Strength of materials

Stress is defined as the force per unit area that is observed by a material when an external force is applied. These external forces are generally uneven heating, permanent deformation, etc. These in turn help students calculate and find the plastic, elastic, and fluid behavior of each material under different forces.

Mathematically, stress is given by,

σ=F/A
Where, σ = Applied Stress
F = Force Applied

A = Area of Force

Types of Stress

There are different types of Stress that can be applied to a material, such as

Compressive Stress

When a force acts on a body, it causes a reduction in the volume of the said body, resulting in deformation. This type of stress is referred to as Compressive stress.

Compressive stress leads to material failure that is ultimately caused due to tension. The compressive stress from its application to brittle materials differs from that of ductile materials.

Tensile Stress

When an external force is applied per unit area on a material, and it results in the stretching of the said material, then it is described as Tensile Stress.

Tensile stress leads to elongation of any material due to external stretching force.

What is Strain?

If a body experiences deformation due to the applied external force in a particular direction, it is called strain. Moreover, the strain does not have any dimensions, as it only explains the change in the shape of the object.

The strain formula is expressed as,

ϵ=δlL
Where, σ = Strain due to Applied Stress
δl = change in length
L = original length

Types of Strain

Similar to stress, strain is also differentiated into Compressive Strain and Tensile Strain.

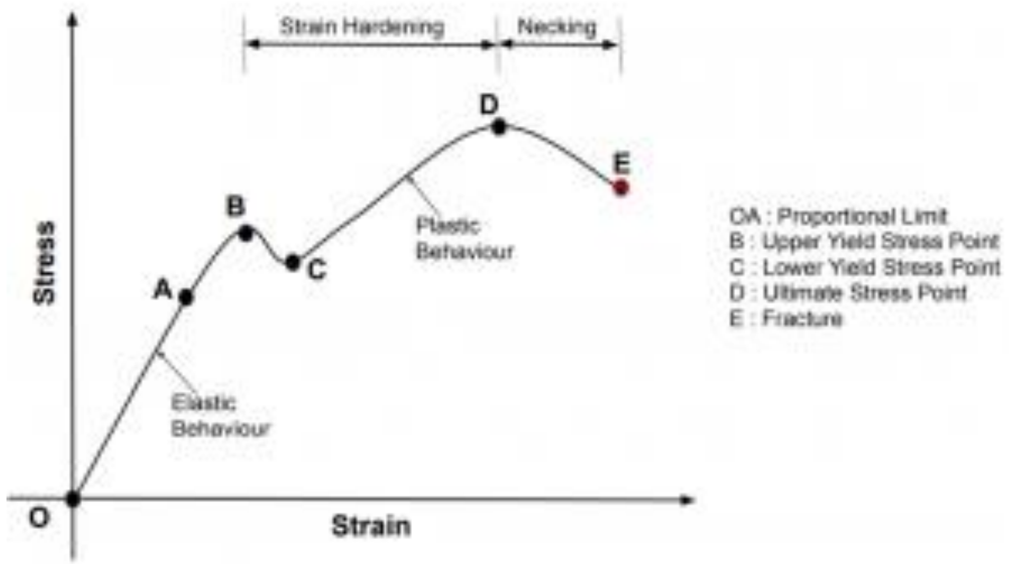
Compressive Strain

Compressive strain is defined as the deformation observed on an object when compressive stress acts on it. And in this type of strain, the length of the material or object generally decreases.

Tensile Strain

The Tensile stress acting on a body or a material that causes the increase in the length of said material is referred to as a tensile strain.

Stress-Strain Curve



This graph explains how stress and strain curves act on a body with respect to each other, as well as the different regions formed on the graph.

Stress-Strain Curve constitutes one of the crucial studies and essentially involves the study of elastic properties of materials understood through the relationship between stress and strain, factoring in various loads. In short, any material's stress-strain curve indicates the relationship between stress and strain. In this curve, the stress and its corresponding strain values are marked.

Let's understand the stress strain diagram in detail,

- The OA line represents the Proportional Limit, as it described the region, where the material or body obeys Hooke's Law. And this line can help students to calculate Young's Modulus, using the ratio of stress and strain.
- Now, the AB line represents the Elastic Limit of the object, which means that after this point, the body does not retain its original shape or size, when the acting force is removed.
- As you can guess, the BC lines describe the Yield Point. Which, when force is applied on the material, then there is complete deformation in the object, which cannot be reversed, even if the force is removed.
- D point on the graph is the point beyond which students can observe the complete failure of the object, as it crosses the maximum stress a material can endure. This point is stated as Ultimate Stress Point.

- E is the Fracture of Breaking Point, at which students can observe the complete failure of deformation of the object, regardless of the force whether it is applied or removed.

The stress-strain curve typically consists of several distinct regions:

Let us understand stress-strain curve as we try to understand the stress-strain graph better through various regions:

- Proportional limit
- Elastic Region
- Yield point
- Stress point
- Fracture or breaking point

Elastic Region: In this region, the material deforms elastically in response to applied stress, meaning it returns to its original shape once the stress is removed. The relationship between stress and strain is linear, and this region is characterized by Hooke's Law, which states that stress is proportional to strain.

Yield Point: Beyond a certain stress threshold known as the yield point, the material begins to deform plastically, meaning it undergoes permanent deformation even after the stress is removed. The yield point marks the transition from elastic to plastic deformation.

Plastic Region: In this region, the material continues to deform plastically with increasing stress, undergoing significant strain without a proportional increase in stress. Plastic deformation is irreversible, and the material's shape changes permanently.

Ultimate Tensile Strength: The ultimate tensile strength (UTS) is the maximum stress that a material can withstand before failure occurs. It represents the highest point on the stress-strain curve and indicates the material's resistance to fracture under tension.

Fracture Point: Beyond the ultimate tensile strength, the material experiences a rapid decrease in stress leading to fracture or failure. The fracture point marks the end of the stress-strain curve, indicating the material's ultimate failure under tension.

Hooke's Law

From the above sections, we have learned all about types of stress and strain, and their units, as well as a graphical representation of stress and strain on objects. Now let us talk about Hooke's law of stress and strain, which plays an important role in helping us understand how stress and strain work on an object when force is applied.

What is the Proportional Limit of the Stress Strain Curve?

The proportional limit id stress-strain curve refers to the highest stress where stress and strain are directly proportional so that the stress-strain graph represents a straight line in such a way that the gradient equals the elastic modulus of the material

What is the Elastic Limit of Stress Strain Diagram?

The elastic limit of the stress-strain diagram illustrates the point where the behavior of the material changes from being elastic to becoming plastic. Where the stress (and therefore strain) applied to the material is lower than the elastic limit, both the stress and strain revert to zero (recover) when the load is removed.

What is the Yield Point of the Stress Strain Diagram?

The yield point on the stress-strain diagram represents the point of the end of elastic deformation and the beginning of permanent deformation. Before this point, the stress-strain curve stays linear, and after the yield point, it turns non-linear.

What is the Breaking Point of the Stress Strain Curve?

The breaking point of stress-strain curve represents the point at which the material's failure takes place. It is also called the fracture point

Define Stress and Strain:

Stress is the internal force per unit area acting on a material, while strain is the measure of deformation or change in shape experienced by the material in response to applied stress. Together, stress and strain form the basis for understanding the mechanical behavior of materials and are essential concepts in engineering, physics, and materials science.

Strain Meaning:

Strain refers to the relative change in size or shape of a material compared to its original dimensions when subjected to external forces or loads. It quantifies the deformation experienced by the material and is expressed as a percentage or in decimal form.

Poisson ratio:- it is the ratio of transverse contraction (or expansion) strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative.

Bulk modulus: - It is a measure of the ability of a substance to withstand changes in volume when under compression on all sides. It is equal to the quotient of the applied pressure divided by the relative deformation.

Modulus of Elasticity, also known as Elastic Modulus or simply Modulus, is the measurement of a material's elasticity. Elastic modulus quantifies a material's resistance to non-permanent, or elastic, deformation.

Mechanical Properties of Materials

1. Elasticity: The property of a substance by which it regains its original shape and size when the deforming force is removed.

2. Plasticity: It is a mechanical property of a material and is defined as the quality of material when it undergoes non-reversible deformation under the effect of an external force. The materials exhibiting this property are known as plastic materials. When stress is applied to a plastic material, the plastic strain which is developed is nonrecoverable and permanent.

3. Toughness: It is also a mechanical property and is defined as the ability of a material to absorb energy and undergo plastic deformation without undergoing fracturing. Mathematically speaking, the toughness of a material is the energy absorbed per unit volume by the material before rupturing. The material should be both strong and ductile in order to be tough.

4. Ductility: It is the ability of a material to undergo plastic deformation before rupturing. The materials which show this property are known as ductile materials. A good ductile material is capable of being drawn into wires.

5. Hardness: It is the capacity of a substance to withstand long-term shape change brought on by external stress. Scratch Hardness, Indentation Hardness, and Rebound Hardness are three different measures of hardness.

6 **Scratch Resistance :**The ability of a material to resist scratches to the outer surface layer caused by external force is known as scratch hardness.
7 **Indentation Resistance :** It is the capacity of a material to resist a punch from an outside item that is both hard and sharp.
8 **Rebound Resistance :** Dynamic hardness is another name for rebound hardness. It is determined by the height at which a hammer with a diamond tip is dropped upon the material from a fixed height.

9 Strength: A material's ability to resist deformation or disintegration in the face of loads or external forces is known as this attribute. Materials that we choose for our engineering goods need to be sufficiently strong mechanically to function under a variety of mechanical forces or loads.

10 Brittleness: A material's brittleness refers to how easily it fractures under the influence of a force or load. When brittle material is stressed, it experiences very little energy and cracks without experiencing a lot of strain. The opposite of a material's ductility is brittleness. Material brittleness is temperature-dependent. At low temperatures, some metals that are ductile at room temperature become brittle.

11 Malleability: The ability of a material to be rolled or hammered into a thin sheet is a common way to classify malleability. This mechanical quality is a component of the material's plasticity. Temperature affects a material's malleability. The malleability of material rises with temperature rising.

12 Wear Resistance: Wear Resistance is a proportion of a material's capacity to endure the impact of two materials scouring against one another. This can take many structures including grip, scraped spot, scratching, gouging, rankling, and others. At the point when the materials are of various hardness, the milder metal can start to show the impacts first, and the board of that might be essential for the plan. In any event, rolling can cause scraped area in view of the presence of unfamiliar materials. Wear opposition might be estimated as how much mass lost for a given number of scraped spot cycles at a given burden.

temperature stress :- When the applied force is in the form of temperature the resultant stress is called Thermal stress. It is observed when an object expands or contracts due to a change in temperature. Thus, we can define Thermal stress as: "Stress caused due to the change in temperature" It is measured using feet or metres.

Thick or thin pressure vessels :- The pressure vessels are identified as thick or thin by the ratio of the mean radius of the vessel to the thickness of the wall. A vessel is considered to be thin walled if the value of this ratio is greater than 10, and if it is below 10, the vessel is called a thick cylindrical.

strain energy: -It is defined as the energy stored in any object which is loaded within its elastic limits. In other words, the strain energy is the energy stored in anybody due to its deformation. The strain energy is also known as Resilience.

What is strain energy and proof stress?

Strain energy is the energy stored in the body associated with the deformation of the member. When an elastic body is loaded within elastic limits, it deforms and some work is done which is stored within the body. This energy stored is strain energy. It is recoverable without loss as soon as load is removed.

center of gravity:- it is the average location of the weight of an object. We can completely describe the motion of any object through space in terms of the translation of the center of gravity of the object from one place to another, and the rotation of the object about its center of gravity if it is free to rotate.

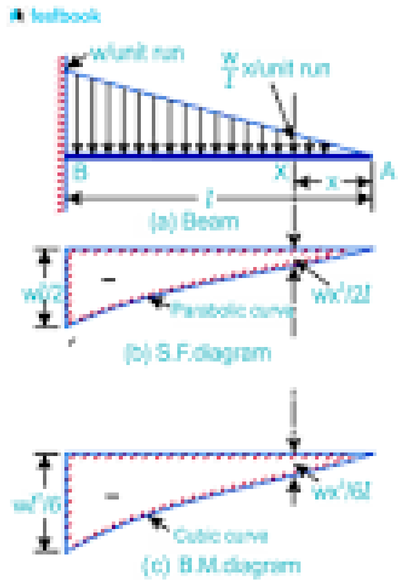
moment of inertia :- quantitative measure of the rotational inertia of a body—i.e., the opposition that the body exhibits to having its speed of rotation about an axis altered by the application of a torque (turning force). The axis may be internal or external and may or may not be fixed.

What is a beam and its types?

A beam, in Structural Engineering terms, is a member that can be comprised of a number of materials (including steel and wood aluminum) to withstand loads – typically applied laterally to the beam axis. Beams can also be referred to as members, elements, rafters, shafts, or purlins.

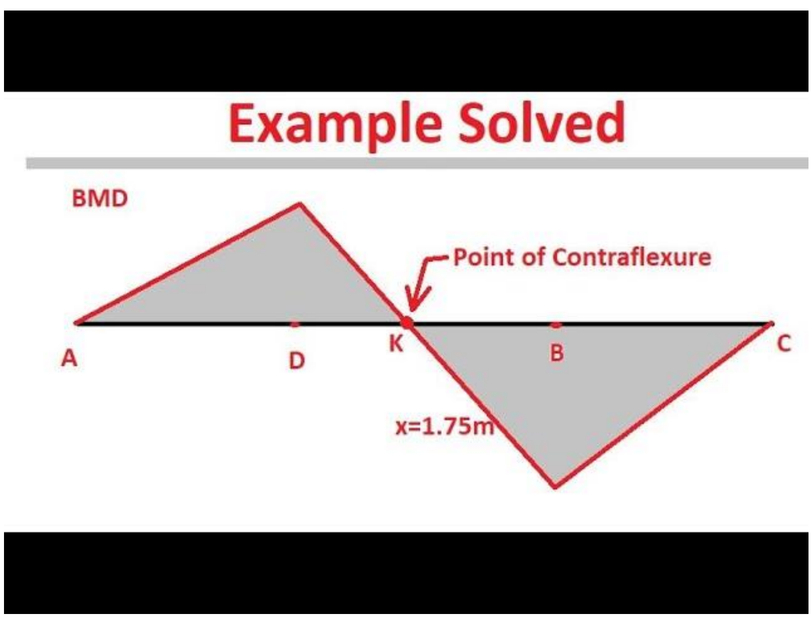
In engineering, beams are of several types: Simply supported – a beam supported on the ends which are free to rotate and have no moment resistance. Fixed or encastré (encastrated) – a beam supported on both ends and restrained from rotation. Overhanging – a simple beam extending beyond its support on one end.

What is shear force and bending moment?



Shear force refers to the force that acts parallel to the cross-section of a structural element, while bending moment is the moment that occurs when an external force is applied to the element causing it to bend.

Point of contraflexure: it is a point where the curvature of the beam changes sign. It is sometimes referred to as a point of inflexion and will be shown later to occur at the point, or points, on the beam where the B.M. is zero.



Simple bending of beams:-

A beam or a part of it is said to be in a state of pure bending when it bends under the action of uniform/constant bending moment, without any shear force. Alternatively, a portion of a beam is said to be in a state of simple bending or pure bending when the shear force over that portion is zero.

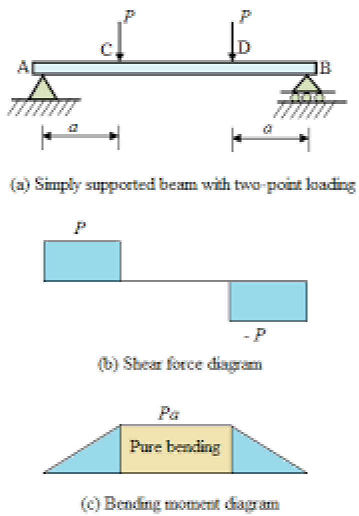


Fig. 4

M / I = σ /y = E / R is the formula for simple bending. The equation of pure bending is considered when bending moment is constant and shear force or rate of bending moment change is equal.

Torsion

In the solid mechanics field, Torsion is defined as the twisting of an object due to a torque applied to it. Torsion can be expressed in either pascals (Pa) or an S.I. unit Newtons per square meter, or in pounds per square inch (psi). In contrast, torque is expressed in Newton-meters (Nm) or foot pound-force (ft.lbf). In the object, some sections are perpendicular to the torque axis; in these sections, the resultant shear stress is perpendicular to the radius. In non-circular cross-sections, a distortion accompanies twisting, this distortion is known as warping. In warping, transverse sections are rough

K = T / θ = GJ / L. Torsion, if defined in simple terms, can be explained as the amount of twist that we give to a particular object at one end when the other end of the object is fixed and doesn't move with the twist applied at the other end of the object..

A **spring** is a device consisting of an elastic but largely rigid material (typically metal) bent or molded into a form (especially a coil) that can return into shape after being compressed or extended.[1] Springs can store energy when compressed. In everyday use, the term most often refers to coil springs, but there are many different spring designs. Modern springs are typically manufactured from spring steel. An example of a non-metallic spring is the bow, made traditionally of flexible yew wood, which when drawn stores energy to propel an arrow.

Types

A spiral torsion spring, or hairspring, in an alarm clock.Battery contacts often have a variable springA volute spring. Under compression the coils slide over each other, so affording longer travel.Vertical volute springs of Stuart tankSelection of various arc springs and arc spring systems (systems consisting of inner and outer arc springs).Tension springs in a folded line reverberation device.A torsion bar twisted under loadLeaf spring on a truck

Classification

Springs can be classified depending on how the load force is applied to them:

Tension/extension spring : The spring is designed to operate with a tension load, so the spring stretches as the load is applied to it.

Compression spring: Designed to operate with a compression load, so the spring gets shorter as the load is applied to it.

Torsion spring : Unlike the above types in which the load is an axial force, the load applied to a torsion spring is a torque or twisting force, and the end of the spring rotates through an angle as the load is applied.

Constant spring; Supported load remains the same throughout deflection cycle[7]

Variable spring: Resistance of the coil to load varies during compression[8]

Variable stiffness spring ;Resistance of the coil to load can be dynamically varied for example by the control system, some types of these springs also vary their length thereby providing actuation capability as well [9]

They can also be classified based on their shape:

Flat spring ;Made of a flat spring steel.

Machined spring : Manufactured by machining bar stock with a lathe and/or milling operation rather than a coiling operation. Since it is machined, the spring may incorporate features in addition to the elastic element. Machined springs can be made in the typical load cases of compression/extension, torsion, etc.

Serpentine spring :A zig-zag of thick wire, often used in modern upholstery/furniture.

Coil spring

Also known as a helical spring. A spring (made by winding a wire around a cylinder) is of two types:

- *Tension* or *extension springs* are designed to become longer under load. Their turns (loops) are normally touching in the unloaded position, and they have a hook, eye or some other means of attachment at each end.
- *Compression springs* are designed to become shorter when loaded. Their turns (loops) are not touching in the unloaded position, and they need no attachment points.
- *Hollow tubing springs* can be either extension springs or compression springs. Hollow tubing is filled with oil and the means of changing hydrostatic pressure inside the tubing such as a membrane or miniature piston etc. to harden or relax the spring, much like it happens with water pressure inside a garden hose. Alternatively tubing's cross-section is chosen of a shape that it changes its area when tubing is subjected to torsional deformation: change of the cross-section area translates into change of tubing's inside volume and the flow of oil in/out of the spring that can be controlled by valve thereby controlling stiffness. There are many other designs of springs of hollow tubing which can change stiffness with any desired frequency, change stiffness by a multiple or move like a linear actuator in addition to its spring qualities.
- **Leaf spring**
- A flat spring used in vehicle suspensions, electrical switches, and bows.

Spring stiffness is based on spring rate . It is also mostly based on proportion though. A ten pound rate may not seem like much on a large spring but on a small spring, it might be just enough. If you lower the amount of coils, you'll increase the spring stiffness which is the spring's rate.

What is the spring stiffness?

The spring stiffness, also known as the spring constant, is a measure of the stiffness of a spring. It indicates how much force is required to stretch or compress the spring by one unit. The spring stiffness is measured in Newtons per metre (N/m).