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المجلة العلمية لنشر البحوث
S . J . R . P

Types of mechanical Stresses

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Stress, according to its definition, refers to the force exerted on a small area, this physical quantity is derived from two fundamental quantities: force [N] and area [m^2], and is classified as a fundamental quantity like energy, torque, and velocity.

Continuum mechanics defines stress as a fundamental physical quantity that explains the forces that occur during deformation. When an object undergoes deformation by being pulled apart, like a stretched elastic band, it is exposed to tensile stress and can experience elongation. Conversely, when an object is pushed together, such as a crumbled sponge, it is exposed to compressive stress and can undergo compression. The intensity of stress is determined by the size of the force and the small area of the object upon which it acts.

The measurement of stress can be expressed as the amount of force applied per unit area, such as [Pa] or [N/m^2]. The analysis of fundamental quantities, including stress, can be analyzed without explicitly considering the material's nature or the physical mechanisms responsible for its occurrence.

Stress and strain are two essential concepts in physics that are used to describe the behavior of continuous materials under different forces. The term "stress" in mechanics refers to the internal forces acting between adjacent particles of a material, while "strain" is used to measure the amount of deformation experienced by the material.

When an upright solid bar supports a weight above it, particles keep pushing the particles below which causes them to compress. The particles below the first layer then apply a compressive force on the particles underneath them, and so on, until the entire bar experiences a downward force.

In the case of liquids which are contained in a closed vessel under pressure, the liquid particles are being pushed by against all the particles that surround it. The container walls will then push against the particles in what is known as a Newtonian reaction. These forces are the result of a vast number of forces that are intermolecular between the particles in those molecules.

Stress is usually represented by the Greek letter [σ]. It can be measured using various methods, such as applying a tensile or compressive load on a sample material and measuring the resulting deformation. Stress is an important concept in many fields of science and engineering, such as material sciences, civil engineering, and biomechanics. For instance, stress analysis is used in the design of buildings, bridges, and other structures to ensure they can withstand external forces such as wind, earthquakes, and loads.

In general, when a particle P exerts stress on another particle Q across a surface, the stress T can have any direction relative to the surface S. The stress vector T can be broken down into two components: normal stress and shear stress. Normal stress is either compression, when the particles are pushed towards each other, or tension, when they are pulled apart, and it acts perpendicular to the surface. Shear stress, on the other hand, is parallel to the surface.

When the surface has a normal unit vector [n], then the normal stress component of T can be expressed as $T_n = T \cdot n$. This means that the normal stress is proportional to the stress vector T and the cosine of the angle between T and n.

Bending stress is a type of normal stress that an object undergoes when it is exposed to an external load at any cross-sectional area. For example, a beam that is supporting a load will experience bending stress along its length, with the highest stress occurring at the point where the load is applied.

Torsional stress, on the other hand, is the shear stress that acts on a transverse cross-section due to the action of a twist. It is caused by the application of a torque, which produces a shear stress that can change along the length of the member.

Normal stress and normal strain occur when a force is applied perpendicular to an area. When a material is subjected to tensile or compressive forces, it experiences normal stress and strain that are correlated to the magnitude of the applied force and the cross-sectional area of the material. These concepts are important in materials science and engineering, as they are used to design and analyze structures and machines that are subjected to several types of stresses and strains.

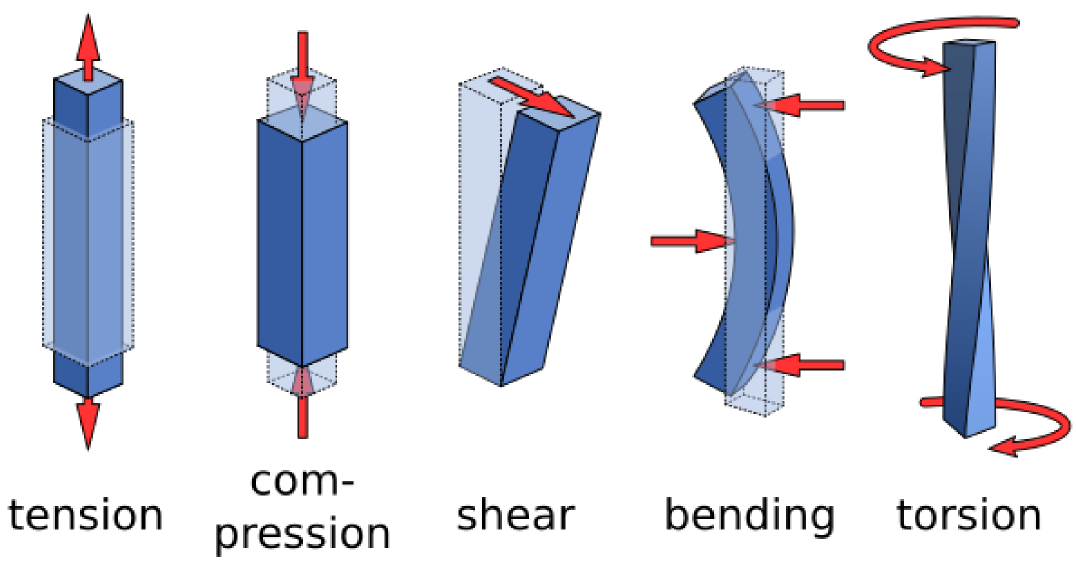
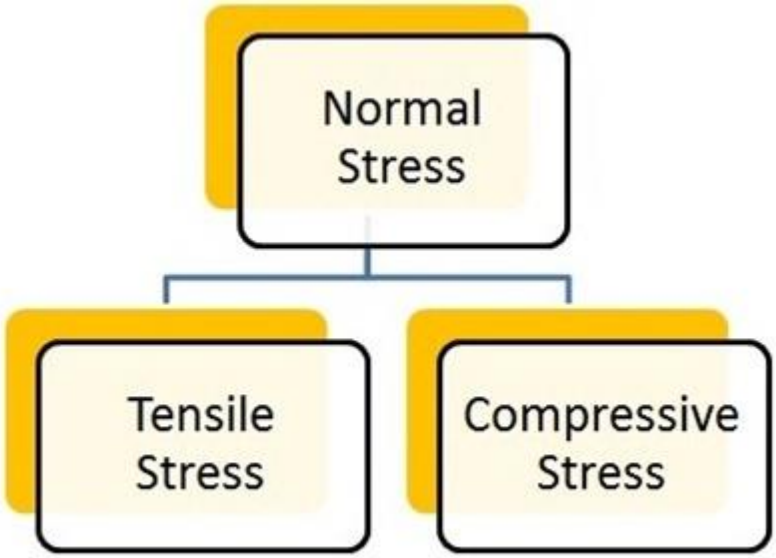


Figure 1: Types of mechanical stresses.



Tensile stresses	Compressive stresses
The application of tensile stress to a material leads to its elongation.	The application of compressive stress to a material results in its shortening.
Tensile stresses are due to the application of an outside stretching force	Compressive stresses are due to the application of outside compressive force
Can be uniaxial, biaxial or triaxial	

Table 1: comparison betweem tensile and compressive stress.

Compressive Stress

Compressive stress is a type of stress that causes materials to experience a decrease in volume. When compressive stresses are applied to low-ductility materials (brittle), such as ceramics or glass, it can result in fracture due to the sudden release of stored energy.

On the other hand, ductile materials, such as metals, are more capable of withstanding compressive stress without failure. When compressive stress is applied to a ductile material, it can deform and compress, without fracturing or breaking.

The equation of compressive stress is as follows:

$$\sigma = \frac{F}{A}$$

Where F is the applied force and A is the area of the applied force.

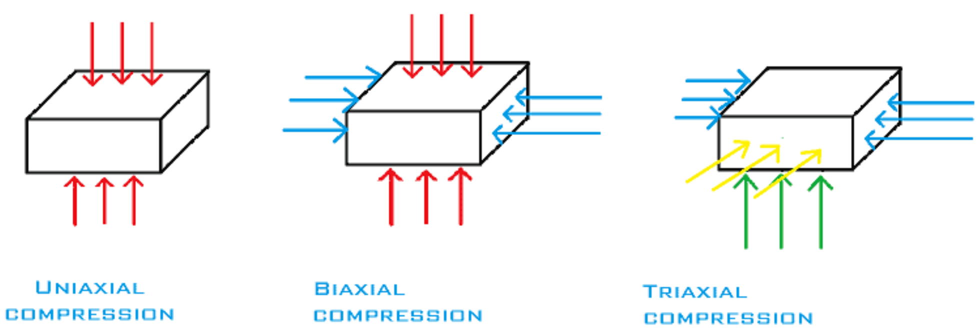


Figure 2 : Types of compression.

The dimensional formula of the force can be expressed as:

$$F = m \times a = kg \times m/s^2 = [M][L][T^{-2}]$$

The SI unit of mass, kg, is replaced by the dimension of mass [M], for the length, m, it is replaced by the dimension of length [L], while for the time, s, it is replaced by the dimension of time [T]

The dimensional formula of the area can be expressed as:

$$A = m^2 = [L^2]$$

Where [L] is the dimension of length.

Substituting the dimensional formulae into the stress formula, we get:

$$\sigma = \frac{F}{A} = \frac{[M][L][T^{-2}]}{[L^2]} = \frac{[M][T^{-2}]}{[L]} = [M][L^{-1}][T^{-2}]$$

Higher compressive stress

When a substance or structure experiences compressive forces that exceed its capacity to withstand without deformation or failure, it is said to be under high compressive stress. The maximum level of compressive stress that can be considered "high" varies depending on the specific material or structure in question and its usage conditions. Under high compressive stress, a material or structure may become deformed, buckled, or fractured. In the fields of engineering and materials science, high compressive stress is taken very seriously due to the potential for structural failure and safety hazards in a wide range of applications.

- ## Compression Testing

Compression testing is a prominent method used to measure compression stress in materials. It involves subjecting a material to compressive forces such as squashing, crushing, or hammering and observing its reaction. This technique is used to determine the elastic limit of the material, which is the maximum force that can be applied before the material breaks or is permanently deformed.

Compression testing is commonly used in industries to assess whether their products can withstand high levels of compression. For example, mattresses and foams are tested to determine their reaction to maximum forces, which helps to improve the quality of the final product. In the construction industry, engineers are required to use materials that have been tested for compression when designing and building structures like bridges, skyscrapers, and houses, since these buildings are constantly exposed to compressive stress.

- **Blacksmith**

The majority of iron and steel products, including swords, knives, and other similar items, are created by hammering the metal until it reaches the desired shape. This constant hammering causes the metal to deform, and compression stress plays an important role in determining the quality of the final product for a blacksmith.

Tensile Stress

Tensile stress is a physical quantity that relates to the stretching actions and tensile forces acting on a material. It causes the elongation along the direction of the applied load. When an object is loaded with a force that tends to pull or stretch the material along its line, the object experiences tensile stress. The load that is associated with the tensile force that causes the elongation of an object is known as tensile strength. The tensile strength of an object with equal areas under tension is independent of the shape of the material's area.

Tensile stress can also be defined as the resistance of an object against a force that tries to rip it apart. It is calculated by determining the maximum amount of tension that an object can endure before tearing occurs. Tensile stress is typically measured in units such as Newtons per square millimeter. This stress measurement is an indication of the strength of the material. Tensile stress is correlated to the force that tries to stretch or tear apart an object.

Tensile tests are a valuable technique to measure various mechanical properties of a material. Tension or normal stresses are different terms for tensile stress. In elastic deformation ($\sigma < \sigma_y$) , when the applied stress is removed, the object returns to its original dimensions. However, in the plastic region ($\sigma_y < \sigma$) , when the applied stress is removed, the material starts to form a constricted region known as a neck. This point is where the material fractures.

Tensile stress can accelerate the process of corrosion, leading to cracks in steel due to intercrystalline corrosion caused by the stress. Both the mechanical properties and the overall strength of corroded steel can be reduced by tensile stress.

Mathematical Expressions

The application of stress concentrations at

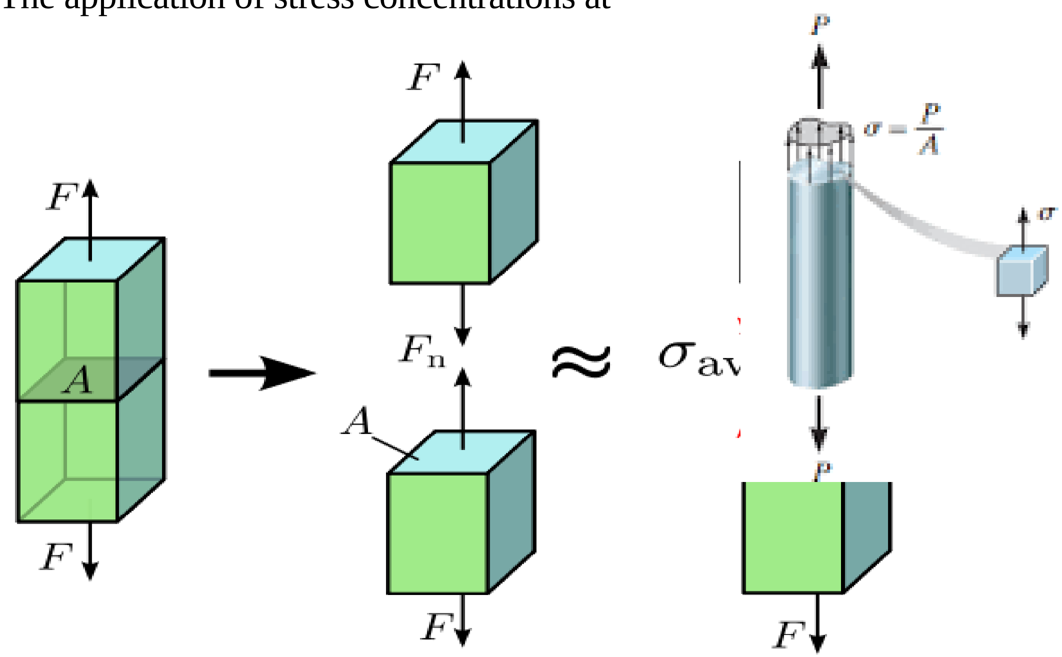


Figure 3 : Schematic of axial tensile stress.

locations of material defects can accelerate the material's strain and cause quick changes in its shape due to the applied tension. Some materials can endure a certain number of defects before failing while exhibiting ductile behavior, while brittle materials may fail below their strength. Tensile stress is defined as the force associated with extension per unit area and is denoted by the symbol [σ].

Tensile Properties

When a certain material is exposed to tensile stress, it exhibits several tensile properties, including the following:

- Ultimate Tensile Strength: This refers to the highest stress a material can endure before it breaks under tension.
- Modulus of Resilience: refers to the highest amount of energy that a material can absorb per unit volume without undergoing any permanent deformation.
- Elastic Modulus: This is a measure of a material's stiffness, expressed as the ratio of stress to tensile strain during completely elastic deformation. The modulus of elasticity is calculated using the stress strain curve.
- Fracture Stress: This is the highest stress that can be experienced by a material's crack point before it breaks down. The symbol used to denote fracture stress is σ_f.

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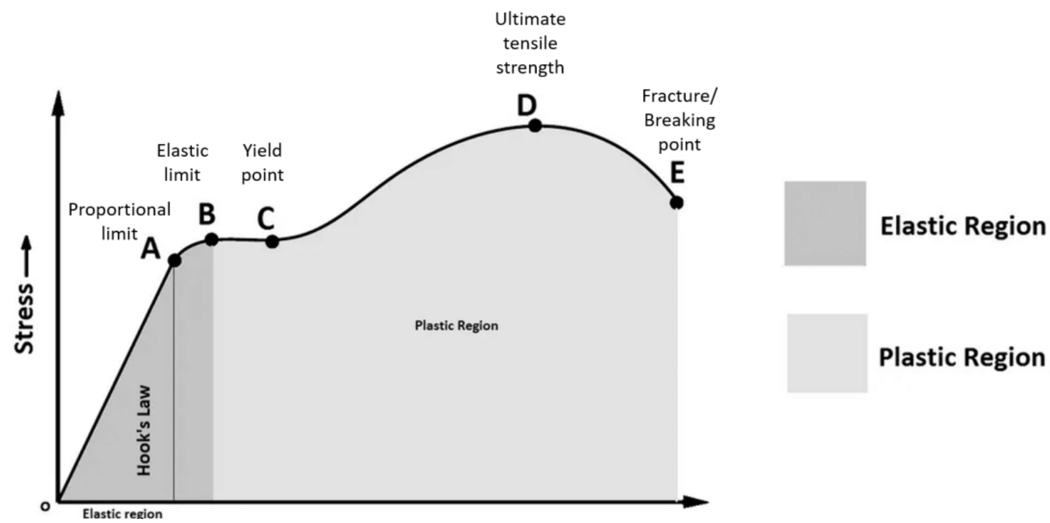

Figure4 : Stress-strain curve.

Elastic limit

The elastic limit is the highest stress that an object can endure without undergoing permanent deformation. If a material is subjected to stress below its elastic limit, once the applied stress is removed, it will return to its original size. However, if the stress exceeds the elastic limit, the material will undergo permanent deformation even after the stress is removed. Determining the elastic limit accurately can be challenging using universal testing machines, so it is mainly used for educational purposes.

Shear Stress

When an external force is applied to an object, it causes the object to undergo deformation. This deformation can occur in various ways, depending on the direction of the force relative to the object's plane. When the force vector is parallel to the plane of the object, the deformation takes place along that plane, resulting in what is called shear or tangential stress. Shear stress is caused by the forces acting in

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parallel planes across the object, and it occurs when the force vector components are parallel to the material's cross-sectional area.

In contrast, normal or longitudinal stress occurs when the force vectors are perpendicular to the cross-sectional area on which they act. In this case, the object is subjected to forces that cause it to compress or stretch along the axis of the applied force. This type of stress is typically seen in situations such as tension or compression tests, where a force is applied in a specific direction to test the strength of the material.

Shearing stress is a type of stress that occurs in a material's cross-section due to shear forces acting on it. These forces consist of a pair of equal and opposite forces acting on opposite sides of the material. Shear stress is a vector that includes both magnitude and direction, represented by the Greek

Average shear stress

The average shear stress over a section is:

$$\tau_{avg} = \frac{V}{A}$$

Where τ_{avg} is the average shear stress a, V is the shear load and A is the area of shear.

Other forms of shear stress

Transverse shear stress is a type of shear stress that acts perpendicular to the longest axis of a body. It occurs when a transverse force is applied to an object, causing it to bend or deform. This type of stress is important in the analysis of structures such as beams and bridges. The transverse shear stress can be found using the following equation:

$$\tau = \frac{VQ}{It}$$

Where τ is the shear stress, V is the shear force, I is the second moment of inertia, t is the width of the section at the point of shear stress, and Q is the first moment of area. The unit of transverse shear stress is defined as [N/m^2] or [Pa].

Torsional shear stress

Torsional shear stress refers to the stress that occurs when a torque is applied to a structural element, causing it to twist. This stress is typically perpendicular to the axis of the element and is calculated based on the amount of torque applied and the cross-sectional properties of the element. It can be expressed as a shear stress or as a shear strain and is an important factor to consider in the design of structures such as shafts, gears, and other rotating machinery.

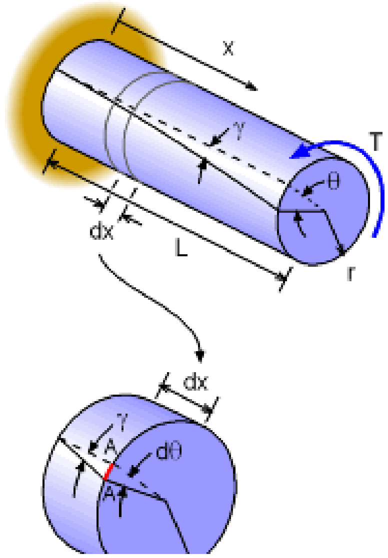

Figure 5 : Torsional shear stress schematic.

Beam shear stress

Beam shear stress is a type of stress that is not uniform in nature and is caused by an internal shear force applied to a beam. It can be defined as the internal shear stress experienced by a beam due to the external shear force acting on it. It can be expressed as follows:

$$\tau = \frac{FQ}{Ib}$$

F is the total shear force, Q is the first moment of area, b is the width of the material perpendicular to the shear force, and I is the second moment of inertia.

Wall shear stress

Wall shear stress is the force exerted by a fluid on a wall. When a fluid flows along a solid boundary, it experiences a shear stress at that boundary. This shear stress arises due to the no-slip condition, which states that the fluid velocity at the boundary relative to the boundary is zero. The region between the boundary and a certain height from it is called the boundary layer. In laminar flow, the shear stress for all Newtonian fluids is directly proportional to the strain rate in the fluid, with viscosity acting as the constant of proportionality. However, for non-Newtonian fluids, viscosity is not constant, leading to an uneven distribution of shear stress on the boundary due to the loss of velocity.

Bending stress

The bending stress is a type of stress that happens in a beam when it is subjected to transverse loads. It is known as the ratio between the bending moment and the section modulus. When a beam bends, it may also experience other effects like twisting and buckling. However, in many cases, investigating the joined effects of bending and twisting can be complex. Therefore, it is often more practical to focus on studying the bending effects only. The equation of bending stress can be expressed as follows:

$$\sigma_b = \frac{My}{I}$$

Where σ_b is known as the bending stress, M is the bending moment, y is the perpendicular distance from the axis, and I is the second moment of inertia.

Bending of beams

When a beam is under a transverse load, it deforms and creates internal stresses. In a quasi-static situation, the amount of bending and stresses remain constant for long periods. For a flat beam supported at both ends and with a load in the middle, the lower part will experience elongation and stretching while the top part will experience shortening and compression. This leads to two types of internal stresses that occur due to the loads: shear stress in the direction of the lateral loading plus complementary shear stress on planes perpendicular to the load direction, and direct compressive stress in the top region of the beam, and direct tensile stress in the bottom region. These last two forces form a moment. By making some simplifying assumptions, it is possible to accurately predict the stress distribution in a beam.

Dynamic bending of beams

The study of the dynamic bending of beams, also referred to as flexural vibrations of beams, was first explored by Daniel Bernoulli in the late 18th century. However, his equation of motion was found to overestimate the natural frequencies of beams. In 1877, Rayleigh made a slight improvement to Bernoulli's equation by introducing a mid-plane rotation. Later in 1921, Stephen Timoshenko further refined the theory by considering the effect of shear on the dynamic response of bending beams. This advancement made it possible to apply the theory to problems involving high frequencies of vibration where the dynamic Euler-Bernoulli theory was insufficient. Today, both the Euler-Bernoulli and Timoshenko theories for the dynamic bending of beams remain widely used in engineering.

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Torsional stress

Torsional stress refers to the shear stress that occurs on a transverse cross-section due to twisting. This type of stress is distinct from normal stress and normal strain, which result from tension or compression of a member when a force is applied perpendicularly to an area.

Torsion force

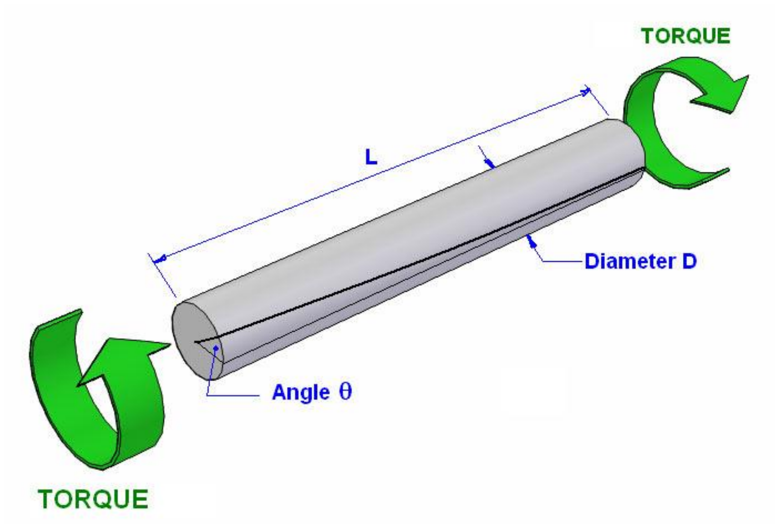

Figure 6 : Schematic of torsional stress.

The torsion force, also known as twist force, is the force that causes one end of a structural member or object to twist with respect to the other end. This twisting action results in shear stress being exerted along the cross-section of the object or structural member.

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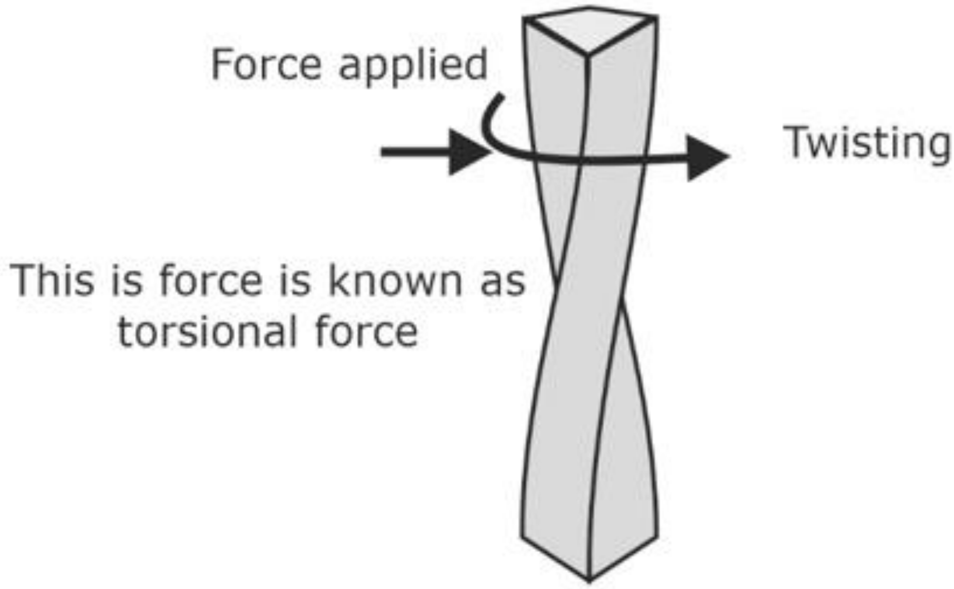

Figure7 : Torsion force schematic.

Importance of torsion

Torsion occurs when a structural member or object twists due to an applied torque. It is a common phenomenon in engineering and design and can be seen in everyday objects such as screws, bolts, and even in human bones. Understanding torsion is essential for designing products that can withstand shear stress and ensure stability and safety.

Torsion is significant in designing products and structures that require high resistance to shear stress. For example, in the aerospace industry, torsion is a critical factor in designing aircraft components, such as wings and propellers. These components experience significant torsional forces during flight and must be designed to withstand them to ensure safe and efficient operation.

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In building and construction, torsion is also an important consideration. For example, edge beams must be designed to resist torsional forces to prevent structural failure. Torsion can also impact the design of columns and shear walls, which must be designed to resist dynamic loads, such as wind and earthquake forces. Neglecting to consider torsion in the design of such structures can lead to premature failure and collapse, resulting in significant safety hazards.

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