JACOBS UNIVERSITY

INDUSTRIAL ENGINEERING

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Chapter 05 – Material Technology

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Chapter 5

MATERIAL TECHNOLOGY

OUTLINE

INTRODUCTION TO MATERIALS

MATERIALS

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Materials may be defined as substance of which something is composed or made of.

Deterioration

Economics

In-service performance

Material selection

Aluminum

Glass

Plastic

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

OVERVIEW OF MATERIALS

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Main groups of materials

Ferrous Materials	Non-Ferrous Metals	Powder and Sintered Materials	Non-Metallic Materials

▪ Iron Alloys
▪ Wrought Iron Alloys / Steels
▪ Casting Alloys
  ▪ Cast steel
  ▪ Malleable cast iron
  ▪ Chilled cast iron
  ▪ Cast iron
	▪ Aluminum
	▪ Beryllium
	▪ Chrome
	▪ Copper
	▪ Gallium
	▪ Germanium
	▪ Gold
	▪ Indium
	▪ Lead
	▪ Magnesium
	▪ Mercury
	▪ Nickel
	▪ Platinum
	▪ Silver
	▪ Silicon
	▪ Tantalum
	▪ Tin/Pewter
	▪ Titanium
	▪ Tungsten/Wolfram
	▪ Zinc
		▪ Filter materials
		▪ Friction materials
		▪ Self-lubrication bearing materials
		▪ Sintered ferrous materials
		▪ Sintered superalloys
		▪ Contact materials
		▪ Sintered magnetic materials
		▪ Carbides
		▪ Non-metallic hard materials
			▪ Plastics
			  ▪ Polymerisates
			  ▪ Polycondensates
			  ▪ Polyadducts
			  ▪ Cellulose derivatives
			▪ Wood
			  ▪ Solid wood
			  ▪ Veneer
			  ▪ Fiberboard
			  ▪ Chipboard
			  ▪ Composite panel
			▪ Minerals
			  ▪ Natural stone
			  ▪ Mortar and concrete
			  ▪ Mineral binders
			  ▪ Ceramic
			  ▪ Technical glass

FERROUS MATERIALS

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Ferrous Materials

- Sintered Iron
- Wrought Iron Alloys / Steel
  - Construction steel
    - General construction steel
    - Building construction steel
    - Prestressing steel
    - Wire steel
    - Rail steel
  - Steels for special heat treatment
    - Case hardening steel
    - Tempered steel
    - Steel for dip hardening
    - Nitriding steel
  - Steel for tools
    - Tool steel
    - High-speed steel
    - Cold-working steel
    - Hot-working steel
  - Steels for thermal stress
    - Boiler-construction steel
    - Linepipe steel
    - Creep-resistant steel
    - High-temperature steel
    - Heat-resistant steel
    - Valve steel
    - Cryogenic steel
  - Steels for corrosive stress
    - Corrosion-resistant steel
    - Weather-resistant steel
  - Steels w/ special characteristics
    - Magnetic steels
    - Compressed hydrogen resistant steel
    - Free-cutting steel
    - Rolling bearing steel
    - Spring steel
- Casting Alloys
  - Cast steel
    - unalloyed
    - alloyed
    - High temperature
    - Heat resistant
    - corrosion-resistant
  - Chilled-cast iron
    - Solid chilled-cast iron
    - Shell chilled-cast iron
    - alloyed chilled-cast iron
  - Cast iron
    - with flake graphite
    - with spheroidal graphite
    - Alloyed cast iron
  - Malle-able cast iron

ALLOYS

An alloy is a combination of metals or of a metal and another element. Alloys are defined by a metallic bonding character.

Alloy	Composition	Properties	Uses
Bronze	• 90% copper • 10% tin	• Hard and strong • Doesn't corrode easily • Has shiny surface	• To build statues and monuments. • In the making of medals, swords and artistic materials.
Brass	• 70% copper • 30% zinc	• Harder than copper	• In the making of musical instruments and kitchenware.
Steel	• 99% iron • 1% carbon	• Hard and strong	• In the construction of building and bridges. • In the building of the body of cars and railway tracks.
Stainless steel	• 74% iron • 8% carbon • 18% chromium	• Shiny • Strong • Doesn't rust	• To make cutlery and surgical instruments.
Duralumin	• 93% aluminum • 3% copper • 3% magnesium • 1% manganese	• Light • Strong	• To make the body of aeroplanes and bullet trains.
Pewter	• 96% tin • 3% copper • 1% antimony	• Luster • Shiny • Strong	• In the making of souvenirs.

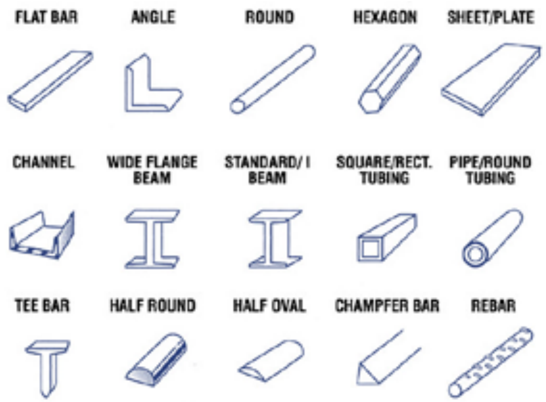
An alloy may be a solid solution of metal elements (a single phase) or a mixture of metallic phases (two or more solutions).

STEEL GRADES

Steel grades classify various steels by their composition and physical properties

SAE designation	Type
1xxx	Carbon steels
2xxx	Nickel steels
3xxx	Nickel-chromium steels
4xxx	Molybdenum steels
5xxx	Chromium steels
6xxx	Chromium-vanadium steels
7xxx	Tungsten steels
8xxx	Nickel-chromium-molybdenum steels
9xxx	Silicon-manganese steels

10xx	Plain carbon (Mn 1.00% max.)
11xx	Resulfurized
12xx	Resulfurized and rephosphorized
15xx	Plain Carbon (Mn 1.00–1.65% max.)



ALUMINUM ALLOYS

Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc.

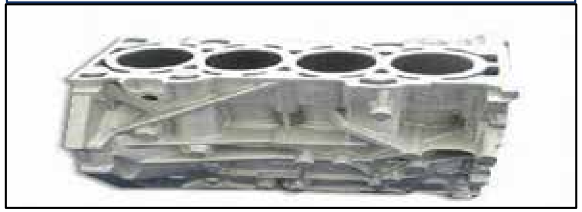
Series Number	Alloying Elements	Alloy Category	Typical Applications
1XXX	Aluminum	Commercially Pure	Electrical, Power Grid & Transmission
2XXX	Copper	Heat-Treatable	Aircraft, Cylinders and Pistons
3XXX	Manganese	Non Heat- Treatable	Coocking Utensils, Beverage Cans
4XXX	Silicon	Non Heat- Treatable	Structural and Automotive
5XXX	Magnesium	Non Heat- Treatable	Storage tanks, Marine, Pressure vessels
6XXX	Magnesium & Silicon	Heat-Treatable	Structural and Automotive
7XXX	Zinc	Heat-Treatable	Aircraft

MATERIAL VARIETY IN CARS

Plastics

Steel

Aluminum



Fiberglass

Carbon Fiber

Leather

Magnesium

Titanium

MATERIALS IN CAR MANUFACTURING

TYPES OF MATERIALS

COMBINATION OF MATERIALS

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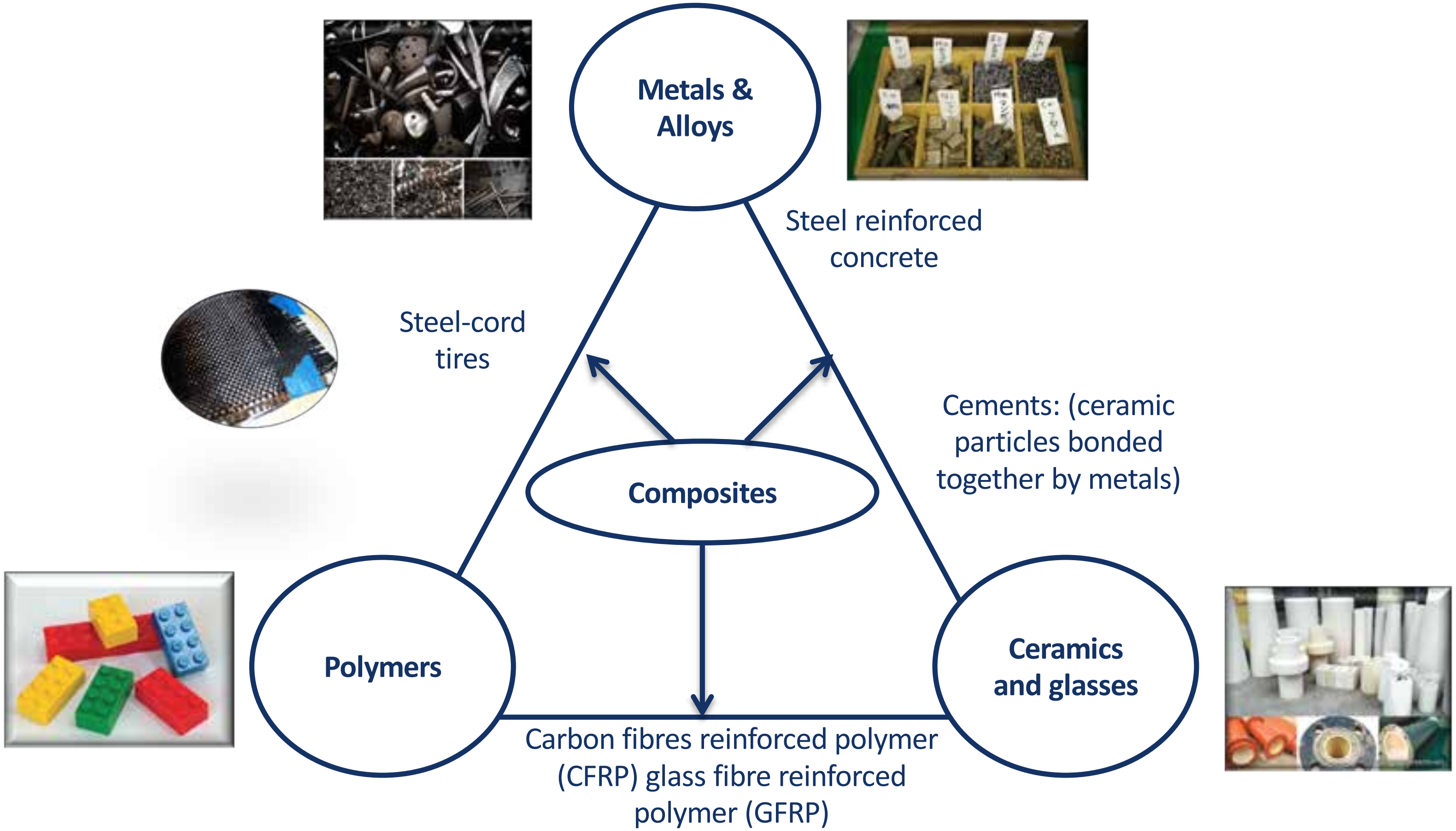
Based on chemical make up and atomic structure, solid materials can be combined to form new materials



Materials have properties that make them useful in structure, machines, devices, products, and systems.

METALS

Composed of one or more metallic elements, e.g. iron, copper, aluminum, in bulk or powder form

- Metals are inorganic and crystalline in nature
- Metallic element may combine with nonmetallic elements, e.g. Silicon Carbide, Iron Oxide
- High strength and deformability

Metals & Alloys

- **Ferrous:** Steel, Cast Iron
- **Nonferrous:** Copper Aluminum

Good thermal and electric conductors

CERAMICS

Metallic and nonmetallic elements are chemically bonded together.

- Inorganic but can be either crystalline, non-crystalline or mixture of both.
- high hardness, abrasion resistance, brittleness and chemical inertness
- Categorized in oxide and non-oxide ceramics
- Examples:
  - Porcelain
  - Glass
  - Silicon nitride.

Ceramics are typically insulative and more resistant to high temperatures and harsh environments than metals and polymers

POLYMERS

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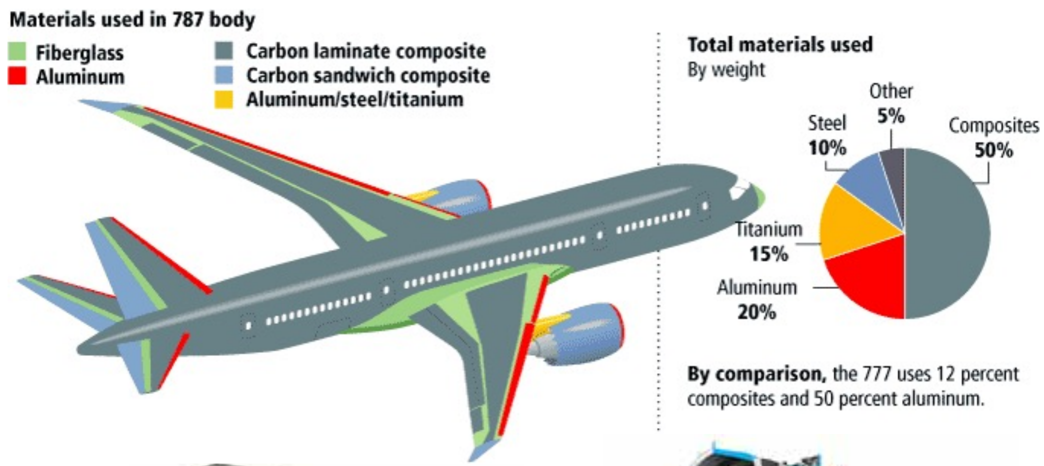
Mainly organic substances and derivatives of carbon and hydrogen.

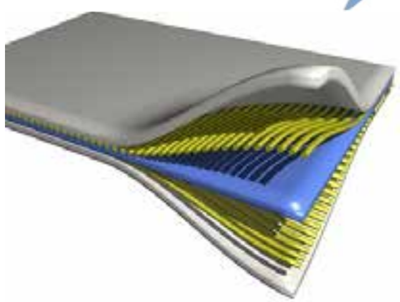
- 3 categories
  - thermoplastic polymers
  - thermosetting polymers
  - Elastomers (rubbers)
- Most plastic polymers are light in weight and soft (compared to metals)
- Polymer materials have typically low densities and may be extremely flexible
- Examples
  - Polyvinyl Chloride (PVC)
  - Polyester, etc.
- Applications:
  - Appliances
  - DVDs
  - Fabrics, etc.

Poor conductors of electricity and hence used as insulators

COMPOSITES

Composition of two or more materials in the first three categories, *e.g. metals, ceramics* and polymers, that has properties from its constituents





- Mixture of two or more materials.
- Consists of a filler material and a binding material
- Materials only bond, will not dissolve in each other.
- Examples
  - Fiberglass (reinforcing material in a polyester or epoxy matrix)
  - Concrete (gravels or steel rods reinforced in cement and sand)
- Applications
  - Aircraft wings and engine
  - construction

Class of engineering material that provides almost an unlimited potential for higher strength, stiffness, and corrosion resistance

MATERIAL SCIENCE AND ENGINEERING - TETRAHEDRON

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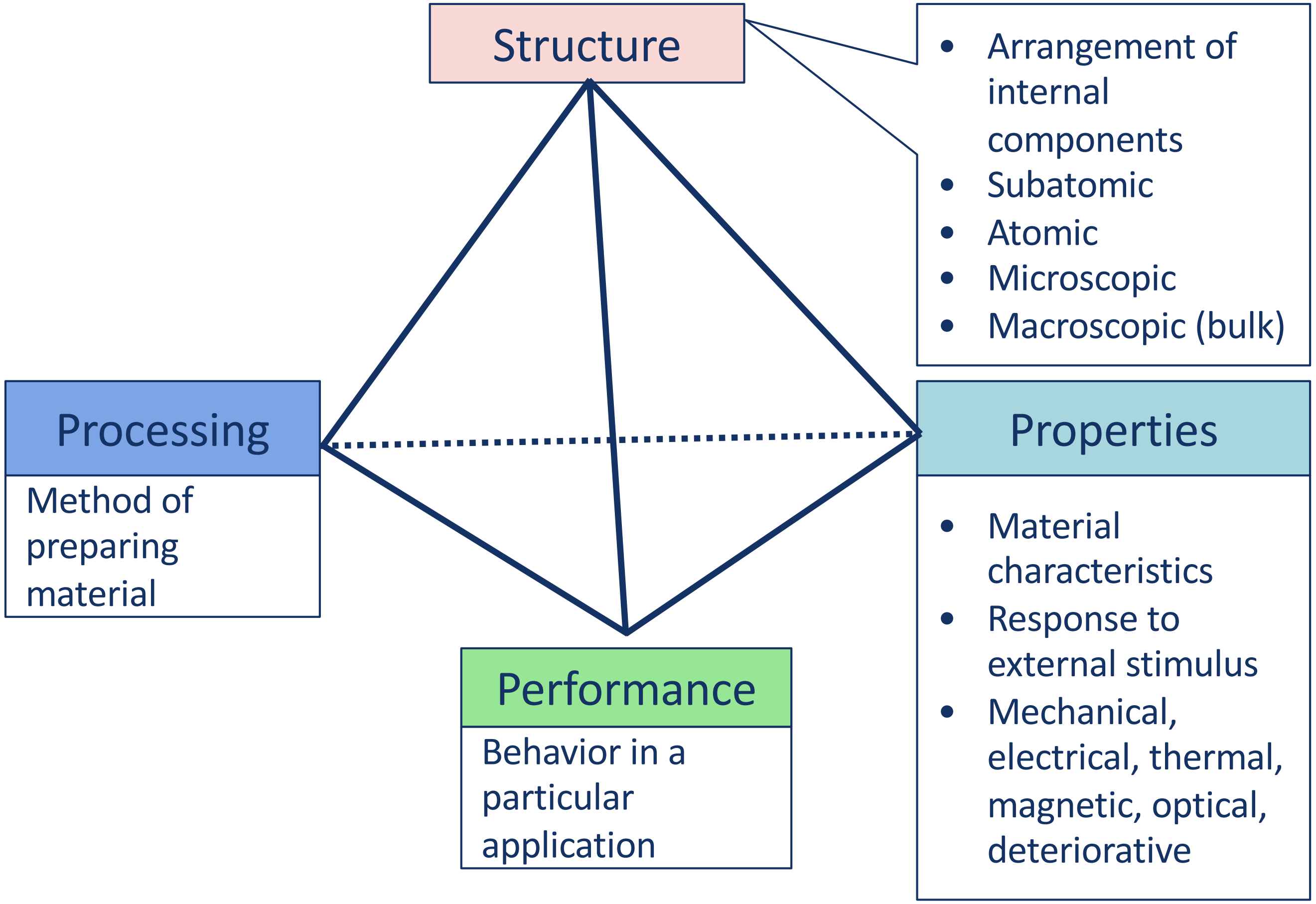
Tetrahedron diagram shows how the performance-to-cost ratio of materials depends upon the composition, microstructure, synthesis, and processing



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MATERIAL PROPERTIES

CLASSIFICATION OF MATERIAL PROPERTIES

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The properties of a material that determine its behavior under applied forces are known as mechanical properties

Materials Properties

Chemical

- Composition (Oxide or Compound)
- Acidity or Alkalinity
- Corrosion

Physical

- Density
- Conductivity (thermal/electrical)
- Acoustical (sound-transmission/absorption)
- Optical
- Combustibility

Mechanical

- Stress
- Strain
- Strength
- Toughness
- Stiffness
- Elasticity
- Plasticity
- Ductility
- Brittleness
- Hardness

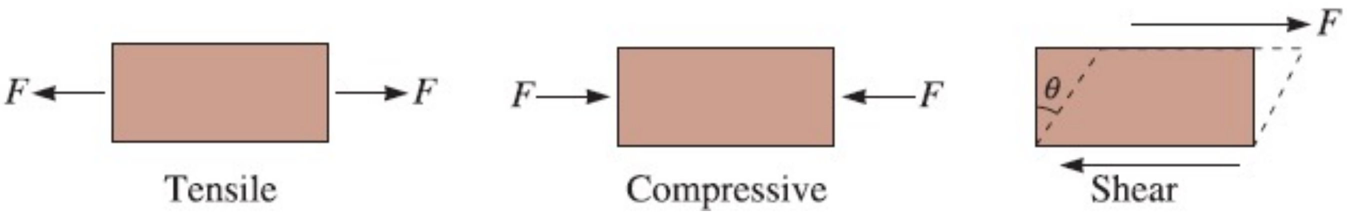
Dimensional

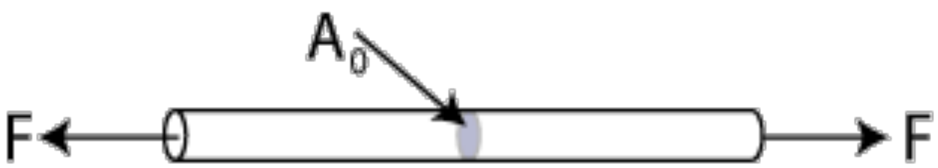
- Size
- Shape

A sound knowledge of mechanical properties of materials provides the basis for predicting behavior of materials under different load conditions and designing the components out of them.

MECHANICAL PROPERTIES – STRESS

Pressure due to applied load tension, compression, shear, torsion, and their combination.





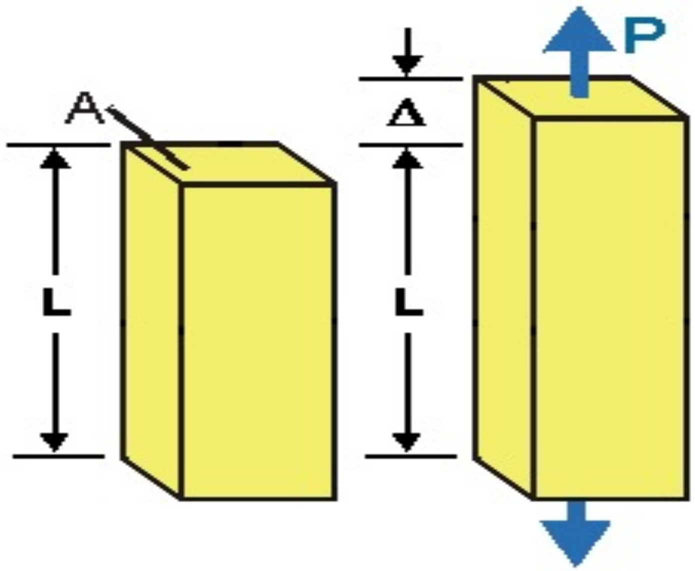
$$\text{Stress, } \sigma = \frac{\text{Force}}{\text{Cross-Sectional Area}} = \frac{F}{A_0}$$

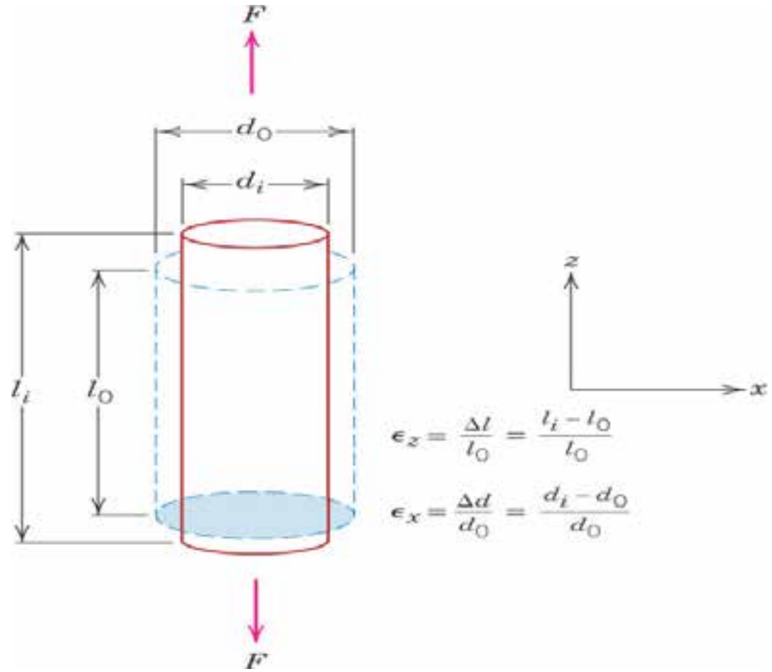
Most common measurements of stress:
[psi - pounds per square inch|
[Pa – Pascal or Newton/m2|

Mathematically, stress is expressed as force divided by cross-sectional area.

MECHANICAL PROPERTIES – STRAIN

Response of the material to stress
(i.e. physical deformation such as elongation due to tension).



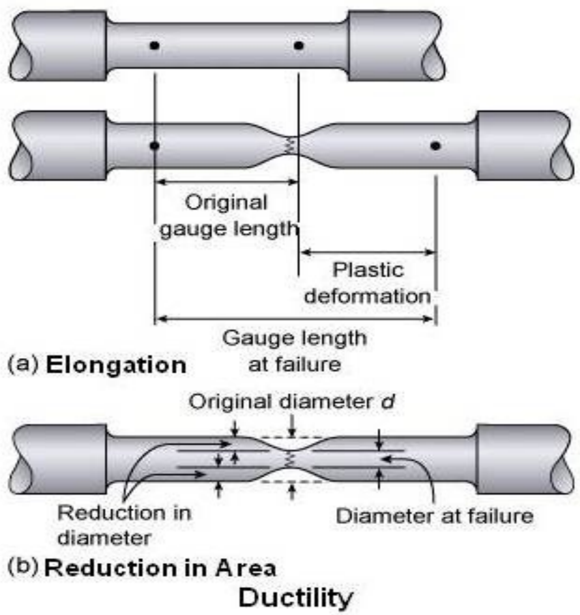


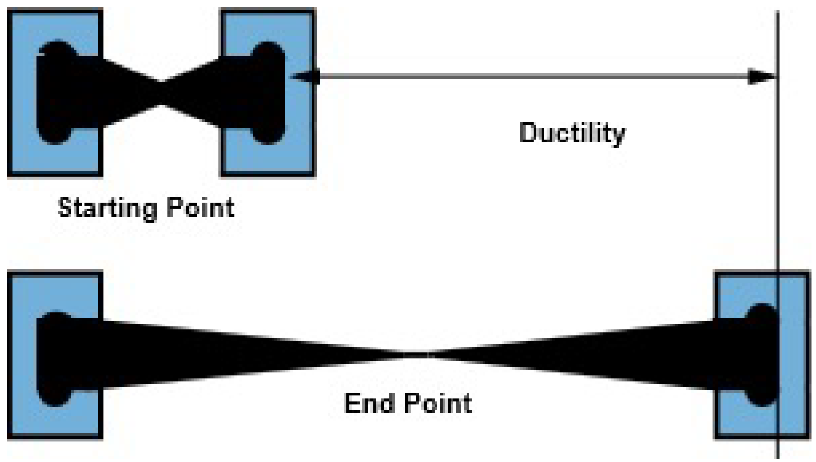
$$Strain = \frac{Elongation}{Original\ length} = \frac{\Delta L}{L_0}$$

Mathematically, strain is the change in length divided by original length

MECHANICAL PROPERTIES - DUCTILITY

It is the property of a material which enables it to draw out into thin wires (deformation under tensile stress)



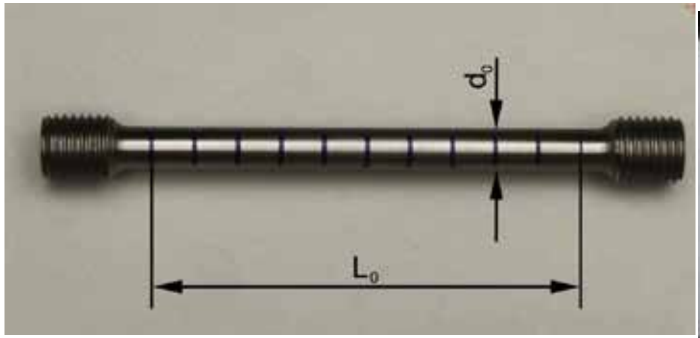


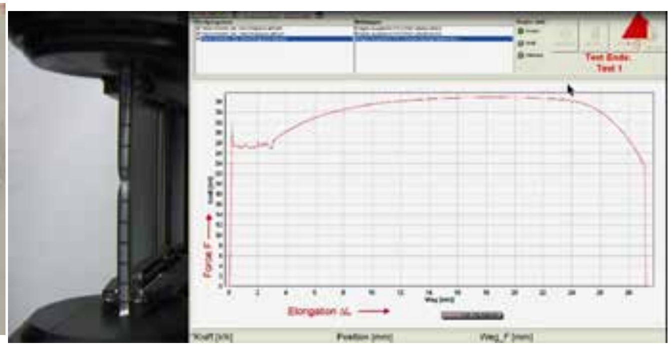
Alloy Properties	Zinc Alloy			Aluminum Alloy				Bronze	Steel
	Die Cast Zemak 3	Per.mold ZA-12	Per.Mold ZA-27	Per.Mold 356-F	Per.Molt 356-T6	Die Cast 380	Wrought Al 6061-T6	Sand Cast C93200	Mild Steel 1018
Elongation (% in 2”)	10	2.20	2.50	5.0	3.5	3	12	20	15-18

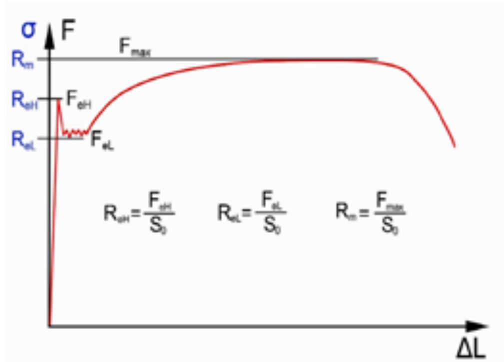
The percent elongation and the reduction in area in tension is often used as empirical measures of ductility.

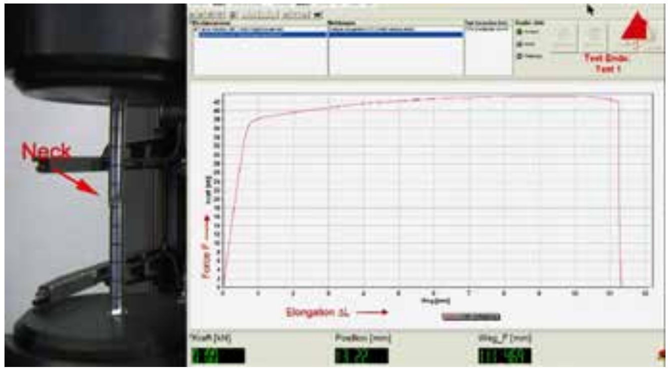
TENSILE TEST

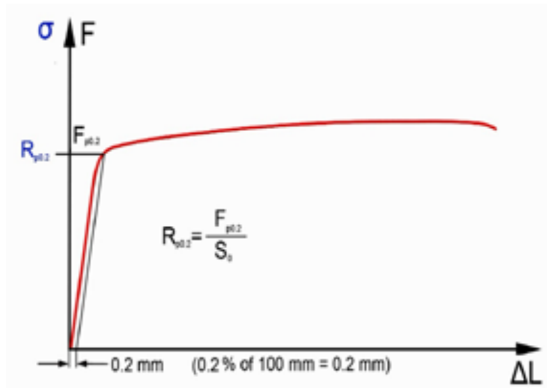
A tensile test measures the resistance of a material to a static or slowly applied force











Tensile tests are used to determine the tensile strength and elongation at fracture

MECHANICAL PROPERTIES - STRENGTH

The strength of a material is its capacity to withstand destruction under the action of external loads

- **Compressive strength**: measurement of the force required to push apart a material
- **Yield strength**: measurement of the force to permanently bend a material
- **Ultimate strength**: maximum stress that any material will withstand before destruction

Alloy Properties	Zinc Alloy			Aluminum Alloy				Bronze	Steel
	Die Cast Zemak 3	Per.mold ZA-12	Per.Mold ZA-27	Per.Mold 356-F	Per.Molt 356-T6	Die Cast 380	Wrought Al 6061-T6	Sand Cast C93200	Mild Steel 1018
Tensile Strength MPa	283	328	426	180	228	324	310	241	440
Yield Strength MPa	221	268	371	125	166	165	241	124	370
Shear Strength MPa	214	241	325	NA	179	186	207	NA	NA

It determines the ability of a material to withstand stress without failure.

MECHANICAL PROPERTY – PLASTICITY

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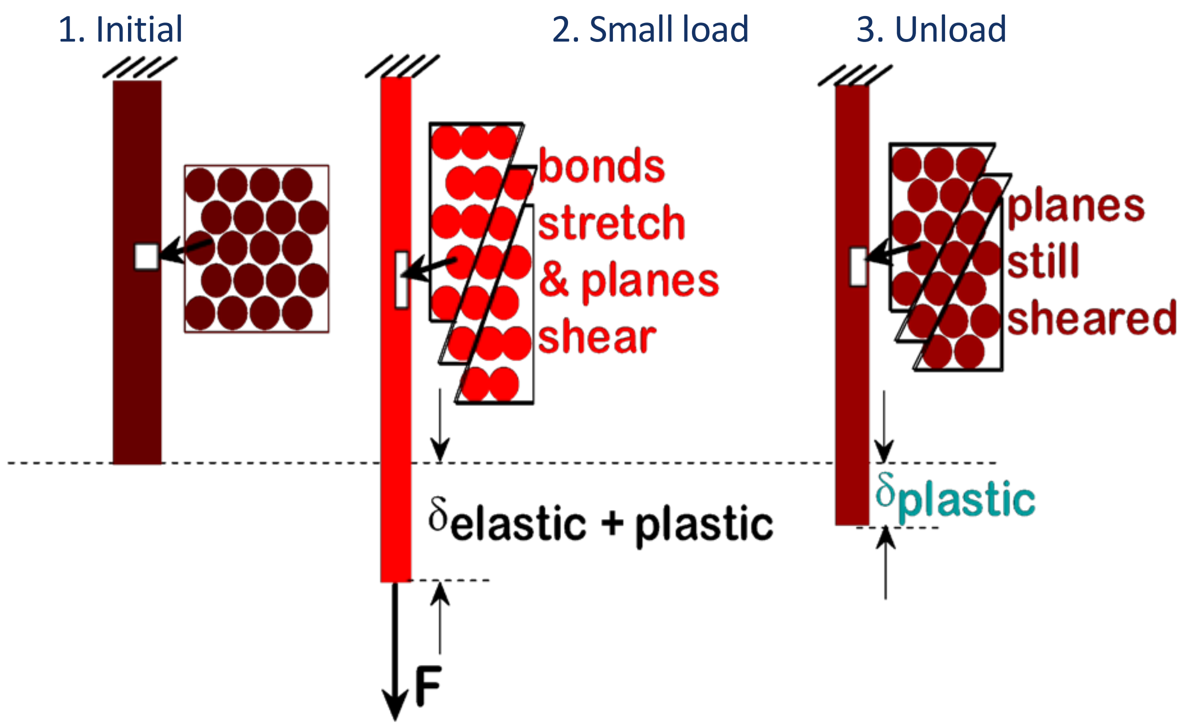
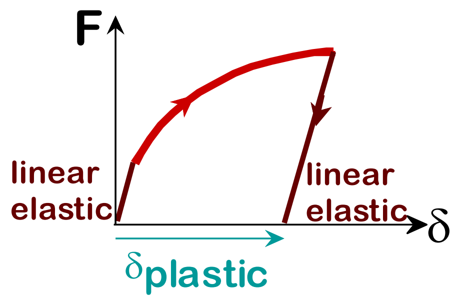
The plasticity of a material is its ability to undergo some degree of permanent deformation up to the yield point without rupture or failure



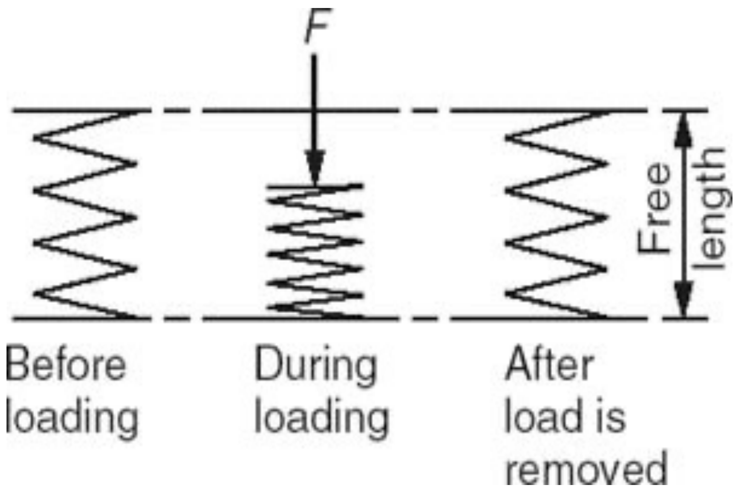


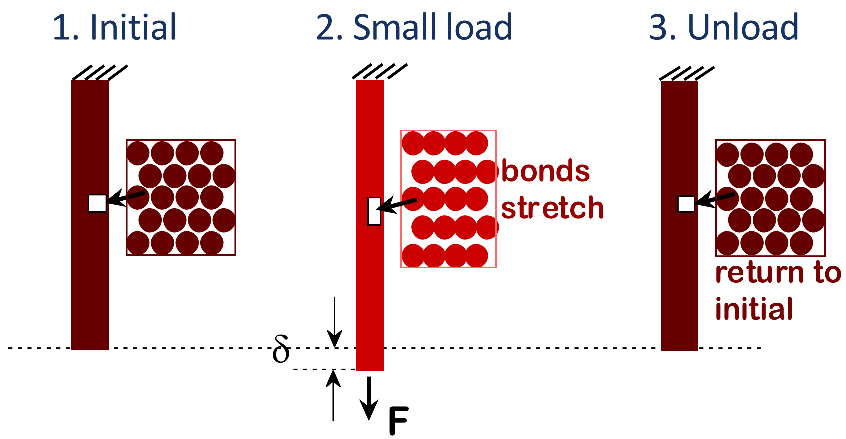
Plastic means permanent!

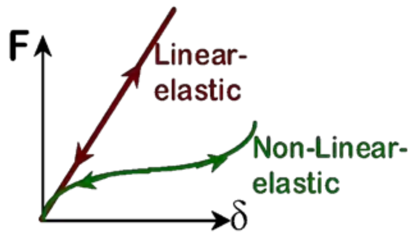
Plastic deformation will take place only after the yield point (elastic limit) is exceeded

MECHANICAL PROPERTIES – ELASTICITY

Elasticity of a material is the power of coming back to its original position after deformation when the stress or load is removed







Elastic means reversible!

Elastic modulus (=Young's modulus) indicates the strength or stiffness of materials

MECHANICAL PROPERTY – ELASTIC/YOUNG´S MODULUS

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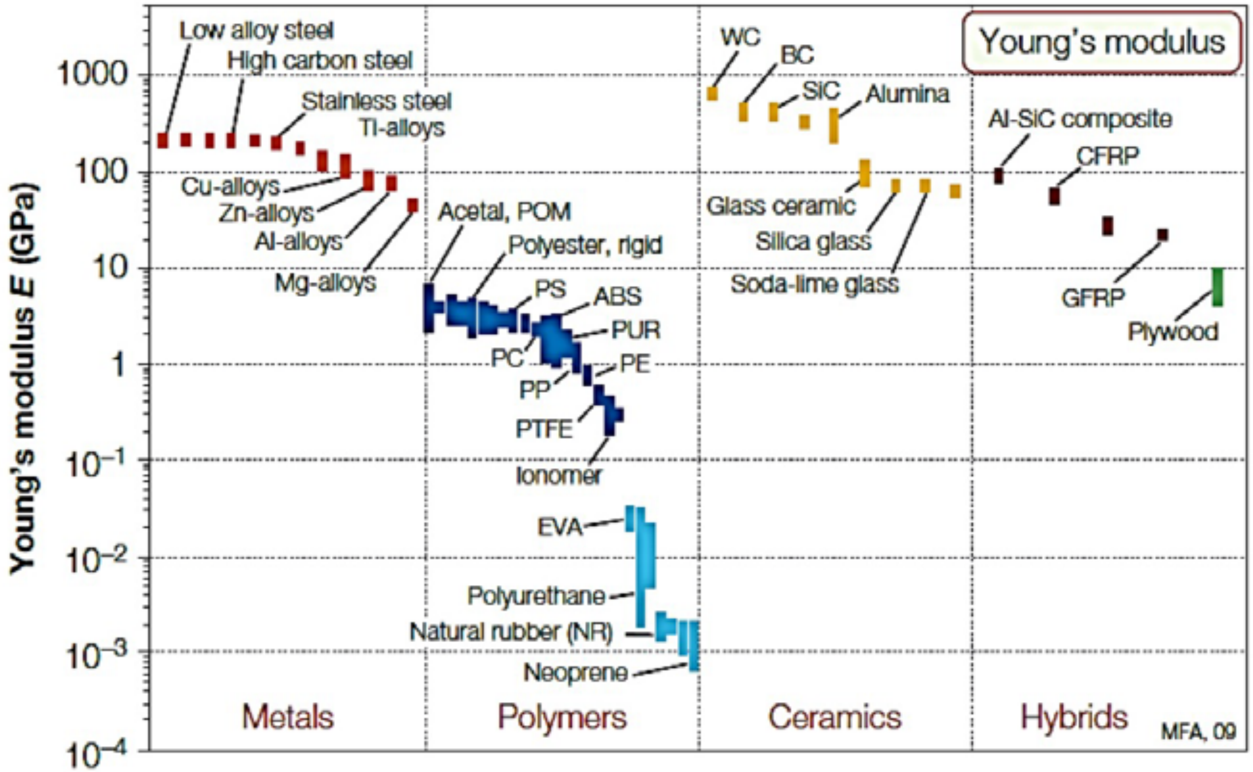
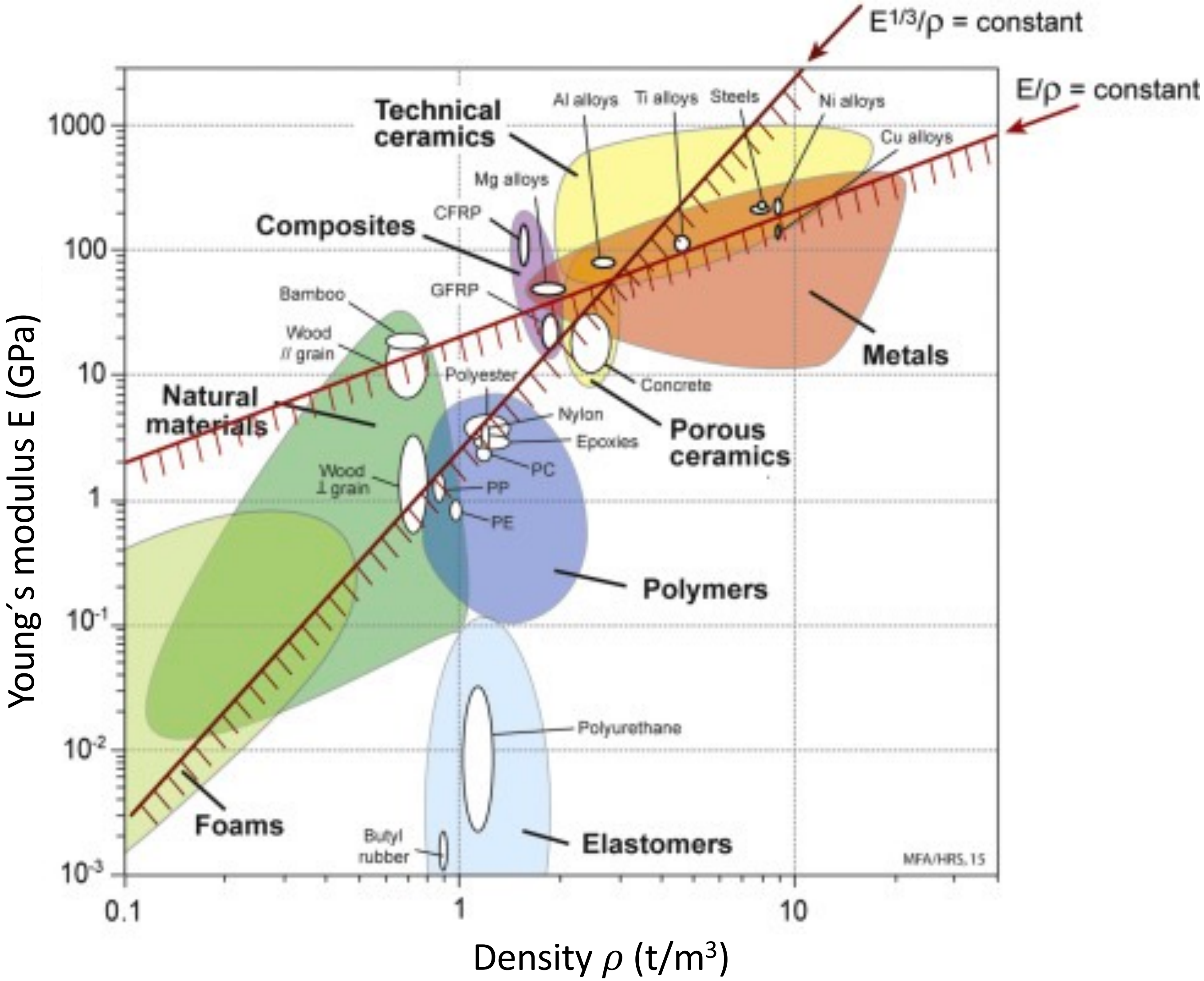
A mechanical property measuring the stiffness of a solid material in the linear elasticity regime of a uniaxial deformation

$$\lambda = \frac{stress}{strain}$$

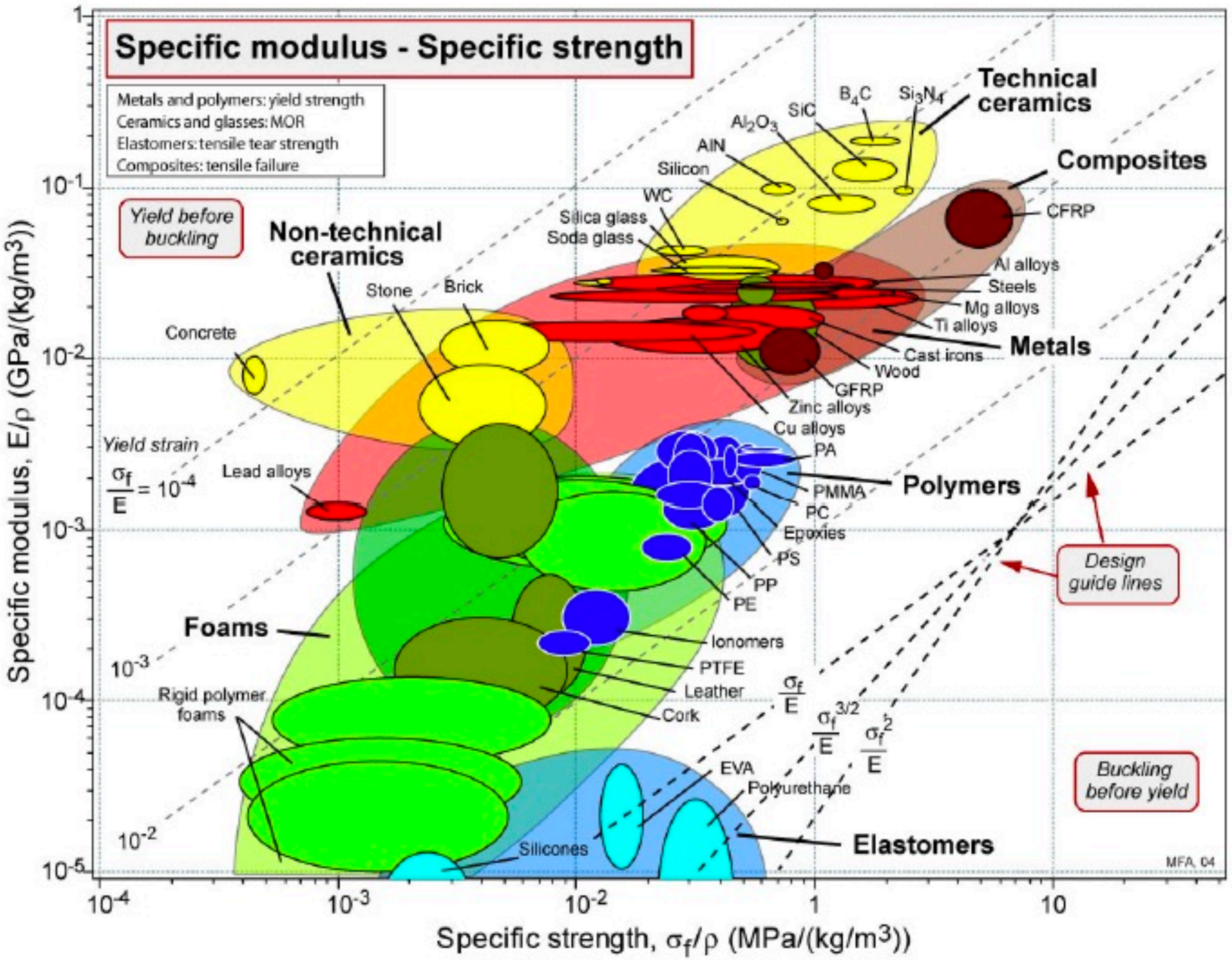


Young´s modulus defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material

MECHANICAL PROPERTY - MODULUS-DENSITY CHART

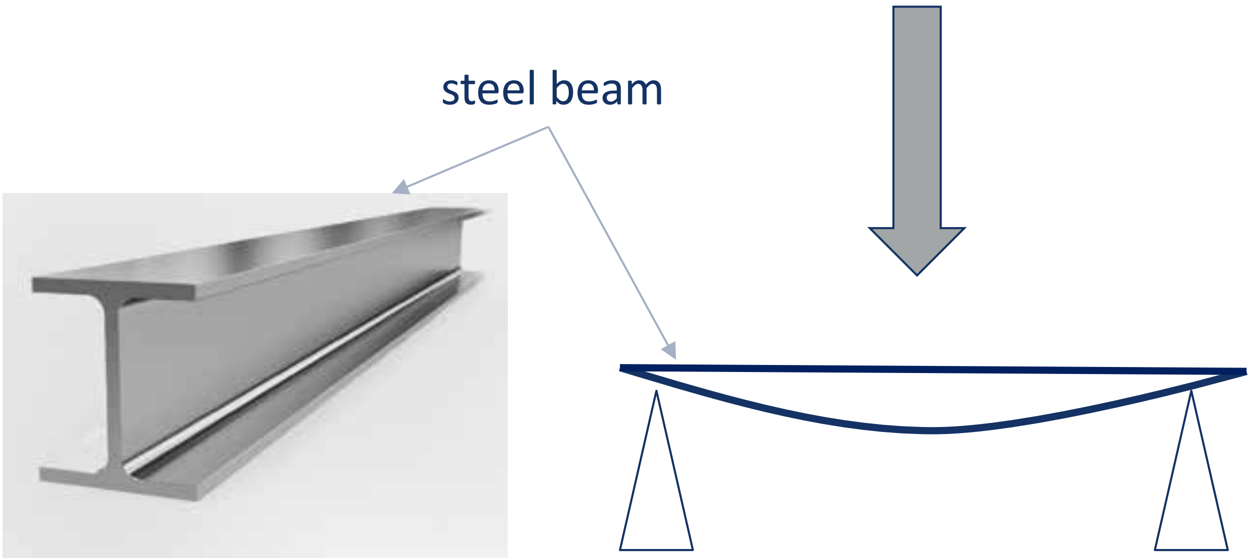


MECHANICAL PROPERTY –
SPECIFIC MODULUS - SPECIFIC STRENGTH CHART



MECHANICAL PROPERTIES - STIFFNESS

The resistance of a material to elastic deformation or deflection is called stiffness or rigidity.



e.g. steel beam is stiffer or more rigid than aluminium beam.

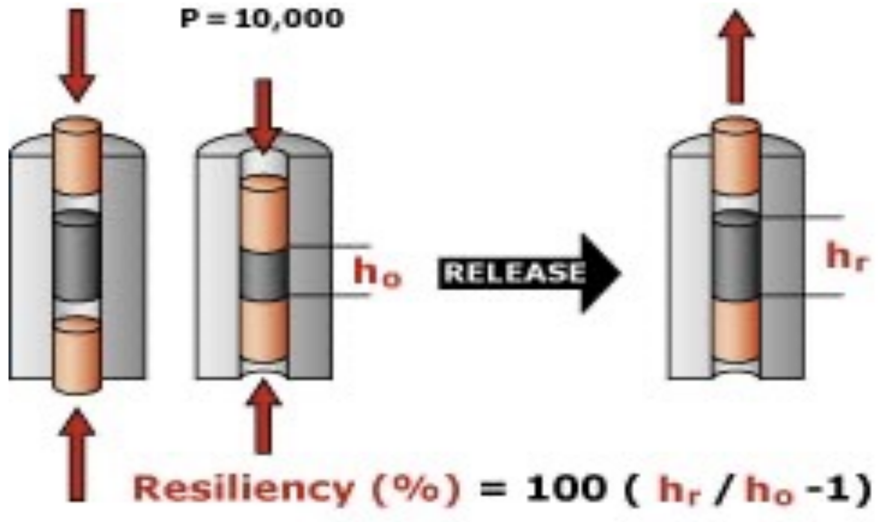
$$k = \frac{F}{\delta} = \frac{force\ on\ the\ body}{displacement\ (change\ in\ length)\ produced\ by\ the\ force}$$

The complementary concept to stiffness is flexibility; the more flexible an object is, the less stiff it is

MECHANICAL PROPERTIES - RESILIENCE

It is the capacity of a material to absorb energy elastically

- Proof resilience: maximum energy which can be stored in a body up to elastic limit
- Modulus of resilience: proof resilience per unit volume

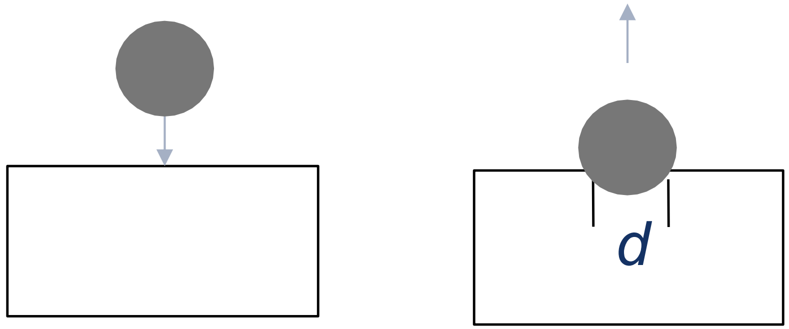


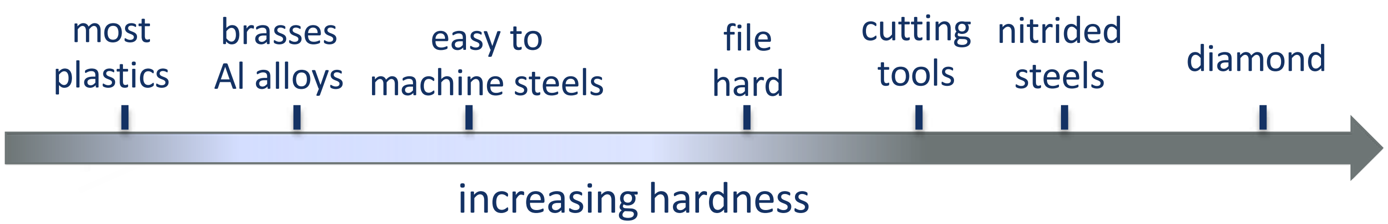
It is measured by the amount of energy absorbed per unit volume within elastic limit.
(this property is essential for spring materials)

MECHANICAL PROPERTIES - HARDNESS

Hardness is the resistance to plastic deformation; usually defined in terms of the ability of a material to resist to scratching, abrasion, cutting, indentation, or penetration

1. Apply known force
2. measure size of indent after removing load
3. Smaller indents mean larger hardness.





Alloy Properties	Zinc Alloy			Aluminum Alloy				Bronze	Steel
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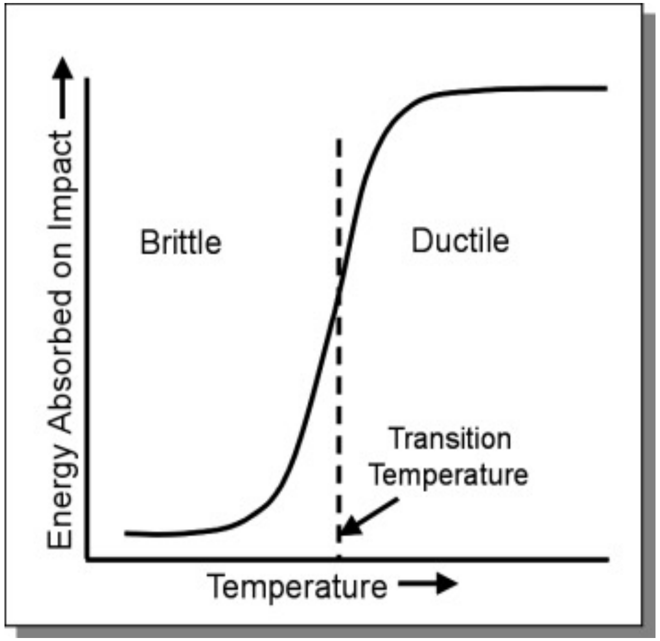
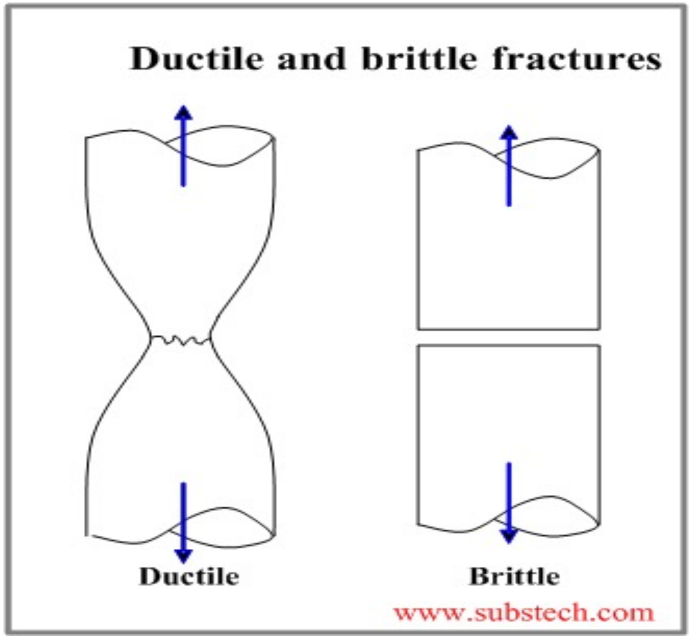
Hardness [Brinell # / HB]	82	89	119	40-70	70	80	95	85	126

Large hardness means resistance to plastic deformation or cracking in compression

MECHANICAL PROPERTIES - BRITTLENESS

It is the property of breaking without much permanent distortion.



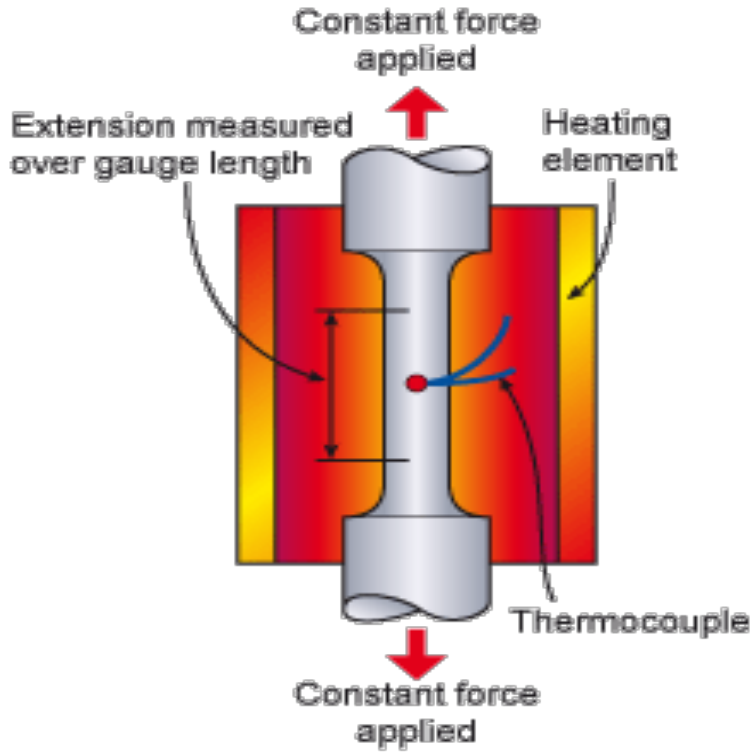


Non-ductile material is considered to be brittle material.
(e.g, glass, cast iron, etc.)

MECHANICAL PROPERTIES - CREEP

The slow and progressive deformation of a material with time at constant stress

- Permanent deformation (elongation) due to continuous load
- Soft materials (lead, zinc, tin, etc.) creep at room temperature
- Heavy metals (iron and copper) tend to creep with increase in temperature

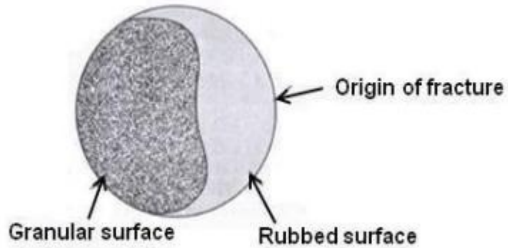


It is most generally defined as time-dependent strain occurring under stress

MECHANICAL PROPERTIES - FATIGUE

Fatigue fractures are progressive beginning as minute cracks and grow under the action of fluctuating stress

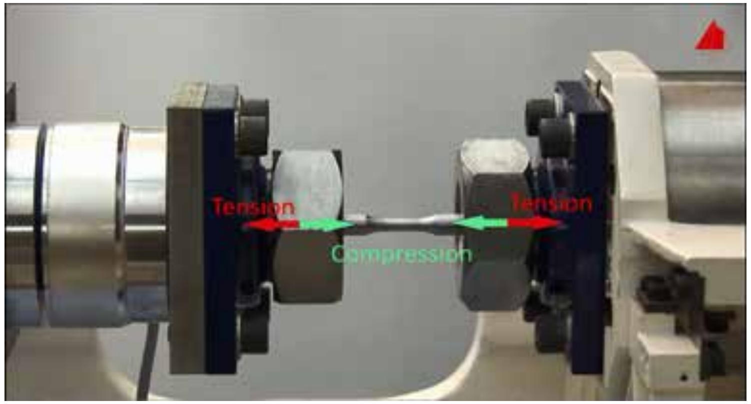
- Permanent deformation & failure of material due to rapidly cyclic or varying load
- Fatigue life affected by
  - temperature
  - surface finish
  - heat treatment

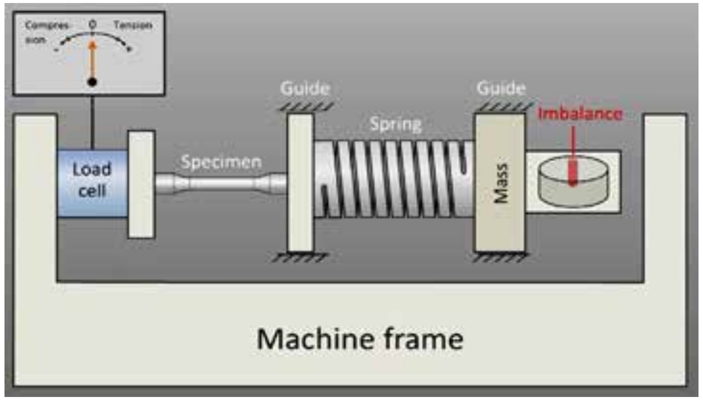


Surface of a Fatigue Fracture

This phenomenon leads to fracture under repeated or fluctuating stress

FATIGUE TEST





MATERIAL SELECTION

MATERIAL SELECTION PROCEDURE

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Defining Material Performance Requirements

- Strength
- Toughness
- Density
- …

Screening of candidate materials

- Metals & alloys
- Ceramics
- Composites
- …

Numerical evaluation

- Cost per unit property
- Pairwise comparison
- Performance index

Selection

NUMERICAL EVALUATION PROCEDURE

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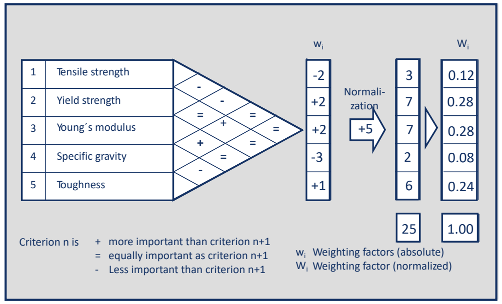
Weighting Factors of Material Properties



Scaling the Material Properties

$$Scaled\ property = \frac{Numerical\ value\ of\ mat.property * 100}{Max.value\ in\ the\ list}$$

Cost per Unit Strength (€/Nm)

$$\frac{Specific\ gravity\ (^{kg}/_{m^3})}{Working\ strength\ (MPa)} * relative\ cost\ per\ unit\ weight\ (€/kg)$$

where,

$$Working\ strength = \frac{Yield\ strength}{Safety\ factor}$$

Calculating the Material Performance Index (γ)

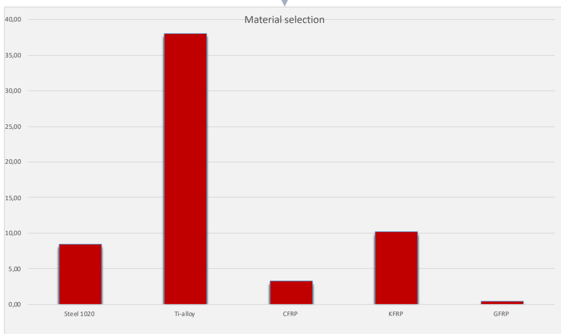
$$\gamma = \sum_{i=1}^{n} \beta_i * \alpha_i$$

where,
β = scaled material property
α = weighting factor of material property

Calculating the Figure of Merit (M)

$$M = \frac{\gamma}{C} * 100$$

where,
γ = material performance index
C = cost of material per unit strength



EXERCISE 5.1

There are different kind of materials for bicycle frames

BMX
steel and aluminium

Racing Bicycle
steel tubing, aluminium and titanium

Mountain Bike
steel, aluminium, carbon fiber, Titanium

Touring Bicycle
Aluminium, steel and titanium

Different materials for different purposes

EXERCISE 5.1

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- Select a proper material for a bicycle frame manufacturing using the spreadsheets S16-S20

Wood

CFRP

Aluminum

Bamboo

Plastics

Steel

KFRP

Titanium

GFRP

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THANK YOU!