Cihan University Sulaymaniya
Engineering Faculty
Archtectural Engineering Department

Building Materials

Chapter Two

(Properties of Engineering Materials)

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Instructor: Diyari B. Hussein

Chapter Two
Properties of Engineering Materials

Introduction:

Materials for engineering applications are selected so as to perform satisfactorily during service. The material for a highway bridge should possess adequate strength, rough surface, and sufficient rigidity. A water-retaining structure would be built with a material that is impermeable, crack-free, strong, and does not react with water. A road surface needs such materials that show little movement under the impact of loads, are water-resistant, and are easy to repair.

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Properties of Engineering Materials

Performance requirements:

Performance requirements, or property specifications, are not the same for all structures or materials. What is expected of a material used for the construction of a liquid-retaining structure is not the same as that chosen for a pavement. To evaluate the performance characteristics of engineering materials, and to assist an engineer in the selection of the most appropriate and economical material for a particular application, one needs to study the properties of the materials of construction.

Chapter Two
Properties of Engineering Materials

Properties of engineering materials:

In general, the common properties of engineering materials are grouped under three major headings:

1. Mechanical Properties
2. Physical Properties
3. Chemical Properties

Chapter Two
Mechanical Properties

1) Mechanical Properties:

The mechanical behavior of materials is the response of the material to external loads. The specific response of a material depends on :

1. Its properties.
2. The magnitude.
3. Type of load.
4. The geometry of the element.

Chapter Two
Mechanical Properties

Loading Conditions:

One of the considerations in the design of a project is the type of loading the structure will be subjected to during its design life.
The two basic types of loads are:

1. Static Loading.
2. Dynamic Loading.

Each type affects the material differently.

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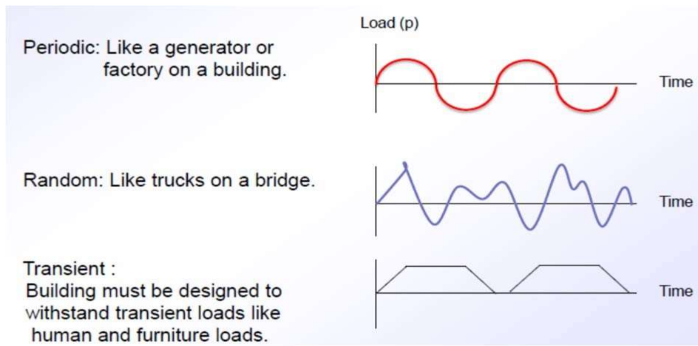
Mechanical Properties

Loading Conditions:

Static Loading: Implies a sustained loading of the structure over a period of time.

Dynamic Loading: Loads that generate a shock or vibration in the structure, can be classified as:



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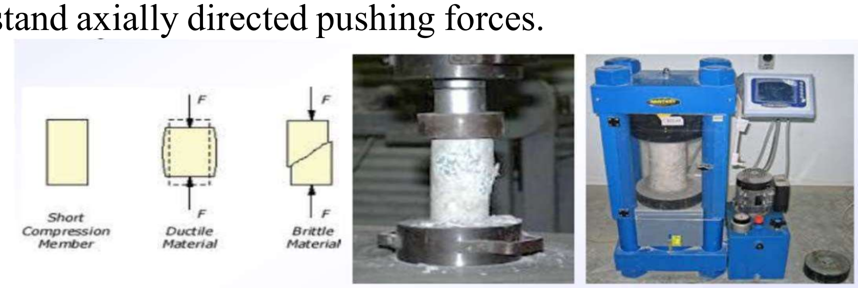
Strength:

Is the ability of a material to resist failure under the action of stresses caused by loads. Most common sorts are compression, tension, bending, impact, fatigue and creep.

1. Compressive Strength: is the capacity of a material or structure to withstand axially directed pushing forces.



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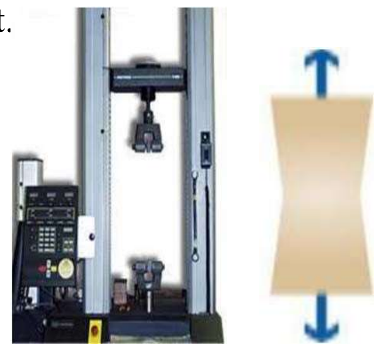
Mechanical Properties

2. Tensile Strength:

is the maximum stress that a material can withstand while being stretched or pulled before *necking*, which is when the specimen's cross-section starts to significantly stretch. Tensile strength is the opposite of compressive strength and the values can be quite different.



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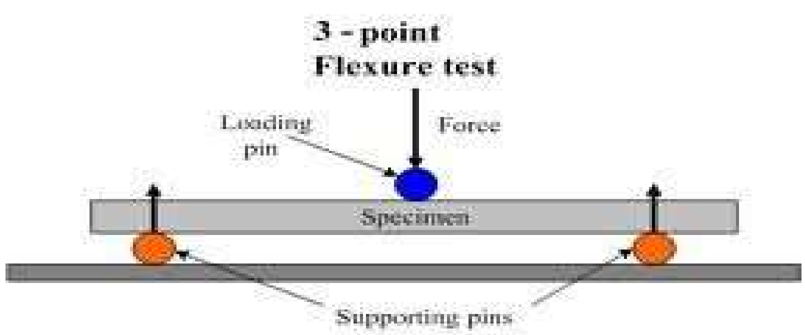
3. Bending Strength:

is defined as a material's ability to resist lateral deformation under load. It is also called "Flexural Strength".



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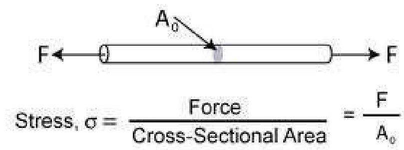
Stress:

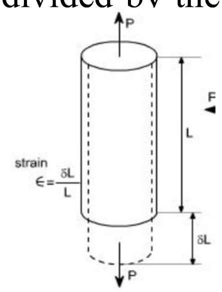
is the applied load divided by the unit area.

Stress(σ)=Applied load/Area=P/A



Strain: The specimen changes its dimensions when subjected to loading. This change in shape (i.e., deformations) divided bv the original dimension gives Strain in that direction.

$$\in = Strain = \frac{Change\ in\ length}{Original\ length} = \frac{\partial L}{L}$$



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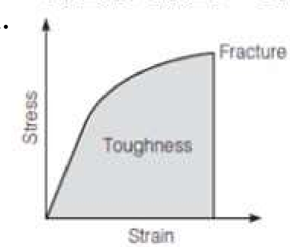
Ductility: Is the ability of a material to undergo large deformation without fracture. It is measured by elongation and reduction of area and expressed as a percentage.

Brittleness: Low resistance to sudden blows. Brittle materials do not stretch and break suddenly.

Toughness: Is the ability of a material to absorb large amount of energy. It is measured by the energy required to fracture the specimen.



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Fatigue: Failure of a material by repeated stresses below the yield or ultimate stress.

Durability: can be defining as the ability of a material to remain serviceable for at least the required lifetime of the structure of which it forms a part.

Elasticity and plasticity: Refer to different response to external forces. Elasticity is the ability of material to come back to its original shape after the removal of external forces. Whereas plastic behavior implies little rebound when the applied stress is released.

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Mechanical Properties

Stress-Strain Relationship:

- When the material is subjected to external forces, it will develops one or more of the following types of strain.

1. Linear elastic
2. Non-linear elastic
3. Plastic

- Material selection is an important step in product development. In a mechanical engineering sense, we select a material based on:

1. Strength (Yield and Ultimate)
2. Stiffness (Modulus of Elasticity)
3. Ductility (Percent Elongation)

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Mechanical Properties

Stress-Strain Relationship:

Glass: shows linear stress-strain relationship up to the point where the material fails.

Steel : a linear relationship is obtained up to a certain limit after which the material deforms without much increase in stress.

Aluminuim Alloys: exhibit a linear stress-strain relationship up to a proportion limit after which a non-linear relation follows.

Concrete : shows a non-linear relationship throughout the whole range.
Soft rubber: shows linear relationship followed by a reverse curve.

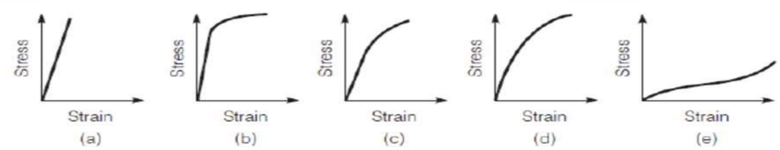

FIGURE 1.2 Typical uniaxial stress–strain diagrams for some engineering materials: (a) glass and chalk, (b) steel, (c) aluminum alloys, (d) concrete, and (e) soft rubber.

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Mechanical Properties

Stress-Strain Relationship:

Elastic Behavior :

Is the ability of a material to return to its initial form and dimensions after the load removed. Ratio of unit stress to unit deformation is termed modulus of Elasticity, E.

$E=\sigma/\varepsilon$ This relationship is known as Hook's law.

Elastic deformation does not change the arrangement of atoms within the materials, but it stretches the bonds between atoms. When the load is removed the atomic bonds return to their original position.

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Mechanical Properties

Stress-Strain Relationship:

Plastic Behavior:

As the stress applied on the specimen is increased, the strain will proportionally increase up to a point. When the load is removed from the specimen, some of the deformation will be recovered and some of the deformation will remain.

Plastic behavior indicates permanent deformation of the specimen so that it does not return to its original shape when the load is removed.

The strain required to cause plastic deformation actually increase. This process is called strain hardening . Mild steel is an example of material that experiences strain hardening during plastic.

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Mechanical Properties

Ductile Material:

A material is said to be ductile if it is capable of withstanding large strains under load before fracture occurs. These large strains are accompanied by a visible change in cross-sectional dimensions and therefore give warning of impending failure. Like mild steel, aluminum and copper.

Brittle Materials:

A brittle material exhibits little deformation before fracture, the strain normally being below 5% . when a brittle materials fails, the structure can collapse in a catastrophic manner. Like concrete, ceramic, glass, cast iron, high strength steel, timber….

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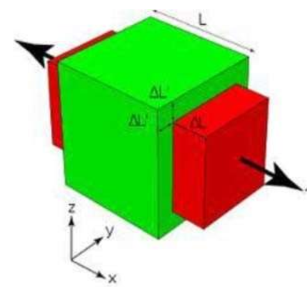
Mechanical Properties

Poisson's ratio:

In the axial tension test, as the material is elongated, there is a reduction of the cross-section in the lateral direction. In axial compression test, the opposite is true. The ratio of the lateral (transverse) strain, ε_t , to the axial strain (longitudinal) ε_L, is poissons ratio , $\boldsymbol{v}$:

$$v = \frac{\varepsilon_t}{\varepsilon_L}$$



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Mechanical Properties

Creep:

Creep is defined as the gradual increase in strain with time, under sustained load.

Some materials such as plastic and rubber exhibit creep at room temperature. In some `` soft`` metals, such as zinc, creep occurs over a relatively short period of time. Where as materials such as concrete may be subjected to creep over a period of years. Creep occurs in steel to a slight extent (at normal temperature) but become very important at temperature above 300 $^{\circ}C$.

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Mechanical Properties

Fatigue:

Many structure, such as bridges, are subjected to repeated loads, creating stresses that are less than the strength of the material. Repeated stresses can cause a material to fail or fatigue, at a stress well below the strength of the material. As the stress level decrease, the number of application before failure increase. Ferrous metals have an apparent *endurance limit*, below which fatigue does not occur.

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Mechanical Properties

Fatigue:

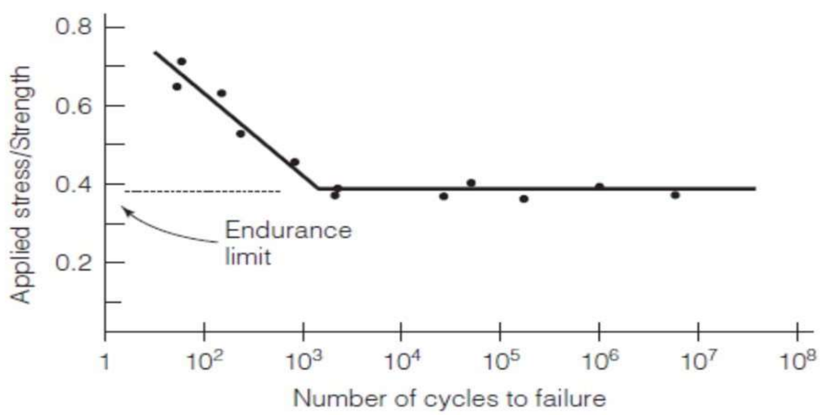

FIGURE 1.16 An example of endurance limit under repeated loading.

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Mechanical Properties

Fatigue:

FIGURE 1.17 Fatigue failure of asphalt pavement due to repeated traffic loading.

Chapter Two
Physical Properties

2) Physical Properties:

can be defined as the characteristics of the materials, other than load response, that affects the selection, use, and performance. It is also called **Non-mechanical properties**. The interesting properties for civil engineers are *density, porosity, thermal properties, and surface characteristics.*

1. Density:

Mass Density (ρ) Is the mass per unit volume of material. $\rho = \frac{m}{V}$ (Kg/m^3)

M: is the mass (kg, gm,….)

V: is the volume (m^3, cm^3, ….).

Weight Density (γ) Is the weight per unit volume of material. $\gamma = \frac{w}{V}$ (N/m^3)

It is also called specific weight or unit weight . $\gamma = \rho . g$

A commonly used value is the specific weight of water on Earth at 5°C which is 9807 N/m^3

Density of Some important Building Materials:

Material	Bulk Density, kg/m^3
Water	1000
Concrete	2300-2400
Steel	7850
Hollow concrete Block	1400
Brick	1600 – 1900
Wood	500 -600
Granite	2500 – 2700

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Physical Properties

Bulk Density :

Is the mass per unit volume of material in its natural state (with pores and voids) . Properties like strength and heat conductivity are greatly affected by their bulk density.

Relative Density (or Specific Gravity):

is the ratio of the density (mass of a unit volume) of a substance to the density of water. Or : is the ratio of weight of a given volume of a solid to the weight of an equal volume of water at 4 $^\circ C$.

2. Porosity (n):

is a measure of the void (i.e., "empty") spaces in a material. Porosity is the ratio of the volume of pores to the total volume of the specimen : n=Vv/V

Void Ratio (e) : is the ratio of volume of voids(Vv) to the volume of solids(Vs).

e = Vv/Vs.

The relation between void ratio and porosity is:

n=e/(e+1)

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Physical Properties

3. Water Absorption:

The ability of the material to absorb and retain water. It is expressed in percentage.

$\%W = (m2 - m1)/m1$, Where:

$m2$ is the mass of saturated material, and $m1$ is the mass of dry material.

Water Permeability: is the capacity of a material to allow water to penetrate under pressure. Materials like glass , steel, and bitumen are impervious.

4. Thermal Conductivity: (or heat conductivity)

Is the ability of a material to conduct heat. It is influenced by the nature of the material, its structure, porosity. Materials of low thermal conductivity are used as thermal insulation. The reciprocal of the thermal conductivity is the thermal resistance (or insulating value, R)

Material	Thermal Resistance, R , (m².ºC/W)
120 mm Brick	0.166
240 mm Brick	0.33
200 mm Concrete	0.21
200 mm Hollow Concrete Block	0.19
50mm White Stone	0.083

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Physical Properties

5. Thermal Expansion:

Is a measure of dimensional changes caused by temperature. All materials expanded as temperature increases and contract as falls. The amount of expansion per unit length due to one temperature increase is the

Coefficient of Thermal Expansion : $\alpha = \frac{\Delta L/\Delta T}{L}$

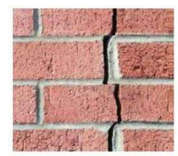
α is linear coefficient of thermal expansion,
ΔL is the change in length of the specimen.
ΔT is the change in temperature .
L is the length of the specimen.

While α for structural materials is different, the materials will strain at different rates with the increase or decrease in temperature. This might lead to fracture. Steel and concrete have closely the same α .

Concrete may also cracks, due to thermal expansion and contraction (in summer and winter), therefore joints are used in buildings, bridges and concrete pavements.







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Physical Properties

Thermal Expansion Coefficient at 20 $^{\circ}C$

Material	Fractional expansion per degree C x10^-6	Fractional expansion per degree F x10^-6
Glass, ordinary	9	5
Concrete 1:2:4	11.9	6.6
Quartz	0.59	0.33
Aluminum	24	13
Brass	19	11
Copper	17	9.4
Iron	12.06	6.7
Steel	13	7.2
Masonry Brick	5.58	3.1
Plastering and Gypsum	16.56	9.2
Gold	14	7.8
Silver	18	10

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Physical Properties

Frost Resistance:

The ability of a water-saturated material to endure repeated freezing and thawing with considerable decrease of mechanical strength. The water contained by the pores increases in volume up to 9% on freezing. Thus cause excess internal pressure and may lead to failure.

Fire Resistance:

Is the ability of material to resist the action of high temp. (fire) without any appreciable deformation and substantial loss of strength. Concrete and brick have high action but steel suffer considerable deformation under the action of high temperature.

Chapter Two
Physical Properties

Failure and Safety :

Failure occurs when a member or structure ceases to perform the function for which it was designed. Failure of a structure can take several modes including fracture, yielding, buckling, and excessive deformation.

A **brittle material** typically fracture suddenly when the static stress reaches the strength of the material. On the other hand, a **ductile material** may fracture due to excessive plastic deformation. Long member subjected to axial compressive loads, may fall due to **buckling**. Some times **excessive deformation** could be defined as failure.

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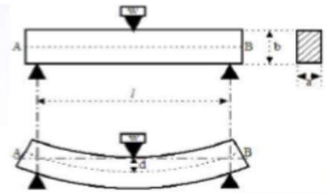
Physical Properties

Buckling

Deflection



To minimize the chance of failure, structures are designed to carry a load greater than the actual applied load.

The factor of safety is defined as the ratio of absolute strength (structural capacity) to actual applied load.

$$FOS = \frac{structural\ capacity}{actual\ applied\ load} \qquad \frac{\sigma_{failure}}{\sigma_{allowable}}$$

Typically:

The larger factor of safety ⇒ the larger required cross-section of the structure and, consequently ⇒ the higher the cost and ⇒ larger life time.

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Physical Properties

Sampling:

Sampling is concerned with the selection of a subset of individuals from within a statistical population to estimate characteristics of the whole population. Two **advantages** of sampling are that:

1- the cost is lower and

2- data collection is faster.

By testing sufficient samples, it is possible to estimate the properties of the entire population, may be randomly selected. Random sampling requires that all element of the population have an equal chance for selection. For example, when sampling a stockpile of aggregate, it is important to collect samples from top, middle, and bottom and to combine them.

Aggregate Sample

Concrete Samples

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Physical Properties

Classification of Tests:

According to the purpose of the test

1. Check testing of factory product as a control of quality of output.
2. Site test of structural adequacy of construction which for some reason may have become suspect to load test.
3. Site investigation on soil to determine its properties for design purposes.
4. Lab. test on small or full scale component to check performance.
5. Regular inspection of structures under special exposure conditions such as offshore structures.

According to their nature

1. Destructive test: Tests to failure point.
2. Non-destructive test: these tests are conducted without affecting the serviceability of the tested component. Such as Ultrasonic puls, Rebound hammer, corrosion potential, …etc.

Chapter Two
Physical Properties

Testing Machines:

1. Universal testing machines: which are designed for use for more than one test.
2. Special testing machine: to be used for certain tests only, thermal conductivity.
3. Devices and equipment for site tests, core-drilling machine, soil investigation machinery, ….etc.

Chapter Two
Chemical Properties

3) Chemical properties:

are those pertaining to the composition and potential reaction of a material. The compounds of composition, such as oxides and carbonates, describe the chemical nature of the material, and the way it would behave in a certain environment. For example, by reviewing the proportions of the principal compounds in various cements, we will be able to choose the right type of cement for a particular application. Knowledge of the chemical composition of clays is indispensable in evaluating the characteristics expected in burned bricks.

Chapter Two
Chemical Properties

Chemical properties:

Chemical properties such as acidity, alkalinity, and resistance to corrosion of materials are especially noteworthy. In addition to the physical, chemical, and mechanical properties, the thermal, electrical, magnetic properties of materials are also of relevance in civil engineering. For example, the coefficient of thermal expansion of concrete, which is a thermal property, is fundamental in assessing the expansion potential of concrete slabs.

End of Chapter Two

Thank You