Properties of Textile Fibres

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Classification of Fibre Properties

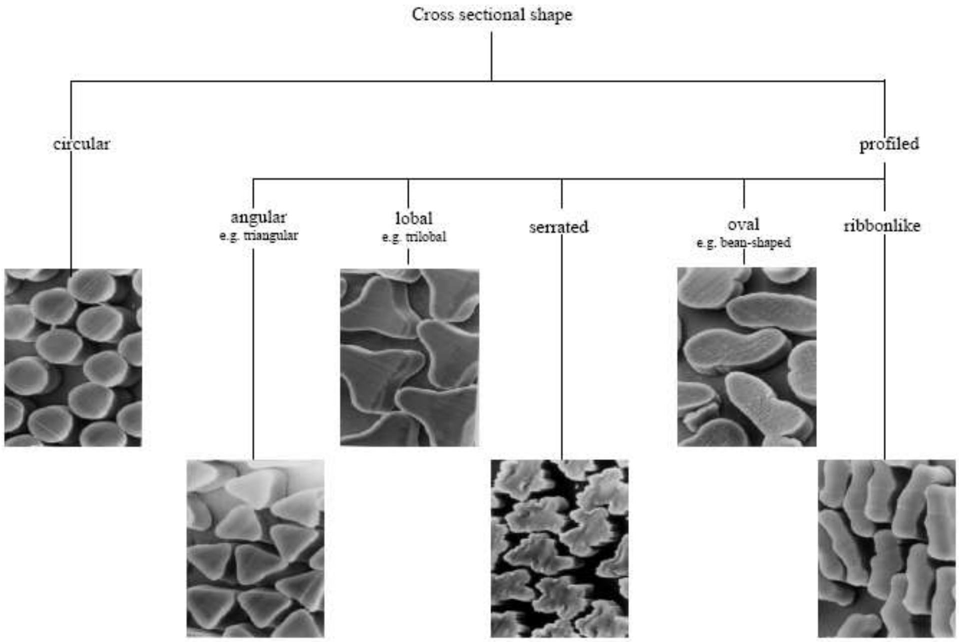
- Classification
  - Physical
  - Mechanical
  - Electrical
  - Thermal
  - Chemical
  - Biological
  - Optical
  - Acoustic
  - Radiological
  - Environmental

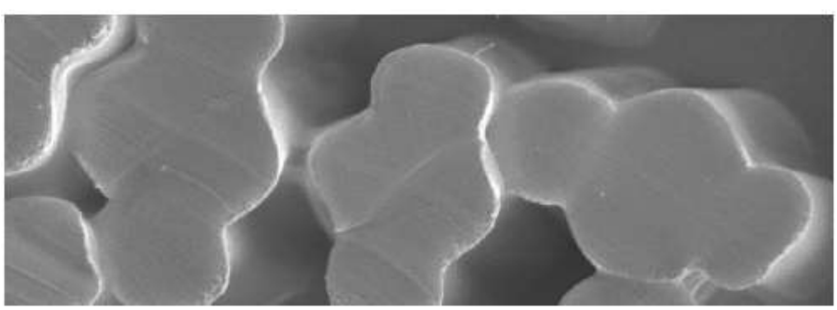
Physical Properties

- A **physical property** is any aspect of an object or substance that can be measured or perceived without changing its identity
- Examples
  - Diameter
  - Linear density
  - Length
  - Cross-section
  - Colour
  - Crimp
  - Density
  - Moisture regain
  - Coefficient of friction
  - Lustre, etc.

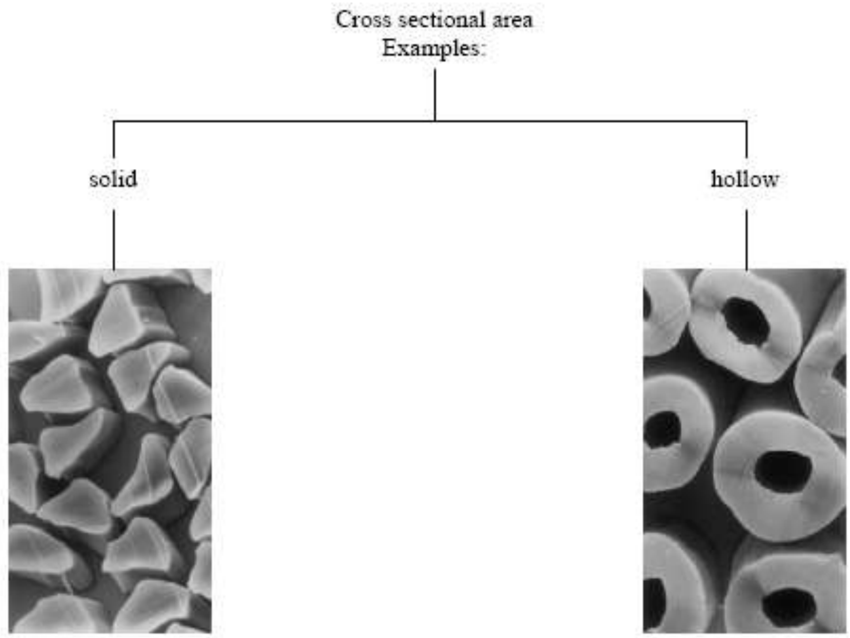
Linear density

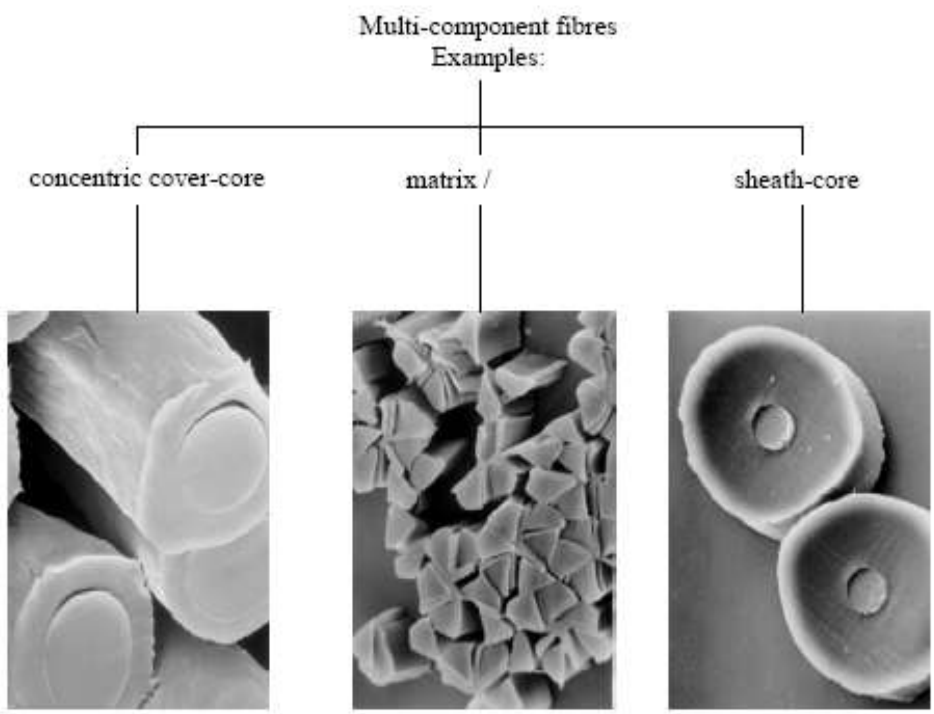
- Denier
  - Weight in grams of 9000 meters of material
- Tex
  - Weight in grams of 1000 meters of material
- dtex
  - Weight in grams of 10,000 meters of material





multichannel


Cross sectional area
Examples:
solid
hollow


Multi-component fibres
Examples:
concentric cover-core
matrix /
sheath-core

Mechanical Properties

- The properties that describe a material's ability to compress, stretch, bend, scratch, dent, or break

Mechanical Properties of Fibers

- Young's modulus / Stiffness
- Tenacity
- Specific modulus
- Tensile strength
- Compressive strength
- Shear strength
- Yield strength
- Elasticity, etc.

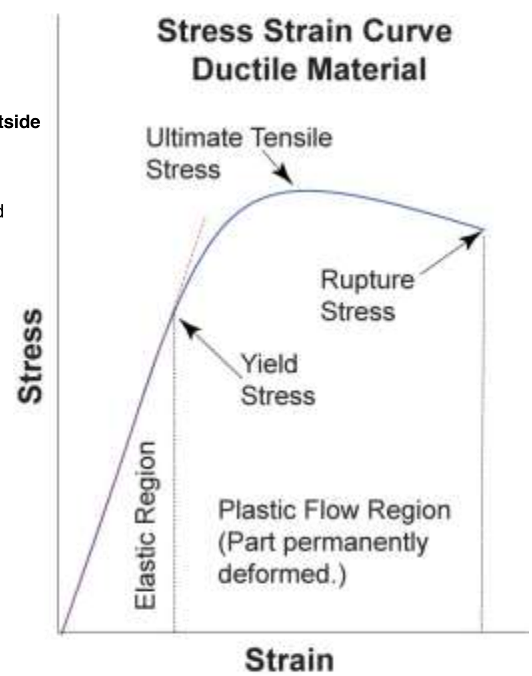
Young's modulus (E)

- A measure of the stiffness of fibers.
- Also known as the **modulus of elasticity**, **elastic modulus** or **tensile modulus**
- It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds.
- This can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material

•**Stress** = (force) / (unit of area) at any given point **inside** an object

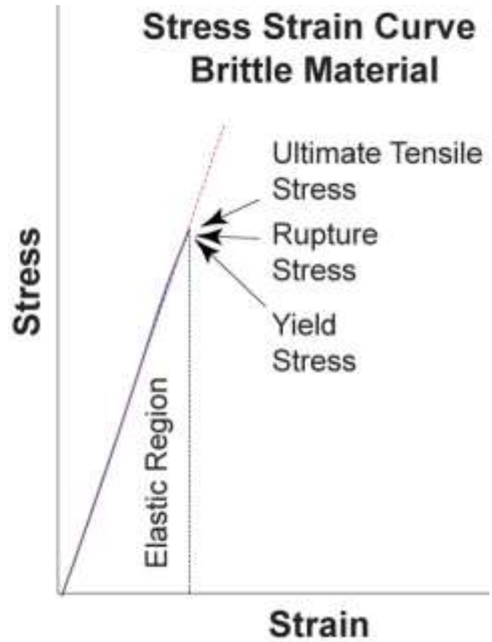
•**Pressue** = (force) / (unit of area) applied to the **outside** surface of an object

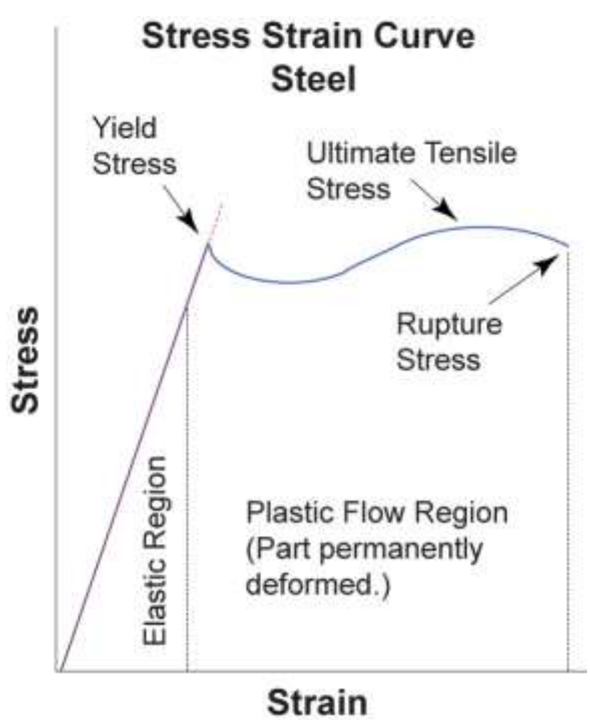
•Pressure is an external load. Stress is an internal condition resulting from external loads of forces and pressures.



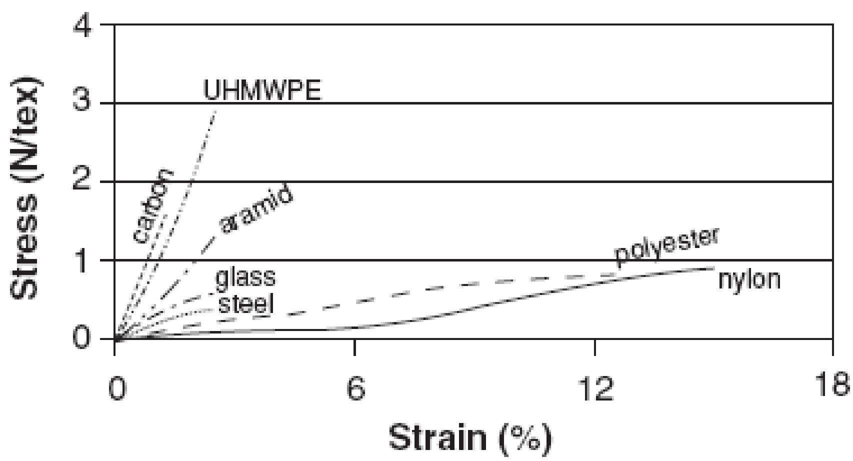
yield stress - max stress before permanent deformation
ultimate tensile stress - max stress before catastrophic failure
rupture stress - max stress at catastrophic failure

Strain = (change in length) / (original length)

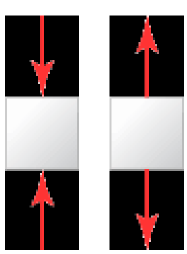

Stress Strain Curve
Brittle Material
Ultimate Tensile Stress
Rupture Stress
Yield Stress
Elastic Region
Stress
Strain


Stress Strain Curve
Steel
Yield Stress
Ultimate Tensile Stress
Rupture Stress
Elastic Region
Plastic Flow Region (Part permanently deformed.)
Stress
Strain

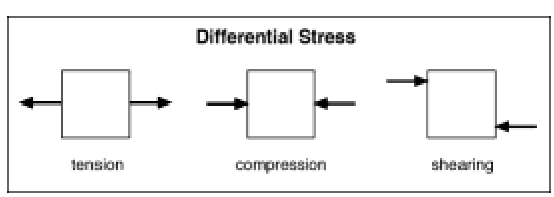
Stress-strain curves of some fibers



Types of Load

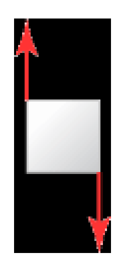


Compression/Tension: Compression is squeezing together. Tension is pulling apart. Compression can be considered negative tension.



Bending Moment: a twisting action

Shear: a force moving apart on each side of the element similar to the action of a pair of scissors or shears.



Stiffness

- The stiffness, *k*, of a body is a measure of the resistance offered by an elastic body to deformation (bending, stretching or compression)

$$k = \frac{P}{\delta}$$

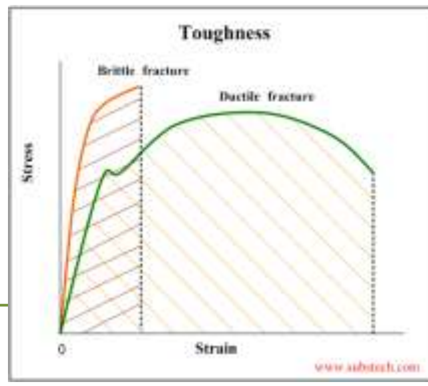
where
P is a steady force applied on the body
δ is the displacement produced by the force

Hardness

- **Hardness** refers to various properties of matter in the solid phase that give it high resistance to various kinds of shape change when force is applied
  - **Scratch hardness**: Resistance to fracture or plastic (permanent) deformation due to friction from a sharp object
  - **Indentation hardness**: Resistance to plastic (permanent) deformation due to a constant load from a sharp object
  - **Rebound hardness**: Height of the bounce of an object dropped on the material, related to elasticity.

Toughness

- The ability of a metal to deform plastically and to absorb energy in the process before fracture is termed toughness.



Specific modulus

- **Specific modulus** is the elastic modulus per mass density of a material.
- It is also known as the **stiffness to weight ratio** or **specific stiffness**.
- High specific modulus materials find wide application in aerospace applications where minimum structural weight is required.
- The utility of specific modulus is to find materials which will produce structures with minimum weight, when the primary design limitation is deflection or physical deformation, rather than load at breaking--this is also known as a "stiffness-driven" structure. Many common structures are commonly stiffness-driven for example airplane wings, bridges, bicycle frames.

Units of Young's modulus

- Young's modulus is the ratio of stress, which has units of pressure, to strain, which is dimensionless; therefore Young's modulus itself has units of pressure.
- The SI unit of modulus of elasticity (E, or less commonly Y) is the pascal (Pa or N/m^2); the practical units are megapascals (MPa or N/mm^2) or gigapascals (GPa or kN/mm^2). In United States customary units, it is expressed as pounds (force) per square inch (psi).

1 pascal (Pa) = 1 N/m^2 = 1 $kg/(m \cdot s^2)$

$$1\ \mathrm{N} = 1\ \frac{\mathrm{kg} \cdot \mathrm{m}}{\mathrm{s}^2}.$$

Tensile Strength

- Yield strength
  - The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently.
- Ultimate strength
  - The maximum stress a material can withstand when subjected to tension, compression or shearing. It is the maximum stress on the stress-strain curve.
- Breaking strength
  - The stress coordinate on the stress-strain curve at the point of rupture.

Units of Tensile Strength

- Tensile strength is measured in units of force per unit area.
- In the SI system, the units are newtons per square metre (N/m^2) or pascals (Pa), with prefixes as appropriate.
- The non-metric units are pounds-force per square inch (lbf/in^2 or PSI).
- Engineers in North America usually use units of ksi which is a thousand psi.
- One megapascal is 145.037738 pounds-force per square inch.

Tenacity

- **Tenacity** is the customary measure of strength of a fiber or yarn.
- In the U.S. it is usually defined as the ultimate (breaking) strength of the fiber (in gram-force units) divided by the denier.
- Units
  - g/denier; cN/tex; N/tex

Material ↓	Yield strength (MPa) ↓	Ultimate strength (MPa) ↓	Density (g/cm³) ↓
first carbon nanotube ropes	?	3,600	1.3
Steel, high strength alloy ASTM A514	690	760	7.8
High density polyethylene (HDPE)	26-33	37	0.95
Polypropylene	12-43	19.7-80	0.91
E-Glass	N/A	3,450	2.57
S-Glass	N/A	4,710	2.48
Basalt fiber	N/A	4,840	2.7
Marble	N/A	15	
Concrete	N/A	3	
Carbon Fiber	N/A	5,650	1.75
Human hair		380	
Spider silk		1,000	
UHMWPE fibers[4][5] (Dyneema or Spectra)		2,300-3,500	0.97
Vectran		2,850-3,340	
Polybenzoxazole (Zylon)		5,800	
Nylon, type 6/6	45	75	1.15
Rubber	-	15	
Boron	N/A	3,100	2.46
Silicon, monocrystalline (m-Si)	N/A	7,000	2.33
Silicon carbide (SiC)	N/A	3,440	
Sapphire (Al2O3)	N/A	1,900	3.9-4.1
Carbon nanotube	N/A	62,000	1.34

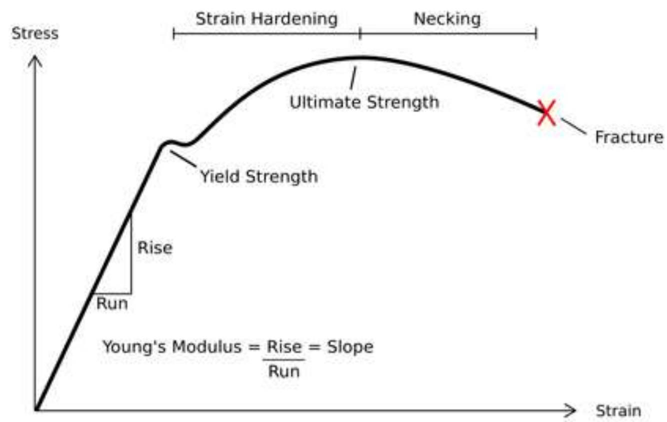
Specific Strength

- The **specific strength** is a material's strength (force per unit area at failure) divided by its density.
- It is also known as the **strength-to-weight ratio** or **strength/weight ratio**.
- Materials with high specific strengths are widely used in aerospace applications where weight savings are worth the higher material cost.
- In fiber or textile applications, tenacity is the usual measure of specific strength.

Material ↓	Specific Strength (kN·m/kg)
Polypropylene	88.88
Nylon	69.0
Glass fiber	1,307
Vectran	2,071
Carbon fiber (AS4)	2,457
Kevlar	2,514
Spectra fiber	3,619
Carbon nanotube	46,268
Colossal carbon tube	59,483

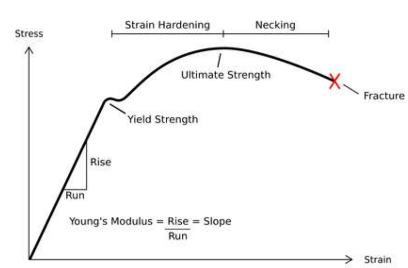
Elastic deformation

- This type of deformation is reversible. Once the forces are no longer applied, the object returns to its original shape.
- The elastic range ends when the material reaches its yield strength. At this point plastic deformation begins



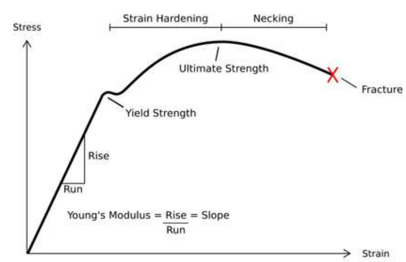
Plastic deformation

- This type of deformation is not reversible. However, an object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.



Plastic deformation…

- Under tensile stress plastic deformation is characterized by a strain hardening region and a necking region and finally, fracture .
- During strain hardening the material becomes stronger through the movement of atomic dislocations.
- The necking phase is indicated by a reduction in cross-sectional area of the specimen. Necking begins after the Ultimate Strength is reached. During necking, the material can no longer withstand the maximum stress and the strain in the specimen rapidly increases. Plastic deformation ends with the fracture of the material.



Mechanical Failure Modes

- Creep
- Fatigue
- Fracture
- Impact
- Mechanical overload
- Rupture
- Wear
- Yielding

Creep

- **Creep** is the tendency of a solid material to slowly move or deform permanently under the influence of stresses.
- It occurs as a result of long term exposure to levels of stress that are below the yield strength of the material.
- Creep is more severe in materials that are subjected to heat for long periods, and near the melting point.
- Creep always increases with temperature.

Fatigue

- **Fatigue** is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading

Fracture

- A **fracture** is the (local) separation of an object or material into two, or more, pieces under the action of stress.

Impact

- An **impact** is a high force or shock applied over a short time period.
  - Such a force or acceleration can sometimes have a greater effect than a lower force applied over a proportionally longer time period.

Mechanical overload

- The failure or fracture of a product or component in a single event is known as **mechanical overload**.

Rupture

- **Rupture** describes a failure mode in which, rather than cracking, the material "pulls apart,”

Wear

- **Wear** is the erosion of material from a solid surface by the action of another surface.
  - It is related to surface interactions and more specifically the removal of material from a surface as a result of mechanical action

Yielding

- The **yield strength** or **yield point** of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically

Electrical Conductivity/resistance

- **Electrical conductivity** or **specific conductance** is a measure of a material's ability to conduct an electric current
- Conductivity is the reciprocal (inverse) of electrical resistivity, ρ (Greek: rho), and has the SI units of siemens per metre ($S{\cdot}m^{-1}$)
- Resistance
  - Ohms (e.g. Resistance of Dyneema is > 10^{14} Ohm)

Dielectric strength

- The maximum electric field strength that an insulating material can withstand intrinsically without breaking down, *i.e.*, without experiencing failure of its insulating properties
  - E.g. dielectric strength of Dyneema is 900 kV/cm

Dielectric constant

- The tendency of a material to resist the flow of an electrical current across the material.
- The lower the value of the dielectric constant, the greater its resistance to the flow of an electrical current.

Thermal properties

- Thermal conductivity
- Flammability
- Glass transition temperature
- Melting point
- Coefficient of linear thermal expansion
- Specific heat capacity

Thermal conductivity

- **Thermal conductivity**, *k*, is the property of a material that indicates its ability to conduct heat
- SI units: watt/meter.Kelvin

Flammability

- **Flammability** is defined at how easily something will burn or ignite, causing fire or combustion
- The **limiting oxygen index (LOI)** is the minimum concentration of oxygen, expressed as a percentage, that will support combustion of a polymer.
  - It is measured by passing a mixture of oxygen and nitrogen over a burning specimen, and reducing the oxygen level until a critical level is reached

Glass transition temperature (Tg)

- The glass transition is the temperature where the polymer goes from a hard, glass like state to a rubber like state.
- Measured by Differential Scanning Calorimeter or Thermal Mechanical Analyser

A polymer below its glass transition temperature, T_g, is said to be in the **"glassy state"**. As the temperature increases, it passes through the glass transition temperature, and it's mechanical properties change from those of a glass (brittle) to those of a rubber (elastic)

Glass Transition and Melting

Glass Transition	Melting
• Property of the amorphous region • Below T_g: Disordered amorphous solid with immobile molecules • Above T_g: Disordered amorphous solid in which portions of molecules can wiggle around	• Property of the crystalline region • Below T_m: Ordered crystalline solid • Above T_m: Disordered melt

Chemical Properties

- Reactivity
- Chemical stability
- Hygroscopicity
- Contact angle
- Ability to protect from chemical weapons

Optical Properties

- Absorbance
- Reflectivity
- Refractive index
- Optical density
- Transmittance
- Colour
- Photosensitivity
- UV visibility
- IR & NIR visibility
- Radar visibility

Refractive index

- A property of a material that changes the speed of light, computed as the ratio of the speed of light in a vacuum to the speed of light through the material.
- The higher the index, the slower the speed of light through the medium

http://www.texloc.com/closet/cl_refractiveindex.html

Refractive Index

- Higher refractive index results in higher light reflection
- A middle refractive index is typical for cotton (1.56) and nylon (1.57).
- But the high refractive index of polyester (1.63) causes such a high light reflection that a deep black on polyester fibres needs relatively high amounts of dyestuff.
- This becomes more critical with micro fibres. Their large surface (about double that of normal fibres) causes even more reflection.
- With silicone finishes (RI 1.43) , preferably with amino-modified macroemulsions, a deep black or other deep colour on polyester micro fibres is achievable, combined with a very soft handle.

Optical density

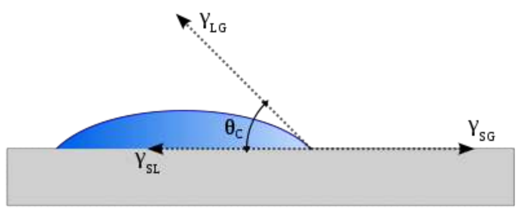
- Materials with large optical densities absorb light going through that material in a shorter distance than materials with smaller optical densities

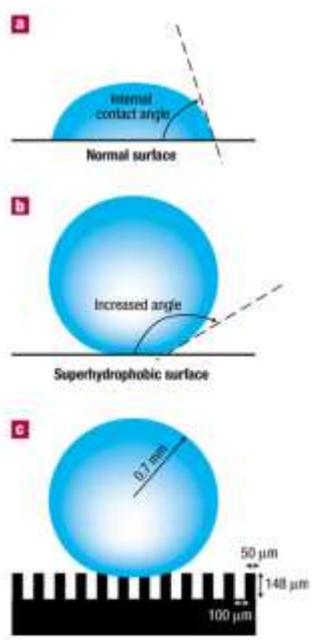
Hygroscopy

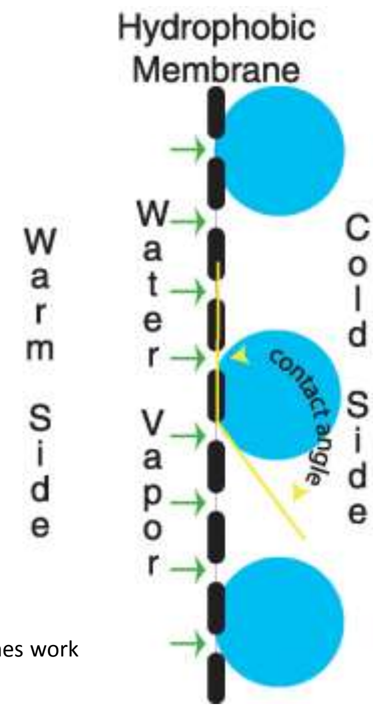
- **Hygroscopy** is the ability of a substance to attract water molecules from the surrounding environment through either absorption or adsorption
- **Adsorption** is the accumulation of atoms or molecules on the surface of a material.
- It is different from absorption, in which a substance diffuses into a liquid or solid.
- The term *sorption* encompasses both processes, while desorption is the reverse process.

Contact angle

- The **contact angle** is the angle at which a liquid/vapor interface meets the solid surface







How waterproof/breathable membranes work

Acoustic properties

- Sonic velocity
- Sound absorption

Radiological properties

- Ability to protect from atomic/nuclear radiations

Biological properties

- Toxicity
- Ability to protect from biological weapons
- Bio-compatibity
  - "the ability of a material to perform with an appropriate host response in a specific application".
  - "the quality of not having toxic or injurious effects on biological systems".
- Anti-microbial properties
- Fungal resistance

Environmental properties

- Photo-stability
- UV stability
- Weathering
- Oxidation