Lecture 5

Mechanical Properties of Materials (2)

Mohamad Fathi GHANAMEH

Lecture Objectives

- ✓ Discuss the mechanical properties and other test related to the development of mechanics of materials

Lecture Outline

- ✓ Hooke's Law
- ✓ Strain Energy
- ✓ Poission's Ratio
- ✓ Shear Stress-Strain Diagram
- ✓ Failure of Materials Due to Creep and Fatigue

Hooke's Law

The stress–strain diagrams for most engineering materials exhibit a linear relationship between stress and strain within the elastic region. Consequently, an increase in stress causes a proportionate increase in strain. This fact was discovered by Robert Hooke in 1676 is known as Hooke's law: $\sigma = E\,.\varepsilon$

Hooke’s Law

Modulus of elasticity or Young’s modulus

Here E represents the constant of proportionality, which is called the modulus of elasticity or Young’s modulus, named after Thomas Young, who published an account of it in 1807.

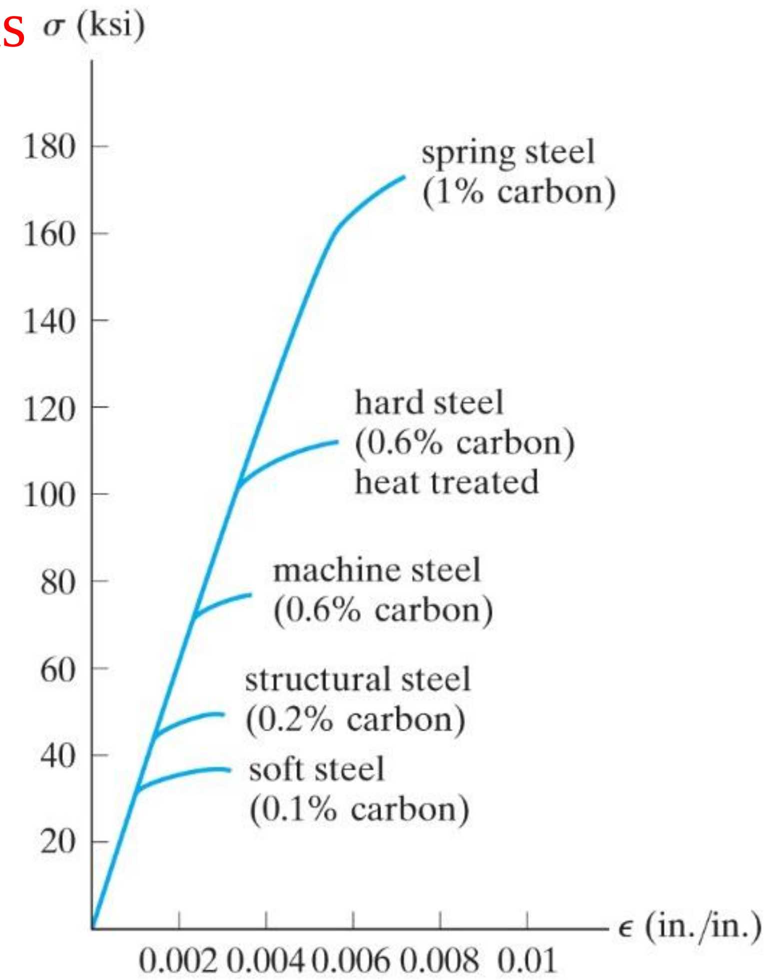
Since strain is dimensionless, E will have the same units as stress

Thomas Young
(1773-1829)

Hooke's Law

Modulus of elasticity or Young's modulus

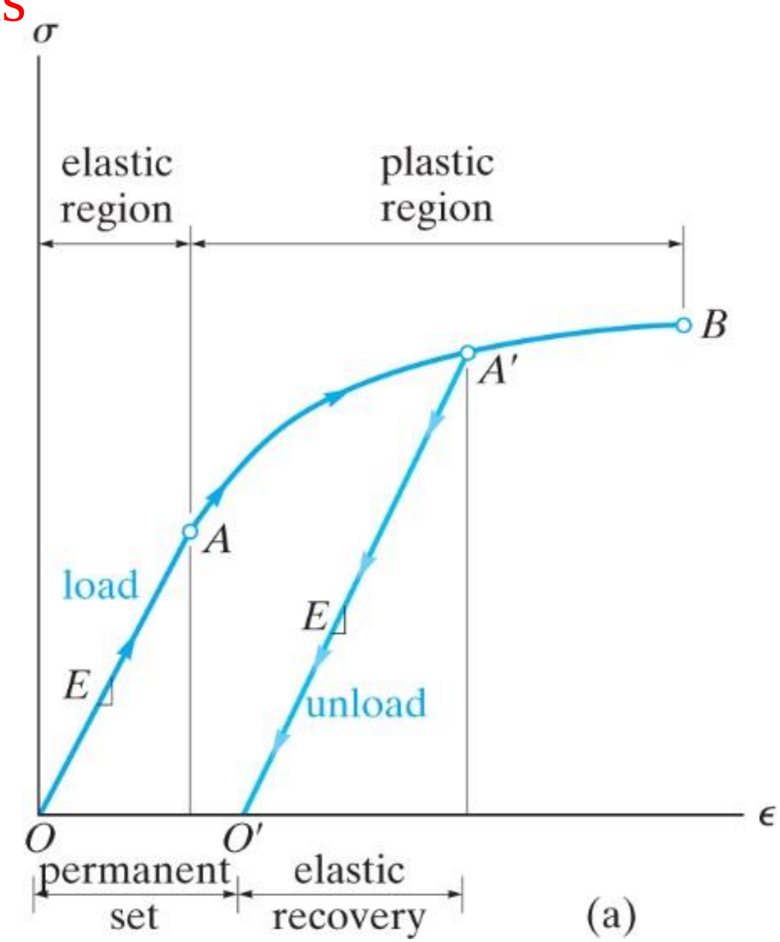
The proportional limit for a particular type of steel alloy depends on its carbon content; however, most grades of steel, from the softest rolled steel to the hardest tool steel, have about the same modulus of elasticity, generally accepted to be 200 GPa



Hooke’s Law

Modulus of elasticity or Young’s modulus

If a specimen of ductile material, such as steel, is loaded into the plastic region and then unloaded, elastic strain is recovered as the material returns to its equilibrium state. The plastic strain remains, however, and as a result the material is subjected to a permanent set.



Properties of Materials

Modulus of elasticity or Young's modulus *E*

It indicates the stiffness of a material.

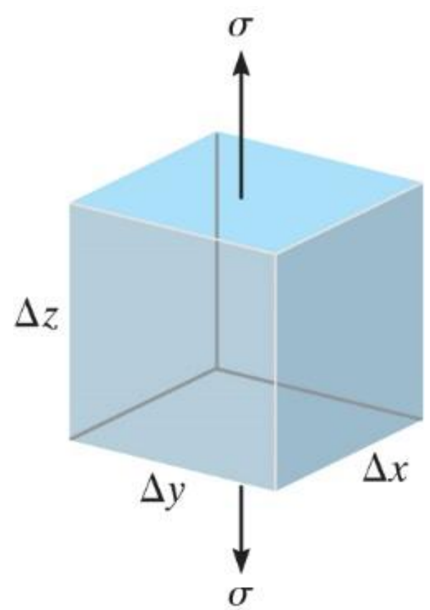
Materials that are very stiff, such as steel, have large values of E (200 GPa), whereas spongy materials such as vulcanized rubber may have low values (0.70 MPa).

Properties of Materials

Strain Energy ΔU

As a material is deformed by an external loading, it tends to store energy internally throughout its volume. Since this energy is related to the strains in the material, it is referred to as strain energy.

$$\Delta U = \frac{1}{2}\sigma.\varepsilon.\Delta V$$



Properties of Materials

Strain Energy density u

It indicates the strain energy per unit volume of material.

$$u = \frac{\Delta U}{\Delta V} = \frac{1}{2}\sigma.\varepsilon$$

If the material behavior is linear elastic, then according to Hooke's law, we can express the elastic strain-energy density in terms of the uniaxial stress

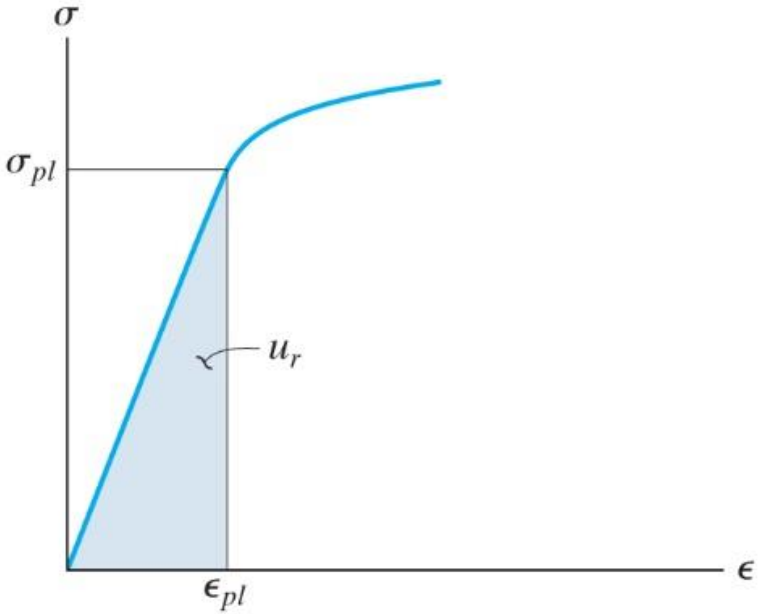
$$u = \frac{1}{2}\sigma.\varepsilon = \frac{\sigma^2}{2E}$$

Properties of Materials

Modulus of Resilience u_r

$$u_r = \frac{1}{2}\sigma_{pl}.\varepsilon_{pl} = \frac{\sigma_{pl}^2}{2E}$$

- It indicates the strain-energy density of the material when the stress reaches the proportional limit.
- It represents the ability of the material to absorb energy without any permanent damage to the material.

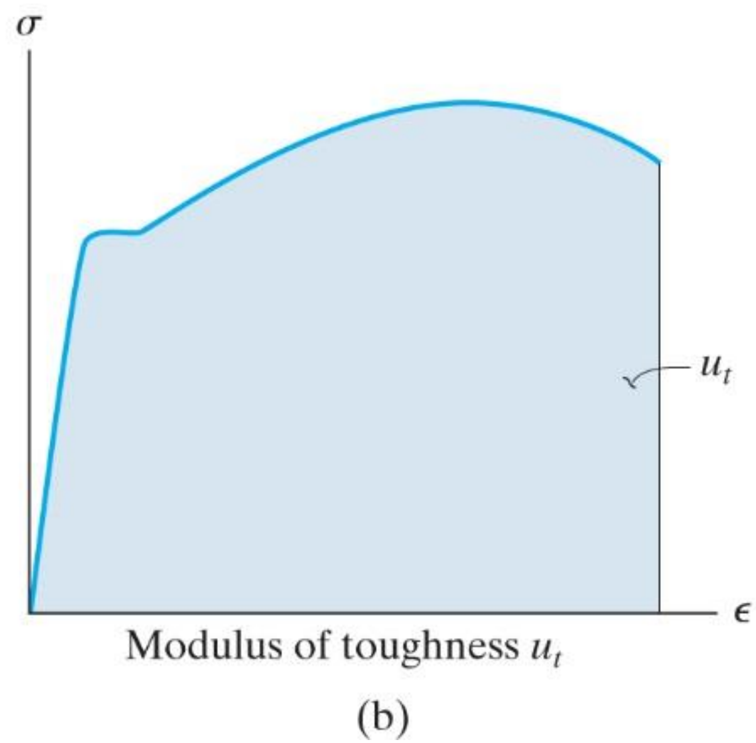


Modulus of resilience u_r

Properties of Materials

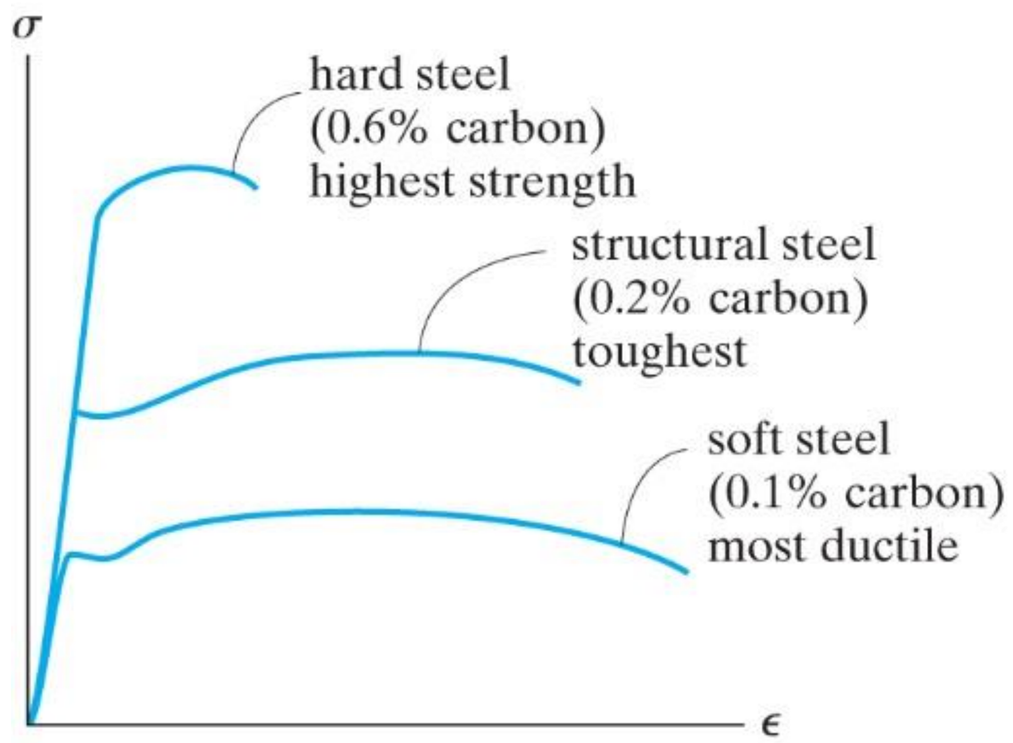
Modulus of Toughness u_t

- It represents the entire area under the stress–strain diagram,
- It indicates the strain-energy density of the material just before it fractures.
- This property becomes important when designing members that may be accidentally overloaded.



Properties of Materials

Alloying metals can also change their resilience and toughness. For example, by changing the percentage of carbon in steel, the resulting stress–strain diagrams show how the degrees of resilience and toughness can be changed.



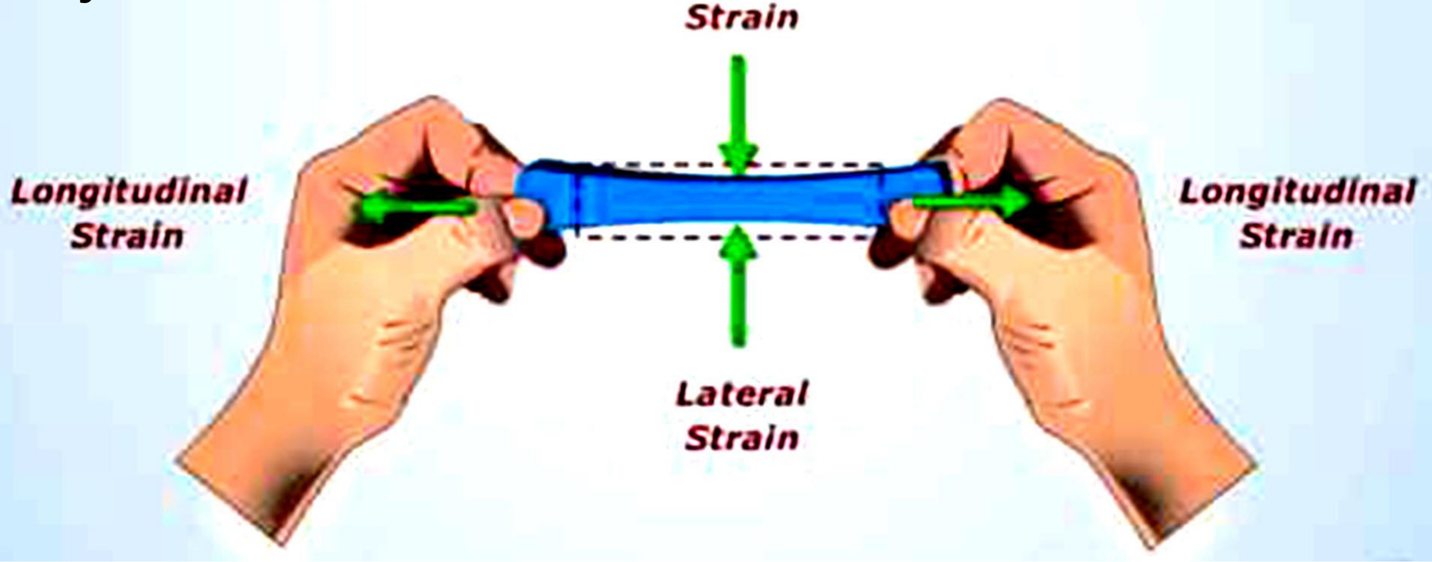
UR الجامعة الدولية للرباط ⵜⴰⵙⴷⴰⵡⵉⵜ ⵜⴰⴳⵔⴰⵖⵍⴰⵏⵜ ⵏ ⵕⴱⴰⵟ Université Internationale de Rabat
UR School of Automotive Engineering
UR School of Aerospace Engineering

Properties of Materials

Poisson's Ratio ν

When a deformable body is subjected to an axial tensile force, not only does it elongate but it also contracts laterally

Likewise, a Compressive force acting on a body causes it to contract in the direction of the force and yet its sides expand laterally.



Properties of Materials

Poisson's Ratio ν

In the early 1800s, the French scientist S. D. Poisson realized that within the elastic range the ratio of these strains is a constant, since the deformations and are proportional. This constant is referred to as **Poisson's ratio**, ν (nu), and it has a numerical value that is unique for a particular material that is both homogeneous and isotropic.

Simeon Denis Poisson.

Properties of Materials

Poisson's Ratio ν

$$\nu = -\frac{\varepsilon_{lat}}{\varepsilon_{long}}$$

lateral contraction (negative strain)

longitudinal elongation (positive strain)

These strains are caused only by the axial or longitudinal force P

Poisson's ratio is a dimensionless quantity,
For most nonporous solids it has a value that is generally between 1/4 and 1/3. For an "ideal material" having no lateral deformation when it is stretched or compressed Poisson's ratio will be 0. Furthermore, the maximum possible value for Poisson's ratio is 0.5

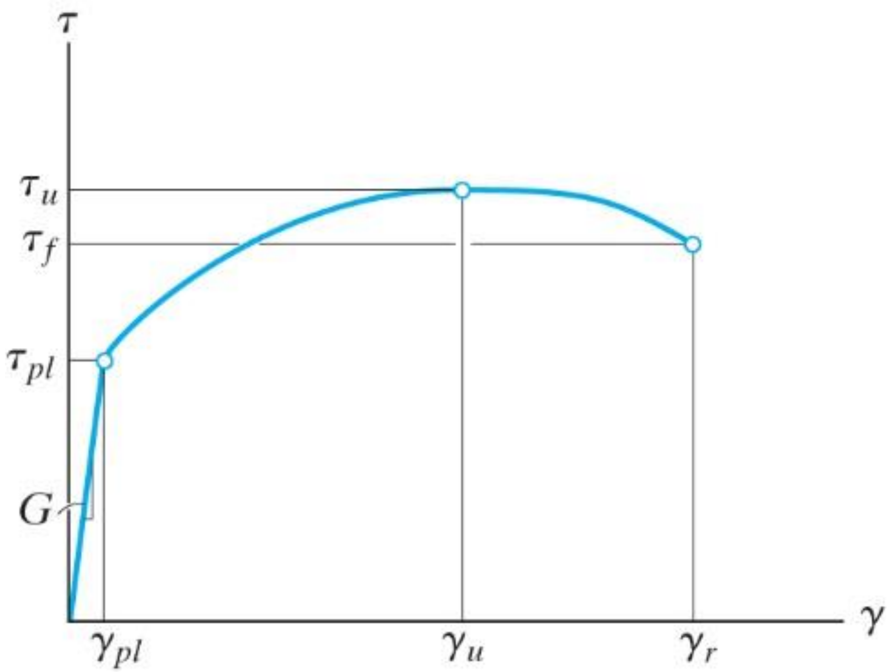
Properties of Materials

Young's modulus And Poisson's Ratio For Some Materials

Materials	Young's Modulus	Poisson's Ratio
Steel	2.1e5	0.3
Cast Iron	1.20e5	0.28
Wrought Iron	1.90e5	0.3
Aluminium	0.70e5	0.35
Aluminium Alloy	0.75e5	0.33
Brass	1.10e5	0.34
Bronze	1.20e5	0.34
Copper	1.20e5	0.34
Copper Alloy	1.25e5	0.33
Magnesium	0.45e5	0.35
Titanium	1.10e5	0.33
Glass	0.60e5	0.22
Rubber	50	0.49
Concrete	0.25e5	0.15

The Shear Stress–Strain Diagram

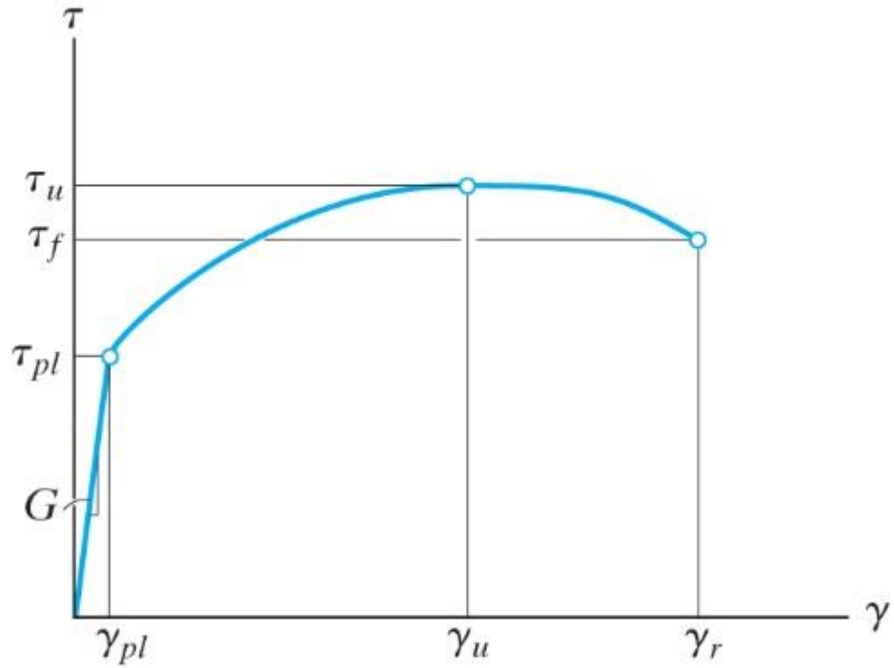
The behavior of a material subjected to pure shear can be studied in a laboratory using specimens in the shape of thin tubes and subjecting them to a torsional loading. If measurements are made of the applied torque and the resulting angle of twist, this data can be used to determine the shear stress and shear strain, and a shear stress–strain diagram plotted.



The Shear Stress–Strain Diagram

The material when subjected to shear will exhibit linear-elastic behavior and it will have a defined *proportional limit .*

Also, strain hardening will occur until an *ultimate shear stress* is reached. And finally, the material will begin to lose its shear strength until it reaches a point where it fractures,



Properties of Materials

Shear modulus of Elasticity or the Modulus of Rigidity G

For most engineering materials, the elastic behavior is *linear*, and so Hooke's law for shear can be written as

$$\tau = G.\gamma$$

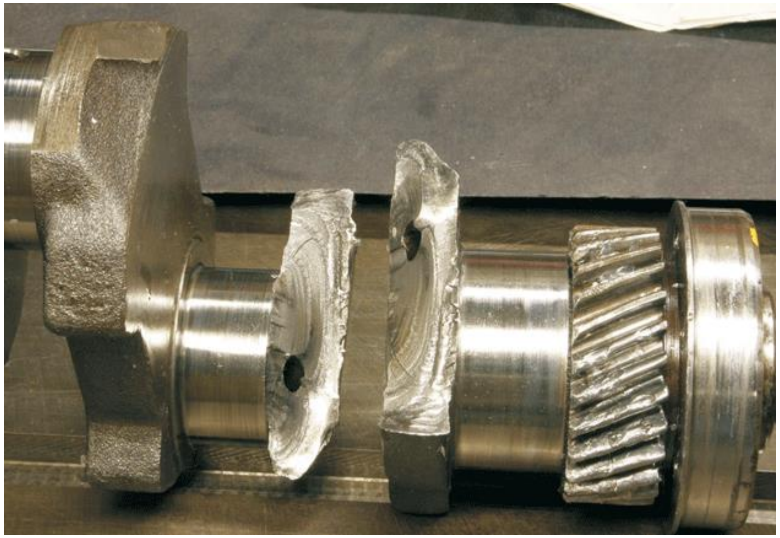
G is called the shear modulus of elasticity or the modulus of rigidity.

Failure

What is Failure?

Failure

Failure : Any change in a machine part which makes it unable to perform its intended function.



Failure

Failure of a member is defined as one of two conditions:

1. Fracture of the material of which the member is made. This type of failure is the characteristic of brittle materials.
2. Initiation of inelastic (Plastic) behavior in the material. This type of failure is the one generally exhibited by ductile materials.

Causes of mechanical failure

The usual causes of mechanical failure in the component or system are:

- Misuse or abuse
- Assembly errors
- Manufacturing defects
- Improper or inadequate maintenance
- Design errors or design deficiencies
- Improper material or poor selection of materials
- Improper heat treatments
- Unforeseen operating conditions
- Inadequate quality assurance
- Inadequate environmental protection/control
- Casting discontinuities.

Types of mechanical failure

The general types of mechanical failure include:

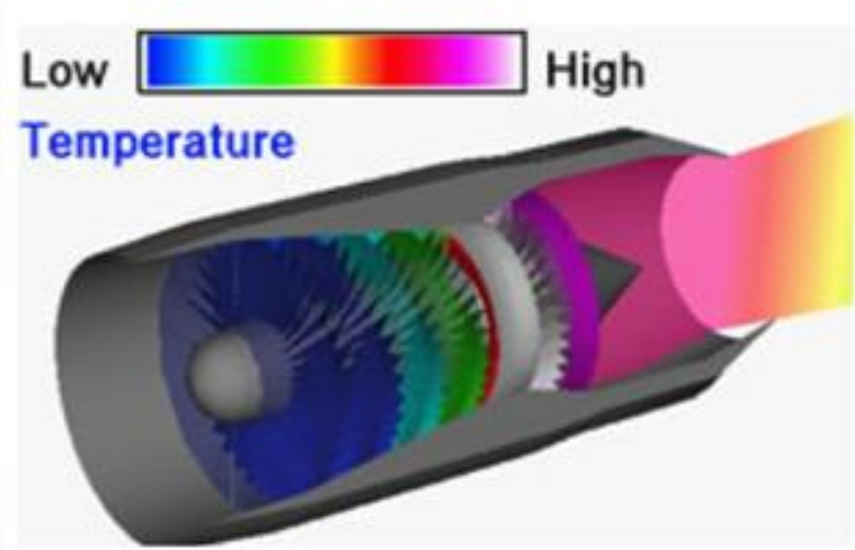
- ✓ Failure by fracture due to static overload, the fracture being either brittle or ductile.
- ✓ Buckling in columns due to compressive overloading.
- ✓ Yield under static loading which then leads to misalignment or overloading on other components.
- ✓ Failure due to impact loading or thermal shock.
- ✓ Failure by fatigue fracture.
- ✓ Creep failure due to low strain rate at high temperature.
- ✓ Failure due to the combined effects of stress and corrosion.
- ✓ Failure due to excessive wear.

Failure of Materials Due to Creep

When a material has to support a load for a very long period of time, it may continue to deform until a sudden fracture occurs or its usefulness is impaired. This time-dependent permanent deformation is known as **creep**.

Failure of Materials Due to Creep

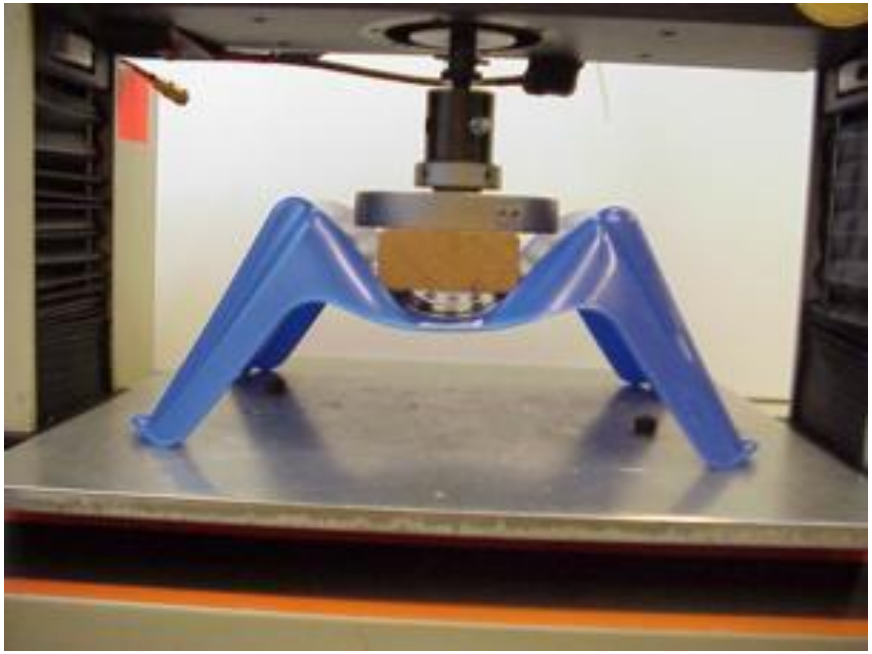
- Normally creep is considered when metals and ceramics are used for structural members or mechanical parts that are subjected to high temperatures.



Temperature variations across a turbojet engine. Image from NASA,

Failure of Materials Due to Creep

- For some materials, such as polymers and composite materials "including wood or concrete" temperature is not an important factor, and yet creep can occur strictly from long-term load application.



Failure of Materials Due to Creep

- Creep strength: This value represents the highest stress the material can withstand during a specified time without exceeding an allowable creep strain.
- The creep strength will vary with time, temperature, and applied stresses.
- In general, the creep strength will decrease for higher temperatures or for higher applied stresses.
- Once the material's creep strength has been determined, however, a factor of safety is applied to obtain an appropriate allowable stress for design.

Failure of Materials Due to Fatigue

When a metal is subjected to repeated *cycles* of stress or strain, it causes its structure to break down, ultimately leading to fracture. This behavior is called **fatigue.**

- Fatigue is usually responsible for a large percentage of failures in connecting rods and crankshafts of engines; steam or gas turbine blades; connections or supports for bridges, railroad wheels, and axis; and other parts subjected to cyclic loading.
- Fracture will occur at a stress that is less than the material's yield stress.
- endurance or fatigue limit: Represents the limit below which no evidence of failure can be detected after applying a load for a specified number of cycles.