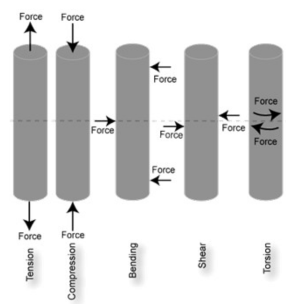
<u>Five fundamental loading conditions</u>

- Tension,
- Compression,
- Bending,
- Shear, and
- Torsion



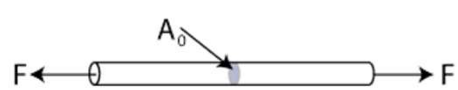
Effect of loading

- Tension - the two sections of material on either side of a plane are pulled apart or elongated
- Compression - reverse of tensile loading (pressing the material together)
- Bending - causes a material to curve and results in compressing the material on one side and stretching it on the other
- Shear - load parallel to a plane which causes the material on one side of the plane to slide across the material on the other side of the plane
- Torsion - causes twisting in a material



Mechanical property, Stress

- Stress is related to the force or load applied to a material
- Used to express the loading in terms of force applied to a certain cross-sectional area of an object (force divided by area on which the force is acting)



$$\text{Stress, } \sigma = \frac{\text{Force}}{\text{Cross-Sectional Area}} = \frac{F}{A_0}$$

units = N/m^2 = Pascal,
Psi = lbs/in^2 (pounds per square inch)

Mechanical property, Strain

- Deformation per unit length, the change in shape (deformation) a substance makes in response to stress
- Strain = ε = change in length divided by original length
- $\varepsilon = (L-L_0)/L_0 = \Delta L/L_0$, L is the final length, L_0 is the original length
- Strain is unit less, reported as : m/m, in/in or %

Mechanical property, Stress & Strain

Two scenarios ?

a) The shelf does not fall down, resists the weight of books, resisting force is stress
b) If the shelf were to change shape (sag in the middle) – amount of change would be strain

Some scenarios

- If the stress is small, the material may only strain a small amount and the material will return to its original size after the stress is released.
- This is called **elastic deformation**, because like elastic it returns to its unstressed state
- If a material is loaded beyond it elastic limit, the material will remain in a deformed condition after the load is removed.
- This is called **plastic deformation**

Hooke's law

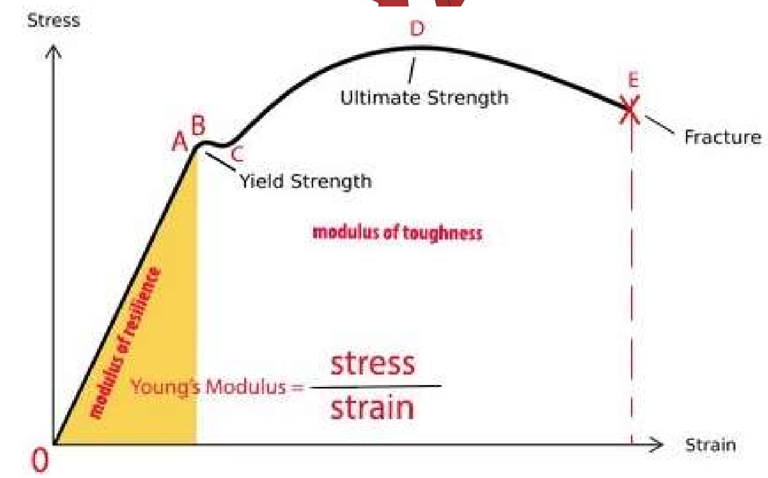
- The proportional relation between the stress and the elastic strain is given by Hooke's law, which can be expressed as

$$\sigma \propto \varepsilon$$

$$\sigma = E\,\varepsilon$$

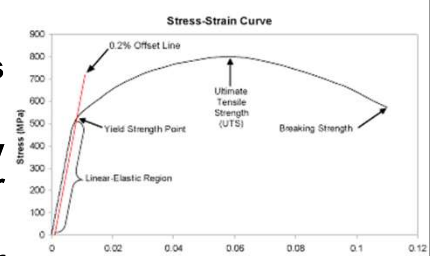
where the constant E is the modulus of elasticity or Young's modulus (stress/strain) = Measure of stiffness.

Stress – strain (SS) ld steel



Stress – strain (SS) curve

- SS curve relates the applied stress to the resulting strain and each material **has its own unique SS curve.**
- SS curve **increases continuously up to fracture**.
- Stress and strain **initially increase with a linear relationship**.
- This is the linear-elastic portion of the curve and it reveals that **no plastic deformation** has occurred. In this region, when the stress is reduced, the material will return to its original shape.



Stress – strain (SS) curve

- At some point, the stress-strain curve **deviates from the straight-line relationship** (as the strain increases faster than the stress).

- From this point on some **permanent deformation** occurs in the specimen and the material is said to react plastically to any further increase in load or stress.

- The material **will not return to its original**, unstressed condition when the load is removed.

- In **brittle materials**, **little or no plastic deformation** occurs and the material fractures near the end of the linear-elastic portion of the curve.

Stress – strain (SS) curve

- The **ultimate tensile strength (UTS)** or, more simply, the tensile strength, is the maximum engineering stress level reached in a tension test.

- The strength of a material is its ability to withstand external forces without breaking.

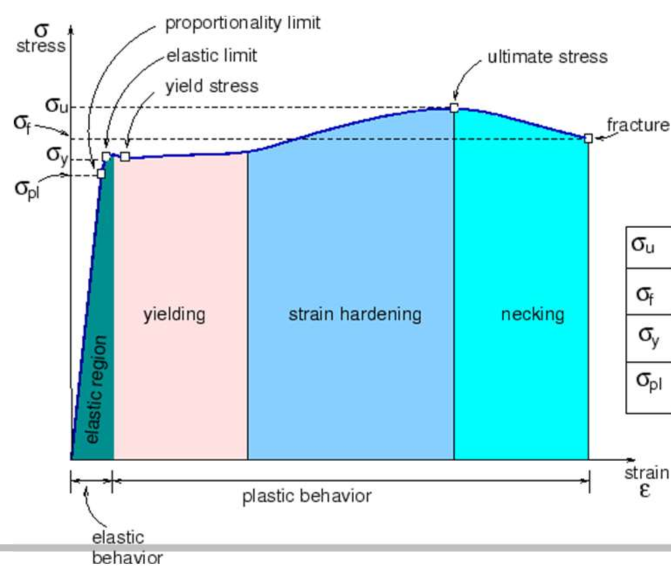
- Breaking point or breaking stress is point where strength of material breaks.

- The stress associates with this point known as breaking strength or rupture strength.

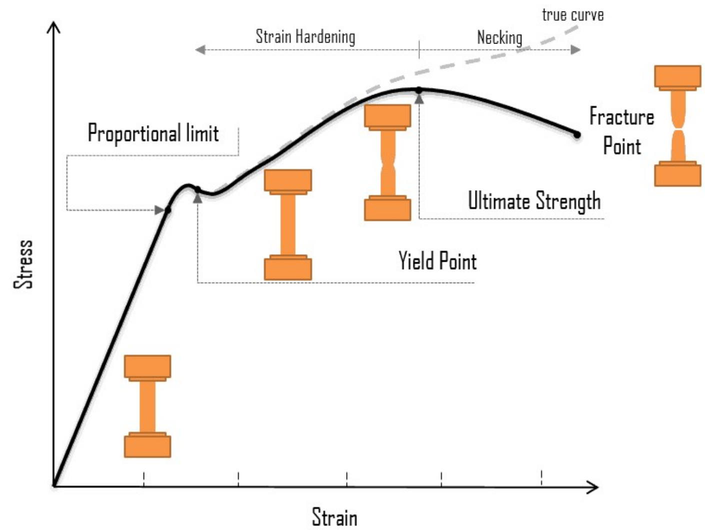
Strength

- Defined as material' ability to withstand an applied force without breaking or bending permanently
- **Tensile strength** is a measurement of the force required to pull something such as rope, wire, or a structural beam to the point where it breaks

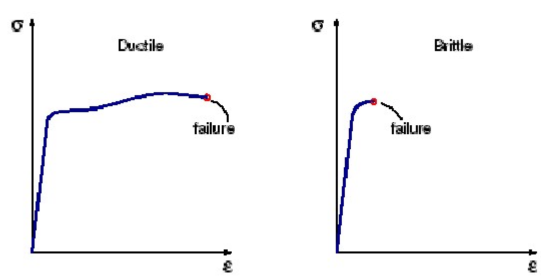
Stress – strain (SS) curve



σ_u	Ultimate stress
σ_f	Fracture stress
σ_y	Yield stress
σ_{pl}	Proportionality limit

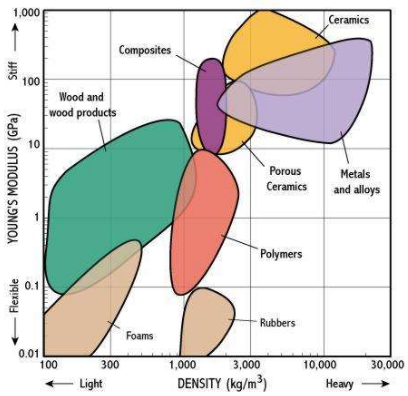


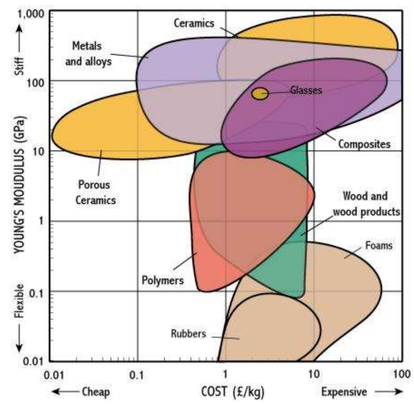
Behaviour of materials



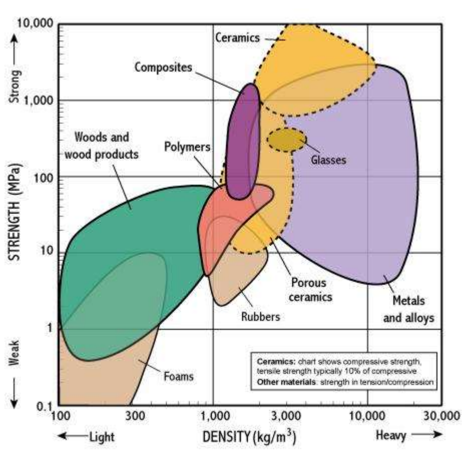
Brittle material vs ductile material

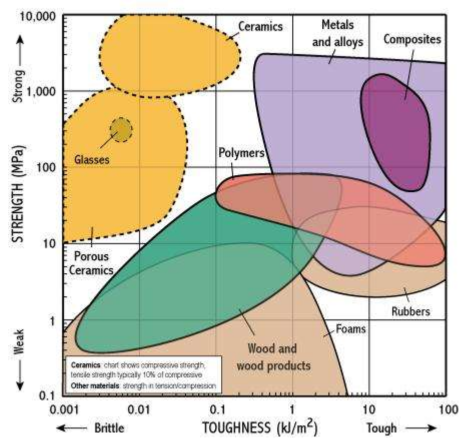
Behaviour of materials



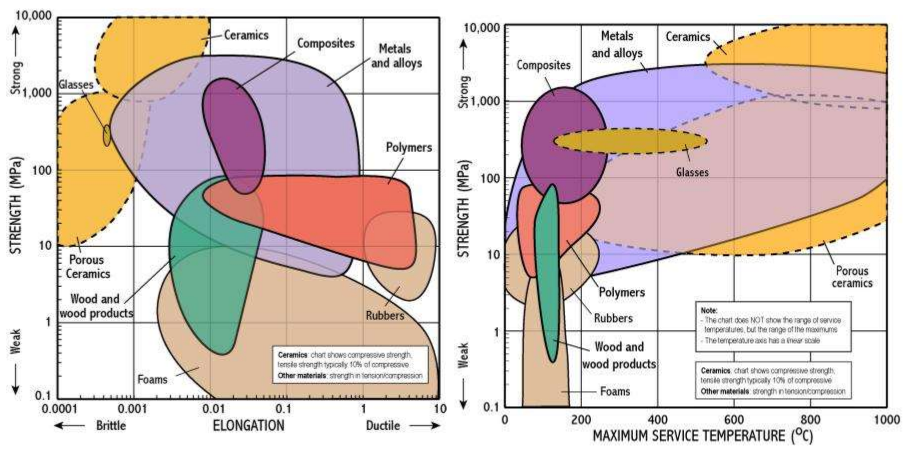


Behaviour of materials





Behaviour of materials



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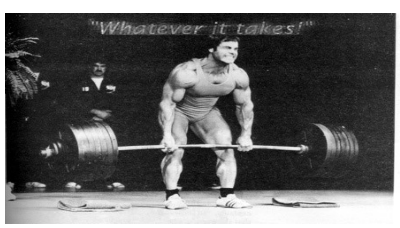
Strength, types



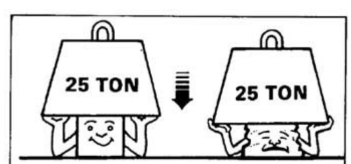


Figure 2-3. Compressive strength.

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Hardness

- The ability of a material to resist abrasive wear or scratching

MOHs hardness is a measure of the relative hardness and resistance to scratching between minerals

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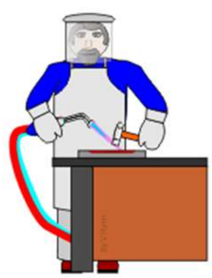
Malleability

- The ability of a material to be reshaped in all directions without cracking



- 'Malleability' - heating a piece of mild steel until it is red hot, then beat it with a hammer to reshape it. At high temperature the steel becomes malleable, it can be reshaped permanently.

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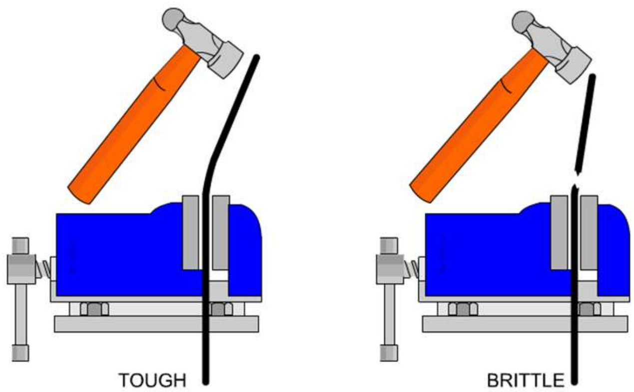
Toughness

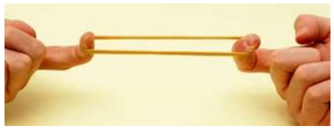
- The ability to withstand sudden shocks or blows without breaking



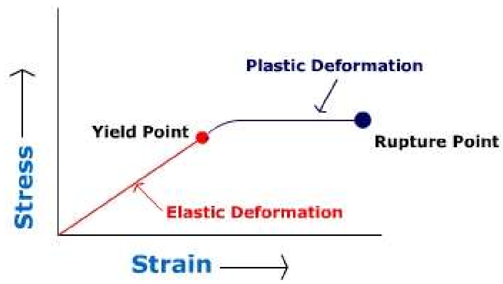
Deformation

- Deformation - Elastic and Plastic deformation
- The elastic deformation is **reversible**. It remains as long as there is a state of stress present. Once we remove the stress, the material comes back to its original shape and position or shape and size.
- Plastic deformation on the other hand is **permanent**, even if you remove the stress applied.

Deformation



Stress- strain curve ?



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Viscoelasticity

- Materials exhibit both viscous and elastic characteristics when undergoing deformation.
- Typical engineering materials have the same response to a force or deformation no matter how fast you apply the force/deformation or how long the force/deformation is present (Ex : spring).
- This is not the case for viscoelastic materials.

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Viscoelasticity

- Viscoelastic materials respond differently depending on how fast they are stretched.
- Remember that displacement (or stretch) is related to strain, so the strain rate defines how fast the material is stretched.
- Therefore, viscoelastic materials are said to be strain rate-dependent. (Example : ....)

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Viscoelasticity

- **Creep:** If you apply a constant force to a viscoelastic material, then the displacement increases over time.
- When this force is released, it takes time for the material to recover to its initial configuration.
- An example of creep is when a bungee cord (a polymer) is used to hang a bike from the ceiling to save floor space. The bike is the constant force, so the bungee cord lengthens over time.

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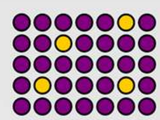
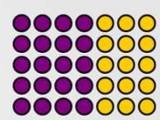
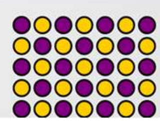
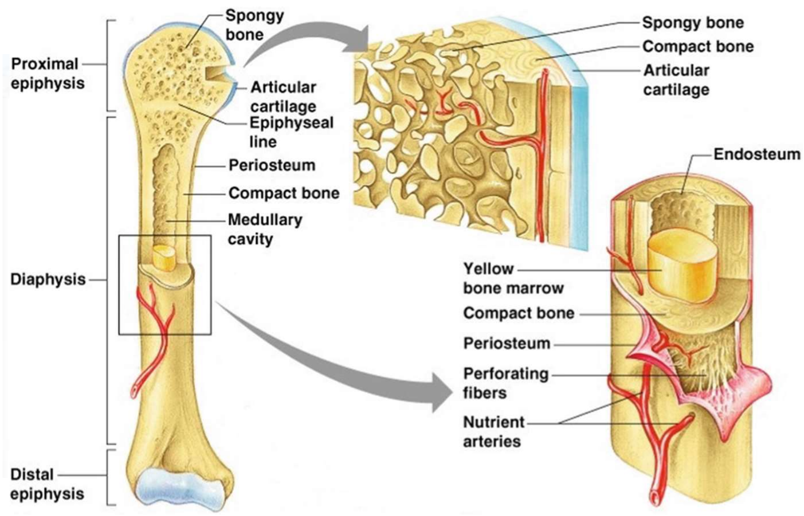
Composite materials

- Combination of **two or more chemically/physically distinct materials** whose physical characteristics/properties are **superior to its constituents** acting independently.
- They have high strength to weight ratio.
- These materials are stronger, lighter when compared to traditional materials but relatively expensive.
- Example - ?
- Diff. b/w alloy ??

Alloy vs Composite

Alloy	combination of **elements** (at least 1 metal) in **solid-solution** with overall **metallic properties**	
Composite	combination of other **materials**, where the **mixed** materials **remain physically distinct**	
Compound	combination of elements with **chemical bonds,** with very different properties from it's base elements	

Natural composites



Composite materials

- Most composites are made of just two materials
- One is the **matrix or binder**. It surrounds and binds together fibres or fragments of the other material, which is called the **reinforcement**
- Within the composite we can easily tell the different materials apart as **they do not dissolve or blend into each other**
- The bone in our body is also a composite. It is made from a hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and flexible material called collagen (which is a protein)

Composites consist of:

Combination of two or more materials = **matrix + fiber (filler):**

Matrix:

- Material component that surrounds the fiber
- Usually **a ductile material with low density**
- **Offers strength**
- Examples include: polymers, metals and ceramics
- Serves to hold the fiber (filler) in a favorable orientation

Fiber or reinforcing material or Filler:

- **Materials that are strong with low densities**
- Examples include glass, carbon or particles

- Composites are designed to display a combination of the best characteristics of each material i.e. **fiberglass acquires strength from glass and flexibility from the polymer**

- Matrix and filler bonded together (adhesive) or mechanically locked together!

Advantages:

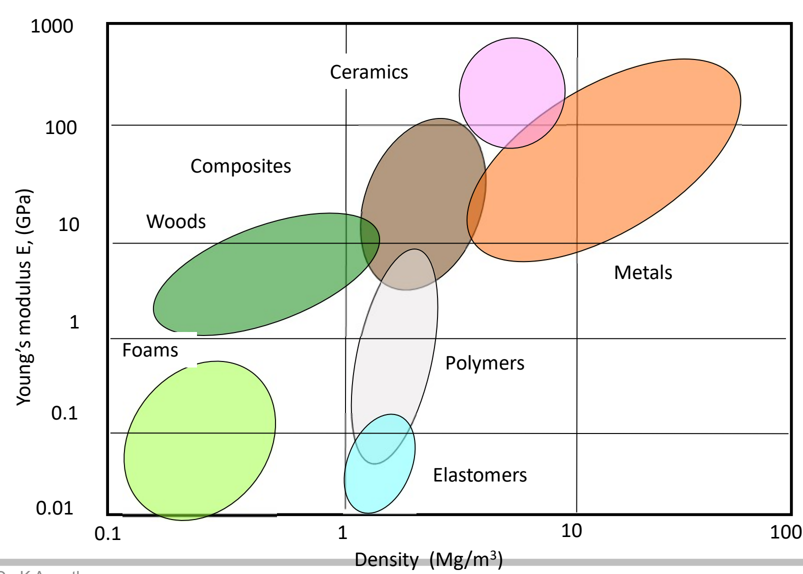
- **High strength to weight ratio** (low density high tensile strength) or high specific strength ratio!
- High **creep resistance**
- High **tensile strength at elevated temperatures**
- **High toughness**
- Generally perform better than steel or aluminum in **applications where cyclic loads** are encountered leading to potential fatigue failure (i.e. helicopter blades).

- Can **with stand impact loads or vibration** – composites can be specially formulated with high toughness and high damping to reduce these load inputs
- Some composites can have much **higher wear resistance** than metals
- **Corrosion resistance**
- Dimensional **changes due to temperature changes can be much less** (Thermal expansion)

Disadvantages (or limitations):

- **Material costs**
- **Fabrication/manufacturing difficulties**
- Repair can be difficult
- Wider range of variability (statistical spread)
- **Operating temperature** can be an issue for polymeric matrix (i.e. 500 F). Less an issue for metal matrix (2,700 F)
- Inspection and testing typically more complex

Young's modulus vs Density Graph



Composite materials

➢ <u>Examples and applications</u>

❑ Reinforced plastics (fibre glass) : composed of glass fibres embedded in a resin matrix

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Composite materials

➢ <u>Examples and applications</u>

❑ Carbon fibre reinforced plastic : lighter and stronger than fibreglass but more expensive

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Composite materials

➢ <u>Examples and applications</u>

❑ Airbus 350

➢ More than 20% of the A350 is made of composite materials, mainly plastic reinforced with carbon fibres.

➢ **Glass-fibre-reinforced aluminium**, a new composite that is 25 % stronger than conventional airframe aluminium but 20 % lighter.

➢ Cost (fuel) effective

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Classification of Composites by Filler Type

❑ Particle-reinforced composites

❑ Fiber-reinforced composites

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Particle Reinforced Composites

- Particles used for reinforcing include:
  - **ceramics and glasses**
  - **metal particles such as aluminum and**
  - **amorphous materials, including polymers and carbon black**
- Particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of the matrix.
- Particle reinforced composites **support higher tensile, compressive and shear stresses**

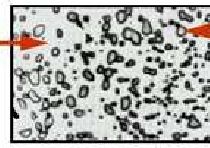
Particle Reinforced Composites

- Particles are also used to produce inexpensive composites
- **Examples**:
  - automobile tyre which has carbon black particles in a matrix of elastomeric polymer
  - spheroidized steel where cementite is transformed into a spherical shape which improves the machinability of the material
  - concrete where the aggregates (sand and gravel) are the particles and cement is the matrix

Particle Reinforced Composites

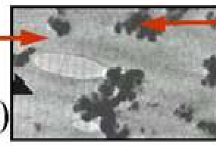
Spheroidized Steel

Matrix:
Ferrite
(α - iron)
Ductile



Particle:
Fe_3C
(cementite)
Brittle

Matrix:
Rubber
(Compliant)



Particle:
Carbon
(Stiffer)

Automobile Tire

Fiber-reinforced Composites

- Composed of **glass or carbon fiber in a plastic resin**
- Resins can be of the form of **thermoset or thermoplastic** materials which each have their own unique advantages and disadvantages
- The glass or carbon fibers are significantly stronger than the plastic matrix but they also tend to be brittle
- A composite construction, therefore, allows one to take advantage of the excellent stiffness and strength properties of glass or carbon by embedding the fibers in a more compliant matrix
- **Carbon fiber is a material consisting of fibers about 5–10 μm in diameter** and composed mostly of carbon atoms

Fiber-reinforced Composites

- Fibers are significantly stronger than bulk materials because: – **They have a far more "perfect" structure**, i.e. **their crystals are aligned along the fiber axis.**
- There are **fewer internal defects, lesser number of dislocations**.
- For this reason fibers of several engineering materials are far more strong than their equivalent bulk material samples.

Thank you all for your attention

Information presented here were collected from various sources – textbooks, articles, manuscripts, internet and newsletters. All the researchers and authors of the above mentioned sources are greatly acknowledged.