# Strength of Materials

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1. Stress and Strain

Theory at a Glance (for IES, GATE, PSU)

1.1 Stress (\(\sigma\))

When a material is subjected to an external force, a resisting force is set up within the component. The internal resistance force per unit area acting on a material or intensity of the forces distributed over a given section is called the stress at a point.

- It uses original cross section area of the specimen and also known as engineering stress or conventional stress.

Therefore, \(\sigma = \frac{P}{A}\)

- \(P\) is expressed in Newton (N) and \(A\), original area, in square meters (m\(^2\)), the stress \(\sigma\) will be expresses in N/ m\(^2\). This unit is called Pascal (Pa).

- As Pascal is a small quantity, in practice, multiples of this unit is used.

\[
\begin{align*}
1 \text{ kPa} &= 10^3 \text{ Pa} = 10^3 \text{ N/ m}^2 \\
1 \text{ MPa} &= 10^6 \text{ Pa} = 10^6 \text{ N/ m}^2 = 1 \text{ N/mm}^2 \\
1 \text{ GPa} &= 10^9 \text{ Pa} = 10^9 \text{ N/ m}^2
\end{align*}
\]

Let us take an example: A rod 10 mm \(\times\) 10 mm cross-section is carrying an axial tensile load 10 kN. In this rod the tensile stress developed is given by

\[
(\sigma_t) = \frac{P}{A} = \frac{10 \text{ kN}}{(10 \text{ mm} \times 10 \text{ mm})} = \frac{10 \times 10^3 \text{ N}}{100 \text{ mm}^2} = 100 \text{ N/mm}^2 = 100 \text{ MPa}
\]

- The resultant of the internal forces for an axially loaded member is normal to a section cut perpendicular to the member axis.

- The force intensity on the shown section is defined as the normal stress.

\[
\sigma = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A} \quad \text{and} \quad \sigma_{avg} = \frac{P}{A}
\]

- **Tensile stress (\(\sigma_t\))**

If \(\sigma > 0\) the stress is tensile. i.e. The fibres of the component tend to elongate due to the external force. A member subjected to an external force tensile \(P\) and tensile stress distribution due to the force is shown in the given figure.
• **Compressive stress (σ<sub>c</sub>)**
If σ < 0 the stress is compressive. i.e. The fibres of the component tend to shorten due to the external force. A member subjected to an external compressive force P and compressive stress distribution due to the force is shown in the given figure.

• **Shear stress (τ)**
When forces are transmitted from one part of a body to other, the stresses developed in a plane parallel to the applied force are the shear stress. Shear stress acts parallel to plane of interest. Forces P is applied transversely to the member AB as shown. The corresponding internal forces act in the plane of section C and are called shearing forces. The corresponding average shear stress (τ) = \( \frac{P}{\text{Area}} \)

1.2 Strain (ε)
The displacement per unit length (*dimensionless*) is known as strain.

• **Tensile strain (ε<sub>t</sub>)**
The elongation per unit length as shown in the figure is known as tensile strain.

\[ \varepsilon_t = \frac{\Delta L}{L_0} \]
It is engineering strain or conventional strain.
Here we divide the elongation to original length not actual length (\( L_0 + \Delta L \))

Let us take an example: A rod 100 mm in original length. When we apply an axial tensile load 10 kN the final length of the rod after application of the load is 100.1 mm. So in this rod tensile strain is developed and is given by

\[ \varepsilon_t = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} = \frac{100.1\text{mm} - 100\text{mm}}{100\text{mm}} = 0.001 \text{ (Dimensionless) Tensile} \]
• **Compressive strain (\( \varepsilon_c \))**

If the applied force is compressive then the reduction of length per unit length is known as compressive strain. It is negative. Then \( \varepsilon_c = (–\Delta L)/L_o \)

**Let us take an example:** A rod 100 mm in original length. When we apply an axial compressive load 10 kN the final length of the rod after application of the load is 99 mm. So in this rod a compressive strain is developed and is given by
\[
(\varepsilon_c) = \frac{\Delta L}{L_o} = \frac{L - L_o}{L_o} = \frac{99\text{mm} - 100\text{mm}}{100\text{mm}} = -1\text{mm}/100\text{mm} = -0.01 \text{ (Dimensionless) compressive}
\]

• **Shear Strain (\( \gamma \))**

When a force \( P \) is applied tangentially to the element shown. Its edge displaced to dotted line. Where \( \delta \) is the lateral displacement of the upper face of the element relative to the lower face and \( L \) is the distance between these faces. Then the shear strain is \( (\gamma) = \frac{\delta}{L} \)

**Let us take an example:** A block 100 mm \( \times \) 100 mm base and 10 mm height. When we apply a tangential force 10 kN to the upper edge it is displaced 1 mm relative to lower face.

Then the direct shear stress in the element
\[
(\tau) = \frac{10\text{kN}}{100\text{mm} \times 100\text{mm}} = \frac{10 \times 10^3 \text{N}}{100\text{mm} \times 100\text{mm}} = 1 \text{N/mm}^2 = 1 \text{ MPa}
\]
And shear strain in the element \( (\gamma) = \frac{1\text{mm}}{10\text{mm}} = 0.1 \text{ Dimensionless} \)

### 1.3 True stress and True Strain

The true stress is defined as the ratio of the load to the cross section area at any instant.
\[
(\sigma_T) = \frac{\text{load}}{\text{Instantaneous area}} = \sigma (1 + \varepsilon)
\]

Where \( \sigma \) and \( \varepsilon \) is the engineering stress and engineering strain respectively.
• True strain

\[ (\varepsilon_T) = \int_{L_0}^{L} \frac{dl}{L_0} = \ln \left( \frac{L}{L_0} \right) = \ln (1 + \varepsilon) = \ln \left( \frac{A_0}{A} \right) = 2 \ln \left( \frac{d_0}{d} \right) \]

or engineering strain \((\varepsilon) = \theta^y - 1\)

The volume of the specimen is assumed to be constant during plastic deformation. \([\because A_0L_0 = AL]\) It is valid till the neck formation.

• Comparison of engineering and the true stress-strain curves shown below:

• The true stress-strain curve is also known as the flow curve.

• True stress-strain curve gives a true indication of deformation characteristics because it is based on the instantaneous dimension of the specimen.

• In engineering stress-strain curve, stress drops down after necking since it is based on the original area.

• In true stress-strain curve, the stress however increases after necking since the cross-sectional area of the specimen decreases rapidly after necking.

• The flow curve of many metals in the region of uniform plastic deformation can be expressed by the simple power law.

\[ \sigma_T = K(\varepsilon_T)^n \]

Where K is the strength coefficient

\(n\) is the strain hardening exponent

\(n = 0\) perfectly plastic solid

\(n = 1\) elastic solid

For most metals, \(0.1 < n < 0.5\)

• Relation between the ultimate tensile strength and true stress at maximum load

The ultimate tensile strength \((\sigma_u) = \frac{P_{\text{max}}}{A_0}\)

The true stress at maximum load \((\sigma_T)_{\text{max}} = \frac{P_{\text{max}}}{A}\)
And true strain at maximum load \( (\varepsilon)_T = \ln \left( \frac{A_o}{A} \right) \) or \( \frac{A_o}{A} = e^{\varepsilon_T} \)

Eliminating \( P_{\text{max}} \) we get, \( (\sigma_u)_T = \frac{P_{\text{max}}}{A} = \frac{P_{\text{max}}}{A_o} \times \frac{A_o}{A} = \sigma_u e^{\varepsilon_T} \)

Where \( P_{\text{max}} = \) maximum force and \( A_o = \) Original cross section area

\( A = \) Instantaneous cross section area

Let us take two examples:

(I.) Only elongation no neck formation

In the tension test of a rod shown initially it was \( A_o = 50 \text{ mm}^2 \) and \( L_o = 100 \text{ mm} \). After the application of load it’s \( A = 40 \text{ mm}^2 \) and \( L = 125 \text{ mm} \).

Determine the true strain using changes in both length and area.

**Answer:** First of all we have to check that does the member forms neck or not? For that check \( A_o L_o = AL \) or not?

Here \( 50 \times 100 = 40 \times 125 \) so no neck formation is there. Therefore true strain

\[
(\varepsilon_T) = \int_{L_o}^{L} \frac{dl}{L} = \ln \left( \frac{125}{100} \right) = 0.223
\]

\[
(\varepsilon_T) = \ln \left( \frac{A_o}{A} \right) = \ln \left( \frac{50}{40} \right) = 0.223
\]

(If no neck formation occurs both area and gauge length can be used for a strain calculation.)

(II.) Elongation with neck formation

A ductile material is tested such and necking occurs then the final gauge length is \( L = 140 \text{ mm} \) and the final minimum cross sectional area is \( A = 35 \text{ mm}^2 \).

Though the rod shown initially it was \( A_o = 50 \text{ mm}^2 \) and \( L_o = 100 \text{ mm} \). Determine the true strain using changes in both length and area.

**Answer:** First of all we have to check that does the member forms neck or not? For that check \( A_o L_o = AL \)

(After necking, gauge length gives error but...
or not?

Here \(A_{o}L_{o} = 50 \times 100 = 5000 \text{ mm}^3\) and \(AL=35 \times 140 = 4200 \text{ mm}^3\). So neck formation is there. Note here \(A_{o}L_{o} > AL\).

Therefore true strain

\[
(\varepsilon_{T}) = \ln\left(\frac{A_{o}}{A}\right) = \ln\left(\frac{50}{35}\right) = 0.357
\]

But not \((\varepsilon_{T}) = \int_{L_{o}}^{L} \frac{dl}{l} = \ln\left(\frac{140}{100}\right) = 0.336 \) (it is wrong)

1.4 Hook’s law

According to Hook’s law the stress is directly proportional to strain i.e. normal stress \((\sigma) \propto \) normal strain \((\varepsilon)\) and shearing stress \((\tau) \propto \) shearing strain \((\gamma)\).

\[
\sigma = E\varepsilon \quad \text{and} \quad \tau = G\gamma
\]

The co-efficient \(E\) is called the \textit{modulus of elasticity} i.e. its resistance to elastic strain. The co-efficient \(G\) is called the \textit{shear modulus of elasticity} or \textit{modulus of rigidity}.

1.5 Volumetric strain \((\varepsilon_v)\)

A relationship similar to that for length changes holds for three-dimensional (volume) change. For volumetric strain \((\varepsilon_v)\), the relationship is \((\varepsilon_v) = (V-V_0)/V_0\) or \((\varepsilon_v) = \Delta V/V_0 = \frac{P}{K}\)

- Where \(V\) is the final volume, \(V_0\) is the original volume, and \(\Delta V\) is the volume change.
- Volumetric strain is a ratio of values with the same units, so it also is a dimensionless quantity.
- \(\Delta V/V = \text{volumetric strain} = \varepsilon_x + \varepsilon_y + \varepsilon_z = \varepsilon_1 + \varepsilon_2 + \varepsilon_3\)
- \textbf{Dilation:} The hydrostatic component of the total stress contributes to deformation by changing the area (or volume, in three dimensions) of an object. Area or volume change is called \textit{dilation} and is positive or negative, as the volume increases or decreases, respectively. \(e = \frac{P}{K}\) where \(p\) is pressure.
1.6 Young’s modulus or Modulus of elasticity (E) = \( \frac{PL}{A\delta} = \frac{\sigma}{\varepsilon} \)

1.7 Modulus of rigidity or Shear modulus of elasticity (G) = \( \frac{\tau}{\gamma} = \frac{PL}{A\delta} \)

1.8 Bulk Modulus or Volume modulus of elasticity (K) = -\( \frac{\Delta p}{\Delta v} = \frac{\Delta p}{\Delta R} \)

1.10 Relationship between the elastic constants E, G, K, \( \mu \)

\[
E = 2G(1 + \mu) = 3K(1 - 2\mu) = \frac{9KG}{3K + G} \quad \text{[VIMP]}
\]

Where K = Bulk Modulus, \( \mu \) = Poisson’s Ratio, E= Young’s modulus, G= Modulus of rigidity

- For a linearly elastic, isotropic and homogeneous material, the number of elastic constants required to relate stress and strain is two. i.e. any two of the four must be known.

- If the material is non-isotropic (i.e. anisotropic), then the elastic modulii will vary with additional stresses appearing since there is a coupling between shear stresses and normal stresses for an anisotropic material.

**Let us take an example:** The modulus of elasticity and rigidity of a material are 200 GPa and 80 GPa, respectively. Find all other elastic modulus.

**Answer:** Using the relation \( E = 2G(1 + \mu) = 3K(1 - 2\mu) = \frac{9KG}{3K + G} \) we may find all other elastic modulus easily

Poisson’s Ratio (\( \mu \)):

\[ 1 + \mu = \frac{E}{2G} \quad \Rightarrow \quad \mu = \frac{E}{2G} - 1 = \frac{200}{2 \times 80} - 1 = 0.25 \]

Bulk Modulus (K):

\[ 3K = \frac{E}{1 - 2\mu} \quad \Rightarrow \quad K = \frac{E}{3(1 - 2\mu)} = \frac{200}{3(1 - 2 \times 0.25)} = 133.33 \text{GPa} \]

1.11 Poisson’s Ratio (\( \mu \))

\[ \frac{\varepsilon_y}{\varepsilon_x} = \text{Transverse strain or lateral strain} \]

\[ \frac{\varepsilon_y}{\varepsilon_x} = \text{Longitudinal strain} \]

(Under unidirectional stress in x-direction)
The theory of isotropic elasticity allows Poisson's ratios in the range from –1 to 1/2.

Poisson's ratio in various materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Poisson's ratio</th>
<th>Material</th>
<th>Poisson's ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>0.25 – 0.33</td>
<td>Rubber</td>
<td>0.48 – 0.5</td>
</tr>
<tr>
<td>C.I</td>
<td>0.23 – 0.27</td>
<td>Cork</td>
<td>Nearly zero</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.2</td>
<td>Novel foam</td>
<td>negative</td>
</tr>
</tbody>
</table>

We use cork in a bottle as the cork easily inserted and removed, yet it also withstand the pressure from within the bottle. Cork with a Poisson's ratio of nearly zero, is ideal in this application.

1.12 For bi-axial stretching of sheet

\[ \varepsilon_1 = \ln \left( \frac{L_{1f}}{L_{1o}} \right) \]

\[ \varepsilon_2 = \ln \left( \frac{L_{2f}}{L_{2o}} \right) \]

Final thickness \( (t_f) = \frac{\text{Initial thickness}(t_o)}{e^{\varepsilon_1} \times e^{\varepsilon_2}} \)

1.13 Elongation

A prismatic bar loaded in tension by an axial force \( P \)

For a prismatic bar loaded in tension by an axial force \( P \). The elongation of the bar can be determined as

\[ \delta = \frac{PL}{AE} \]

Let us take an example: A Mild Steel wire 5 mm in diameter and 1 m long. If the wire is subjected to an axial tensile load 10 kN find its extension of the rod. (\( E = 200 \) GPa)

Answer: We know that \( \delta = \frac{PL}{AE} \)
Here given, Force (P) = 10 kN = 10 × 1000 N
Length (L) = 1 m
Area (A) = \( \frac{\pi d^2}{4} = \frac{\pi \times (0.005)^2}{4} \) m² = 1.963 × 10⁻⁵ m²

Modulus of Elasticity (E) = 200 GPa = 200 × 10⁹ N/m²
Therefore Elongation (\( \delta \)) = \( \frac{PL}{AE} \) = \( \frac{(10 \times 1000) \times 1}{(1.963 \times 10^{-5}) \times (200 \times 10^9)} \) m
= 2.55 × 10⁻³ m = 2.55 mm

**Elongation of composite body**

Elongation of a bar of varying cross section A₁, A₂, A₃ of lengths l₁, l₂, l₃, respectively.
\[
\delta = \frac{P}{E} \left( \frac{l_1}{A_1} + \frac{l_2}{A_2} + \frac{l_3}{A_3} + \ldots + \frac{l_n}{A_n} \right)
\]

Let us take an example: A composite rod is 1000 mm long, its two ends are 40 mm² and 30 mm² in area and length are 300 mm and 200 mm respectively. The middle portion of the rod is 20 mm² in area and 500 mm long. If the rod is subjected to an axial tensile load of 1000 N, find its total elongation. (E = 200 GPa).

**Answer:** Consider the following figure

Given, Load (P) = 1000 N
Area; (A₁) = 40 mm², A₂ = 20 mm², A₃ = 30 mm²
Length; (l₁) = 300 mm, l₂ = 500 mm, l₃ = 200 mm
E = 200 GPa = 200 × 10⁹ N/m² = 200 × 10³ N/mm²
Therefore Total extension of the rod
\[
\delta = \frac{P}{E} \left( \frac{l_1}{A_1} + \frac{l_2}{A_2} + \frac{l_3}{A_3} \right) = \frac{1000 N}{200 \times 10^3 N/mm^2} \times \left[ \frac{300 mm}{40 mm^2} + \frac{500 mm}{20 mm^2} + \frac{200 mm}{30 mm^2} \right] = 0.196 mm
\]

**Elongation of a tapered body**

Elongation of a tapering rod of length ‘L’ due to load ‘P’ at the end
\[
\delta = \frac{4PL}{\pi Ed_1d_2} \quad (d_1 \text{ and } d_2 \text{ are the diameters of smaller & larger ends})
\]
You may remember this in this way, \( \delta = \frac{PL}{E \left( \frac{\pi}{4} d_1 d_2 \right)} \) i.e. \( \frac{PL}{EA_{eq}} \)

Let us take an example: A round bar, of length \( L \), tapers uniformly from small diameter \( d_1 \) at one end to bigger diameter \( d_2 \) at the other end. Show that the extension produced by a tensile axial load \( P \) is \( \delta = \frac{4PL}{\pi d_1 d_2 E} \).

If \( d_2 = 2d_1 \), compare this extension with that of a uniform cylindrical bar having a diameter equal to the mean diameter of the tapered bar.

Answer: Consider the figure below \( d_1 \) be the radius at the smaller end. Then at a \( XX \) cross section located at a distance \( x \) from the smaller end, the value of diameter \( \frac{d_x}{2} \) is equal to

\[
\frac{d_x}{2} = \frac{d_1}{2} + \frac{x \left( d_2 - d_1 \right)}{L} \left( \frac{2}{2} - \frac{2}{2} \right)
\]

or \( d_x = d_1 + \frac{x}{L} (d_2 - d_1) = d_1 (1 + kx) \) where \( k = \frac{d_2 - d_1}{L} \times \frac{1}{d_1} \)

We now taking a small strip of diameter \( 'd_x' \) and length \( 'dx' \) at section \( XX \).

Elongation of this section \( 'd_x' \) length

\[
d(\delta) = \frac{PL}{AE} = \frac{P \cdot dx}{\left( \frac{\pi d_x^2}{4} \right) \times E} = \frac{4P \cdot dx}{\pi \cdot \left( d_1 (1 + kx) \right)^2 E}
\]
Therefore total elongation of the taper bar
\[
\delta = \int d(\delta) = \int \frac{4P}{\pi Ed_{1}^{2}(1+kx)} \, dx = \frac{4PL}{\pi Ed_{1}d_{2}}
\]

**Comparison:** Case-I: Where \(d_{2} = 2d_{1}\)

\[
\text{Elongation } (\delta_{1}) = \frac{4PL}{\pi Ed_{1} \times 2d_{1}} = \frac{2PL}{\pi Ed_{1}^{2}}
\]

Case –II: Where we use Mean diameter

\[
d_{m} = \frac{d_{1} + d_{2}}{2} = \frac{d_{1} + 2d_{1}}{2} = 3d_{1} \quad \frac{3}{2} d_{1}
\]

\[
\text{Elongation of such bar } (\delta_{II}) = \frac{PL}{AE} = \frac{P.L}{\pi (\frac{3}{2} d_{1})^{2}E} = \frac{16PL}{9\pi Ed_{1}^{2}}
\]

\[
\frac{\text{Extension of taper bar}}{\text{Extension of uniform bar}} = \frac{2}{16} = \frac{9}{8}
\]

- **Elongation of a body due to its self weight**

  (i) Elongation of a uniform rod of length ‘L’ due to its own weight ‘W’

\[
\delta = \frac{WL}{2AE}
\]

  The deformation of a bar under its own weight as compared to that when subjected to a direct axial load equal to its own weight will be half.

  (ii) Total extension produced in rod of length ‘L’ due to its own weight ‘\(\omega\)’ per with

\[
\delta = \frac{\omega L^{2}}{2EA}
\]

(iii) Elongation of a conical bar due to its self weight

\[
\delta = \frac{\rho g L^{2}}{6E} = \frac{WL}{2A_{\text{max}}E}
\]

1.14 Structural members or machines must be designed such that the working stresses are less than the ultimate strength of the material.
Working stress \( (\sigma_w) = \frac{\sigma}{n} \)  
\[ \begin{align*} 
&= \frac{\sigma_{ult}}{n_1} \quad \text{n}_2 \text{ to } 3 \quad \text{factor of safety} \\
&= \frac{\sigma_p}{n} \quad \sigma_p = \text{Proof stress} 
\end{align*} \]

1.15 Factor of Safety: \( (n) = \frac{\sigma_y \text{ or } \sigma_p \text{ or } \sigma_{ult}}{\sigma_w} \)

1.16 Thermal or Temperature stress and strain

- When a material undergoes a change in temperature, it either elongates or contracts depending upon whether temperature is increased or decreased of the material.

- If the elongation or contraction is not restricted, i.e. free then the material does not experience any stress despite the fact that it undergoes a strain.

- The strain due to temperature change is called thermal strain and is expressed as,

\[ \varepsilon = \alpha (\Delta T) \]

- Where \( \alpha \) is co-efficient of thermal expansion, a material property, and \( \Delta T \) is the change in temperature.

- The free expansion or contraction of materials, when restrained induces stress in the material and it is referred to as thermal stress.

\[ \sigma_t = \alpha E (\Delta T) \]

Where, \( E = \) Modulus of elasticity

- Thermal stress produces the same effect in the material similar to that of mechanical stress. A compressive stress will produce in the material with increase in temperature and the stress developed is tensile stress with decrease in temperature.

**Let us take an example:** A rod consists of two parts that are made of steel and copper as shown in figure below. The elastic modulus and coefficient of thermal expansion for steel are 200 GPa and \( 11.7 \times 10^{-6} \) per °C respectively and for copper 70 GPa and \( 21.6 \times 10^{-6} \) per °C respectively. If the temperature of the rod is raised by 50°C, determine the forces and stresses acting on the rod.
Answer: If we allow this rod to freely expand then free expansion
\[ \delta_f = \alpha (\Delta T) L \]
\[ = (11.7 \times 10^{-6}) \times 50 \times 500 + (21.6 \times 10^{-6}) \times 50 \times 750 \]
\[ = 1.1025 \text{ mm (Compressive)} \]

But according to diagram only free expansion is 0.4 mm.
Therefore restrained deflection of rod = 1.1025 mm – 0.4 mm = 0.7025 mm

Let us assume the force required to make their elongation vanish be P which is the reaction force at the ends.

\[ \delta = \left( \frac{PL}{AE} \right)_{\text{Steel}} + \left( \frac{PL}{AE} \right)_{\text{Cu}} \]

or \[ 0.7025 = \frac{P \times 500}{\pi \times (0.075)^2 \times (200 \times 10^9)} + \frac{P \times 750}{\pi \times (0.050)^2 \times (70 \times 10^9)} \]

or \[ P = 116.6 \text{ kN} \]

Therefore, compressive stress on steel rod
\[ \sigma_{\text{Steel}} = \frac{P}{A_{\text{Steel}}} = \frac{116.6 \times 10^3}{\pi \times (0.075)^2} \text{ N/m}^2 = 26.39 \text{ MPa} \]

And compressive stress on copper rod
\[ \sigma_{\text{Cu}} = \frac{P}{A_{\text{Cu}}} = \frac{116.6 \times 10^3}{\pi \times (0.050)^2} \text{ N/m}^2 = 59.38 \text{ MPa} \]

1.17 Thermal stress on Brass and Mild steel combination

A brass rod placed within a steel tube of exactly same length. The assembly is making in such a way that elongation of the combination will be same. To calculate the stress induced in the brass rod, steel tube when the combination is raised by \( t^\circ \text{C} \) then the following analogy have to do.
(a) Original bar before heating.

(b) Expanded position if the members are allowed to expand freely and independently after heating.

(c) Expanded position of the compound bar i.e. final position after heating.

- Compatibility Equation:
  \[ \delta = \delta_s + \delta_{st} = \delta_{rt} - \delta_{bt} \]

- Equilibrium Equation:
  \[ \sigma_s A_s = \sigma_b A_b \]

Where, \( \delta \) = Expansion of the compound bar = AD in the above figure.

\( \delta_s \) = Free expansion of the steel tube due to temperature rise \( t^\circ C = \alpha_s L t \)
  = AB in the above figure.

\( \delta_{st} \) = Expansion of the steel tube due to internal force developed by the unequal expansion.
  = BD in the above figure.

\( \delta_{rt} \) = Free expansion of the brass rod due to temperature rise \( t^\circ C = \alpha_b L t \)
  = AC in the above figure.

\( \delta_{bt} \) = Compression of the brass rod due to internal force developed by the unequal expansion.
  = BD in the above figure.

And in the equilibrium equation

Tensile force in the steel tube = Compressive force in the brass rod

Where, \( \sigma_s \) = Tensile stress developed in the steel tube.

\( \sigma_b \) = Compressive stress developed in the brass rod.

\( A_s \) = Cross section area of the steel tube.
$A_b = \text{Cross section area of the brass rod.}$

**Let us take an example:** See the Conventional Question Answer section of this chapter and the question is “Conventional Question IES-2008” and its answer.

### 1.18 Maximum stress and elongation due to rotation

(i) $\sigma_{\text{max}} = \frac{\rho \omega^2 L^2}{8}$ and $(\delta L) = \frac{\rho \omega^2 L^3}{12E}$

(ii) $\sigma_{\text{max}} = \frac{\rho \omega^2 L^2}{2}$ and $(\delta L) = \frac{\rho \omega^2 L^3}{3E}$

For remember: You will get (ii) by multiplying by 4 of (i)

### 1.18 Creep

When a member is subjected to a constant load over a long period of time it undergoes a slow permanent deformation and this is termed as “creep”. This is dependent on temperature. Usually at elevated temperatures creep is high.

- The materials have its own different melting point; each will creep when the homologous temperature $> 0.5$. Homologous temp = $\frac{\text{Testing temperature}}{\text{Melting temperature}} > 0.5$

A typical creep curve shows three distinct stages with different creep rates. After an initial rapid elongation $\varepsilon_o$, the creep rate decrease with time until reaching the steady state.

1) **Primary creep** is a period of transient creep. The creep resistance of the material increases due to material deformation.

2) **Secondary creep** provides a nearly constant creep rate. The average value of the creep rate during this period is called the minimum creep rate. A stage of balance between competing.
Strain hardening and recovery (softening) of the material.

3) Tertiary creep shows a rapid increase in the creep rate due to effectively reduced cross-sectional area of the specimen leading to creep rupture or failure. In this stage intergranular cracking and/or formation of voids and cavities occur.

Creep rate = \( c_1 \sigma^2 \)

Creep strain at any time = zero time strain intercept + creep rate × Time

\[ \varepsilon = \varepsilon_0 + c_1 \sigma^2 \times t \]

Where, \( c_1, c_2 \) are constants and \( \sigma \) = stress

1.19 If a load \( P \) is applied suddenly to a bar then the stress & strain induced will be double than those obtained by an equal load applied gradually.

1.20 Stress produced by a load \( P \) in falling from height \( h \)

\[ \sigma = \sigma_0 \left[ 1 + \sqrt{1 + \frac{2h}{\varepsilon L}} \right] \]

\( \varepsilon \) being stress & strain produced by static load \( P \) & \( L \) = length of bar.

\[ = \frac{A}{P} \left[ 1 + \sqrt{1 + \frac{2AEh}{PL}} \right] \]

1.21 Loads shared by the materials of a compound bar made of bars \( x \) & \( y \) due to load \( W \),

\[
P_x = W \cdot \frac{A_x E_x}{A_x E_x + A_y E_y} \\
P_y = W \cdot \frac{A_y E_y}{A_x E_x + A_y E_y} \\
\]

1.22 Elongation of a compound bar, \( \delta = \frac{PL}{A_x E_x + A_y E_y} \)
1.23 Tension Test

i) **True elastic limit**: based on micro-strain measurement at strains on order of $2 \times 10^{-6}$. Very low value and is related to the motion of a few hundred dislocations.

ii) **Proportional limit**: the highest stress at which stress is directly proportional to strain.

iii) **Elastic limit**: is the greatest stress the material can withstand without any measurable permanent strain after unloading. Elastic limit > proportional limit.

iv) **Yield strength** is the stress required to produce a small specific amount of deformation. The offset yield strength can be determined by the stress corresponding to the intersection of the stress-strain curve and a line parallel to the elastic line offset by a strain of 0.2 or 0.1%. ($\varepsilon = 0.002$ or 0.001).

- The offset yield stress is referred to proof stress either at 0.1 or 0.5% strain used for design and specification purposes to avoid the practical difficulties of measuring the elastic limit or proportional limit.

v) **Tensile strength or ultimate tensile strength (UTS)** $\sigma_u$ is the maximum load $P_{\text{max}}$ divided by the original cross-sectional area $A_o$ of the specimen.

vi) **% Elongation**, $\frac{L_f - L_0}{L_0}$, is chiefly influenced by uniform elongation, which is dependent on the strain-hardening capacity of the material.
vii) Reduction of Area: 
\[ q = \frac{A_o - A_f}{A_o} \]

- Reduction of area is more a measure of the deformation required to produce failure and its chief contribution results from the necking process.
- Because of the complicated state of stress state in the neck, values of reduction of area are dependent on specimen geometry, and deformation behaviour, and they should not be taken as true material properties.
- RA is the most structure-sensitive ductility parameter and is useful in detecting quality changes in the materials.

viii) Stress-strain response

1.24 Elastic strain and Plastic strain

The strain present in the material after unloading is called the residual strain or plastic strain and the strain disappears during unloading is termed as recoverable or elastic strain.

Equation of the straight line CB is given by

\[ \sigma = \varepsilon_{total} \times E - \varepsilon_{Plastic} \times E = \varepsilon_{Elastic} \times E \]

Carefully observe the following figures and understand which one is Elastic strain and which one is Plastic strain.
Let us take an example: A 10 mm diameter tensile specimen has a 50 mm gauge length. The load corresponding to the 0.2% offset is 55 kN and the maximum load is 70 kN. Fracture occurs at 60 kN. The diameter after fracture is 8 mm and the gauge length at fracture is 65 mm. Calculate the following properties of the material from the tension test.

(i) % Elongation
(ii) Reduction of Area (RA) %
(iii) Tensile strength or ultimate tensile strength (UTS)
(iv) Yield strength
(v) Fracture strength
(vi) If E = 200 GPa, the elastic recoverable strain at maximum load
(vii) If the elongation at maximum load (the uniform elongation) is 20%, what is the plastic strain at maximum load?

Answer: Given, Original area \( A_o = \frac{\pi}{4} \times (0.010)^2 \text{ m}^2 = 7.854 \times 10^{-5} \text{ m}^2 \)

Area at fracture \( A_f = \frac{\pi}{4} \times (0.008)^2 \text{ m}^2 = 5.027 \times 10^{-5} \text{ m}^2 \)

Original gauge length \( L_0 = 50 \text{ mm} \)

Gauge length at fracture \( L = 65 \text{ mm} \)

Therefore

(i) % Elongation \( \frac{L - L_0}{L_0} \times 100\% = \frac{65 - 50}{50} \times 100 = 30\% \)
(ii) Reduction of area \( (RA) = q = \frac{A_o - A_f}{A_o} \times 100\% = \frac{7.854 - 5.027}{7.854} \times 100\% = 36\% 

(iii) Tensile strength or Ultimate tensile strength \( (UTS), \sigma_u = \frac{P_{max}}{A_o} = \frac{70 \times 10^3}{7.854 \times 10^{-5}} \text{N/m}^2 = 891 \text{ MPa} 

(iv) Yield strength \( (\sigma_y) = \frac{P_y}{A_o} = \frac{55 \times 10^3}{7.854 \times 10^{-5}} \text{N/m}^2 = 700 \text{ MPa} 

(v) Fracture strength \( (\sigma_f) = \frac{P_{Fracture}}{A_o} = \frac{60 \times 10^3}{7.854 \times 10^{-5}} \text{N/m}^2 = 764 \text{ MPa} 

(vi) Elastic recoverable strain at maximum load \( (\varepsilon_E) = \frac{P_{max} / A_o}{E} = \frac{891 \times 10^6}{200 \times 10^9} = 0.0045 

(vii) Plastic strain \( (\varepsilon_P) = \varepsilon_{total} - \varepsilon_E = 0.2000 - 0.0045 = 0.1955 

1.25 Elasticity

This is the property of a material to regain its original shape after deformation when the external forces are removed. When the material is in elastic region the strain disappears completely after removal of the load. The stress-strain relationship in elastic region need not be linear and can be non-linear (example rubber). The maximum stress value below which the strain is fully recoverable is called the elastic limit. It is represented by point A in figure. All materials are elastic to some extent but the degree varies, for example, both mild steel and rubber are elastic materials but steel is more elastic than rubber.

1.26 Plasticity

When the stress in the material exceeds the elastic limit, the material enters into plastic phase where the strain can no longer be completely removed. Under plastic conditions materials ideally deform without any increase in stress. A typical stress strain diagram for an elastic-perfectly plastic material is shown in the figure. Mises-Henky criterion gives a good starting point for plasticity analysis.
1.27 Strain hardening

If the material is reloaded from point C, it will follow the previous unloading path and line CB becomes its new elastic region with elastic limit defined by point B. Though the new elastic region CB resembles that of the initial elastic region OA, the internal structure of the material in the new state has changed. The change in the microstructure of the material is clear from the fact that the ductility of the material has come down due to strain hardening. When the material is reloaded, it follows the same path as that of a virgin material and fails on reaching the ultimate strength which remains unaltered due to the intermediate loading and unloading process.

1.28 Stress reversal and stress-strain hysteresis loop

We know that fatigue failure begins at a local discontinuity and when the stress at the discontinuity exceeds elastic limit there is plastic strain. The cyclic plastic strain results crack propagation and fracture.

When we plot the experimental data with reversed loading and the true stress strain hysteresis loops is found as shown below.
Due to cyclic strain the elastic limit increases for annealed steel and decreases for cold drawn steel. Here the stress range is $\Delta \sigma$. $\Delta \varepsilon_p$ and $\Delta \varepsilon_e$ are the plastic and elastic strain ranges, the total strain range being $\Delta \varepsilon$. Considering that the total strain amplitude can be given as 

$$\Delta \varepsilon = \Delta \varepsilon_p + \Delta \varepsilon_e$$
OBJECTIVE QUESTIONS (GATE, IES, IAS)

Previous 20-Years GATE Questions

Stress in a bar due to self-weight

GATE-1. Two identical circular rods of same diameter and same length are subjected to same magnitude of axial tensile force. One of the rods is made out of mild steel having the modulus of elasticity of 206 GPa. The other rod is made out of cast iron having the modulus of elasticity of 100 GPa. Assume both the materials to be homogeneous and isotropic and the axial force causes the same amount of uniform stress in both the rods. The stresses developed are within the proportional limit of the respective materials. Which of the following observations is correct? [GATE-2003]
(a) Both rods elongate by the same amount
(b) Mild steel rod elongates more than the cast iron rod
(c) Cast iron rod elongates more than the mild steel rod
(d) As the stresses are equal strains are also equal in both the rods

GATE-2. A steel bar of 40 mm × 40 mm square cross-section is subjected to an axial compressive load of 200 kN. If the length of the bar is 2 m and E = 200 GPa, the elongation of the bar will be: [GATE-2006]
(a) 1.25 mm
(b) 2.70 mm
(c) 4.05 mm
(d) 5.40 mm

True stress and true strain

GATE-3. The ultimate tensile strength of a material is 400 MPa and the elongation up to maximum load is 35%. If the material obeys power law of hardening, then the true stress-true strain relation (stress in MPa) in the plastic deformation range is: [GATE-2006]
(a) $\sigma = 540 \varepsilon^{0.30}$
(b) $\sigma = 775 \varepsilon^{0.30}$
(c) $\sigma = 540 \varepsilon^{0.25}$
(d) $\sigma = 775 \varepsilon^{0.25}$

Elasticity and Plasticity

GATE-4. An axial residual compressive stress due to a manufacturing process is present on the outer surface of a rotating shaft subjected to bending. Under a given bending load, the fatigue life of the shaft in the presence of the residual compressive stress is: [GATE-2008]
(a) Decreased
(b) Increased or decreased, depending on the external bending load
(c) Neither decreased nor increased
GATE-5. A static load is mounted at the centre of a shaft rotating at uniform angular velocity. This shaft will be designed for
(a) The maximum compressive stress (static)  (b) The maximum tensile stress (static)
(c) The maximum bending moment (static)  (d) Fatigue loading

GATE-6. Fatigue strength of a rod subjected to cyclic axial force is less than that of a rotating beam of the same dimensions subjected to steady lateral force because
(a) Axial stiffness is less than bending stiffness  [GATE-1992]
(b) Of absence of centrifugal effects in the rod
(c) The number of discontinuities vulnerable to fatigue are more in the rod
(d) At a particular time the rod has only one type of stress whereas the rod
the tensile and compressive stresses.

Relation between the Elastic Modulii

GATE-7. A rod of length $L$ and diameter $D$ is subjected to a tensile load $P$. Which of the following is sufficient to calculate the resulting change in diameter?
(a) Young's modulus  (b) Shear modulus  [GATE-2008]
(c) Poisson's ratio  (d) Both Young's modulus and shear modulus

GATE-8. In terms of Poisson's ratio ($\mu$) the ratio of Young's Modulus ($E$) to Shear Modulus ($G$) of elastic materials is: [GATE-2004]
(a) $2(1 + \mu)$  (b) $2(1 + \mu)$  (c) $\frac{1}{2}(1 + \mu)$  (d) $\frac{1}{2}(1 + \mu)$

GATE-9. The relationship between Young's modulus ($E$), Bulk modulus ($K$) and Poisson's ratio ($\mu$) is given by:
(a) $E = 3K(1-2\mu)$  (b) $K = 3E(1-2\mu)$
(c) $E = 3K(1-\mu)$  (d) $K = 3E(1-\mu)$

Stresses in compound strut

GATE-10. In a bolted joint two members are connected with an axial tightening force of 2200 N. If the bolt used has metric threads of 4 mm pitch, then torque required for achieving the tightening force is
(a) 0.7Nm  (b) 1.0 Nm  [GATE-2004]
(c) 1.4Nm  (d) 2.8Nm
GATE-11. The figure below shows a steel rod of 25 mm$^2$ cross sectional area. It is loaded at four points, K, L, M and N. 

![Steel Rod Diagram](image)

Assume $E_{\text{steel}} = 200$ GPa. The total change in length of the rod due to loading is:
(a) 1 µm  
(b) -10 µm  
(c) 16 µm  
(d) -20 µm

GATE-12. A bar having a cross-sectional area of 700 mm$^2$ is subjected to axial loads at the positions indicated. The value of stress in the segment QR is:

![Bar Diagram](image)

(a) 40 MPa  
(b) 50 MPa  
(c) 70 MPa  
(d) 120 MPa

GATE-13. An ejector mechanism consists of a helical compression spring having a spring constant of $K = 981 \times 10^3$ N/m. It is pre-compressed by 100 mm from its free state. If it is used to eject a mass of 100 kg held on it, the mass will move up through a distance of:

(a) 100 mm  
(b) 500 mm  
(c) 981 mm  
(d) 1000 mm

![Ejector Diagram](image)
GATE-14. The figure shows a pair of pin-jointed gripper-tongs holding an object weighing 2000 N. The coefficient of friction ($\mu$) at the gripping surface is 0.1. $XX$ is the line of action of the input force and $YY$ is the line of application of gripping force. If the pin-joint is assumed to be frictionless, then magnitude of force $F$ required to hold the weight is:

(a) 1000 N  
(b) 2000 N  
(c) 2500 N  
(d) 5000 N

\[\text{[GATE-2004]}\]

GATE-15. A uniform, slender cylindrical rod is made of a homogeneous and isotropic material. The rod rests on a frictionless surface. The rod is heated uniformly. If the radial and longitudinal thermal stresses are represented by $\sigma_r$ and $\sigma_z$, respectively, then

(a) $\sigma_r = 0, \sigma_z = 0$  
(b) $\sigma_r \neq 0, \sigma_z = 0$  
(c) $\sigma_r = 0, \sigma_z \neq 0$  
(d) $\sigma_r \neq 0, \sigma_z \neq 0$

\[\text{[GATE-2005]}\]

**Tensile Test**

GATE-16. A test specimen is stressed slightly beyond the yield point and then unloaded. Its yield strength will:

(a) Decrease  
(b) Increase  
(c) Remains same  
(d) Becomes equal to ultimate tensile strength

\[\text{[GATE-1995]}\]

GATE-17. Under repeated loading a material has the stress-strain curve shown in the figure, which of the following statements is true?

(a) The smaller the shaded area, the better the material damping  
(b) The larger the shaded area, the better the material damping  
(c) Material damping is an independent material property and does not depend on this curve  
(d) None of these

\[\text{[GATE-1999]}\]
GATE-18. Match the items in Columns I and II. [GATE-2006]

<table>
<thead>
<tr>
<th>Column I</th>
<th>Column I</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. Wrinkling</td>
<td>1. Yield point elongation</td>
</tr>
<tr>
<td>Q. Orange peel</td>
<td>2. Anisotropy</td>
</tr>
<tr>
<td>R. Stretcher strains</td>
<td>3. Large grain size</td>
</tr>
<tr>
<td>S. Earing</td>
<td>4. Insufficient blank holding force</td>
</tr>
<tr>
<td></td>
<td>5. Fine grain size</td>
</tr>
<tr>
<td></td>
<td>6. Excessive blank holding force</td>
</tr>
</tbody>
</table>

(a) P – 6, Q – 3, R – 1, S – 2  
(b) P – 4, Q – 5, R – 6, S – 1  
(c) P – 2, Q – 5, R – 3, S – 4  
(d) P – 4, Q – 3, R – 1, S – 2

### Previous 20-Years IES Questions

#### Stress in a bar due to self-weight

**IES-1.** A solid uniform metal bar of diameter D and length L is hanging vertically from its upper end. The elongation of the bar due to self weight is: [IES-2005]

(a) Proportional to L and inversely proportional to D²  
(b) Proportional to L² and inversely proportional to D²  
(c) Proportional of L but independent of D  
(d) Proportional of U but independent of D

**IES-2.** The deformation of a bar under its own weight as compared to that when subjected to a direct axial load equal to its own weight will be: [IES-1998]

(a) The same  
(b) One-fourth  
(c) Half  
(d) Double

**IES-3.** A rigid beam of negligible weight is supported in a horizontal position by two rods of steel and aluminum, 2 m and 1 m long having values of cross-sectional areas 1 cm² and 2 cm² and E of 200 GPa and 100 GPa respectively. A load P is applied as shown in the figure [GATE-2002]

If the rigid beam is to remain horizontal then

(a) The forces on both sides should be equal  
(b) The force on aluminum rod should be twice the force on steel  
(c) The force on the steel rod should be twice the force on aluminum  
(d) The force P must be applied at the centre of the beam
Bar of uniform strength

IES-4. Which one of the following statements is correct? [IES-2007]
A beam is said to be of uniform strength, if
(a) The bending moment is the same throughout the beam
(b) The shear stress is the same throughout the beam
(c) The deflection is the same throughout the beam
(d) The bending stress is the same at every section along its longitudinal axis

IES-5. Which one of the following statements is correct? [IES-2006]
Beams of uniform strength vary in section such that
(a) Bending moment remains constant  (b) Deflection remains constant
(c) Maximum bending stress remains constant  (d) Shear force remains constant

IES-6. For bolts of uniform strength, the shank diameter is made equal to [IES-2003]
(a) Major diameter of threads  (b) Pitch diameter of threads
(c) Minor diameter of threads  (d) Nominal diameter of threads

IES-7. A bolt of uniform strength can be developed by [IES-1995]
(a) Keeping the core diameter of threads equal to the diameter of unthreaded portion of the bolt
(b) Keeping the core diameter smaller than the diameter of the unthreaded portion
(c) Keeping the nominal diameter of threads equal the diameter of unthreaded portion of the bolt
(d) One end fixed and the other end free

Elongation of a Taper Rod

IES-8. Two tapering bars of the same material are subjected to a tensile load P. The lengths of both the bars are the same. The larger diameter of each of the bars is D. The diameter of the bar A at its smaller end is D/2 and that of the bar B is D/3. What is the ratio of elongation of the bar A to that of the bar B? [IES-2006]
(a) 3 : 2  (b) 2 : 3  (c) 4 : 9  (d) 1 : 3

IES-9. A bar of length L tapers uniformly from diameter 1.1 D at one end to 0.9 D at the other end. The elongation due to axial pull is computed using mean diameter D. What is the approximate error in computed elongation? [IES-2004]
(a) 10%  (b) 5%  (c) 1%  (d) 0.5%

IES-10. The stretch in a steel rod of circular section, having a length 'l' subjected to a tensile load' P' and tapering uniformly from a diameter d₁ at one end to a diameter d₂ at the other end, is given [IES-1995]
(a) \( \frac{Pl}{4Ed_d} \)  (b) \( \frac{p_l \pi}{Ed_d} \)  (c) \( \frac{pl \pi}{4Ed_d} \)  (d) \( \frac{4pl}{\pi Ed_d} \)
IES-11. A tapering bar (diameters of end sections being d) and a bar of uniform cross-section ‘d’ have the same length and are subjected the same axial pull. Both the bars will have the same extension if ‘d’ is equal to [IES-1998]

\[ \frac{d_1 + d_2}{2} \quad (b) \sqrt{d_1 d_2} \quad (c) \sqrt{\frac{d_1 + d_2}{2}} \quad (d) \sqrt{\frac{d_1^2 + d_2^2}{2}} \]

Poisson’s ratio

IES-12. In the case of an engineering material under unidirectional stress in the x-direction, the Poisson’s ratio is equal to (symbols have the usual meanings) [IAS 1994, IES-2000]

(a) \frac{\varepsilon_y}{\varepsilon_x} \quad (b) \frac{\sigma_y}{\sigma_x} \quad (c) \frac{\sigma_y}{\varepsilon_x} \quad (d) \frac{\sigma_y}{\sigma_x}

IES-13. Which one of the following is correct in respect of Poisson’s ratio (v) limits for an isotropic elastic solid? [IES-2004]

(a) \(-1 \leq v \leq 1\) \quad (b) \(\frac{1}{4} \leq v \leq \frac{1}{3}\) \quad (c) \(-\frac{1}{2} \leq v \leq \frac{1}{2}\) \quad (d) \(-1/2 \leq v \leq 1/2\)

IES-14. Match List-I (Elastic properties of an isotropic elastic material) with List-II (Nature of strain produced) and select the correct answer using the codes given below the Lists: [IES-1997]

<table>
<thead>
<tr>
<th>List-I</th>
<th>List-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Young's modulus</td>
<td>1. Shear strain</td>
</tr>
<tr>
<td>B. Modulus of rigidity</td>
<td>2. Normal strain</td>
</tr>
<tr>
<td>C. Bulk modulus</td>
<td>3. Transverse strain</td>
</tr>
<tr>
<td>D. Poisson's ratio</td>
<td>4. Volumetric strain</td>
</tr>
</tbody>
</table>

Codes: A B C D | A B C D
(a) 1 2 3 4 | (b) 2 1 3 4
(c) 2 1 4 3 | (d) 1 2 4 3

IES-15. If the value of Poisson's ratio is zero, then it means that [IES-1994]

(a) The material is rigid.
(b) The material is perfectly plastic.
(c) There is no longitudinal strain in the material
(d) The longitudinal strain in the material is infinite.

IES-16. Which of the following is true (\(\mu = \text{Poisson's ratio}\)) [IES-1992]

(a) \(0 < \mu < 1/2\) \quad (b) \(1 < \mu < 0\) \quad (c) \(1 < \mu < -1\) \quad (d) \(\infty < \mu \ll -\infty\)

Elasticity and Plasticity

IES-17. If the area of cross-section of a wire is circular and if the radius of this circle decreases to half its original value due to the stretch of the wire by a load, then the modulus of elasticity of the wire be: [IES-1993]
IES-18. The relationship between the Lame's constant ‘λ’, Young’s modulus ‘E’ and the Poisson’s ratio ‘μ’

\[ \lambda = \frac{E\mu}{(1 + \mu)(1 - 2\mu)} \]  
\[ \lambda = \frac{E\mu}{(1 + 2\mu)(1 - \mu)} \]  
\[ \lambda = \frac{E\mu}{1 + \mu} \]  
\[ \lambda = \frac{E\mu}{(1 - \mu)} \]

IES-19. Which of the following pairs are correctly matched?  
1. Resilience................. Resistance to deformation.
2. Malleability .............. Shape change.
3. Creep ........................ Progressive deformation.
4. Plasticity ................. Permanent deformation.

Select the correct answer using the codes given below:

Codes:  
(a) 2, 3 and 4  
(b) 1, 2 and 3  
(c) 1, 2 and 4  
(d) 1, 3 and 4

Creep and fatigue

IES-20. What is the phenomenon of progressive extension of the material i.e., strain increasing with the time at a constant load, called?  
(a) Plasticity  
(b) Yielding  
(c) Creeping  
(d) Breaking

IES-21. The correct sequence of creep deformation in a creep curve in order of their elongation is:

(a) Steady state, transient, accelerated  
(b) Transient, steady state, accelerated  
(c) Transient, accelerated, steady state  
(d) Accelerated, steady state, transient

IES-22. The highest stress that a material can withstand for a specified length of time without excessive deformation is called

(a) Fatigue strength  
(b) Endurance strength  
(c) Creep strength  
(d) Creep rupture strength

IES-23. Which one of the following features improves the fatigue strength of a metallic material?

(a) Increasing the temperature  
(b) Scratching the surface  
(c) Overstressing  
(d) Under stressing

IES-24. Consider the following statements:

For increasing the fatigue strength of welded joints it is necessary to employ

Of the above statements

(a) 1 and 2 are correct  
(b) 2 and 3 are correct  
(c) 1 and 3 are correct  
(d) 1, 2 and 3 are correct
Relation between the Elastic Modulii

IES-25. For a linearly elastic, isotropic and homogeneous material, the number of elastic constants required to relate stress and strain is: [IAS 1994; IES-1998]
(a) Two  (b) Three  (c) Four  (d) Six

IES-26. E, G, K and μ represent the elastic modulus, shear modulus, bulk modulus and Poisson’s ratio respectively of a linearly elastic, isotropic and homogeneous material. To express the stress-strain relations completely for this material, at least
(a) E, G and μ must be known  (b) E, K and μ must be known
(c) Any two of the four must be known  (d) All the four must be known

IES-27. The number of elastic constants for a completely anisotropic elastic material which follows Hooke’s law is: [IES-1999]
(a) 3    (b) 4    (c) 21    (d) 25

IES-28. What are the materials which show direction dependent properties, called?
(a) Homogeneous materials  (b) Viscoelastic materials  [IES 2007]
(c) Isotropic materials  (d) Anisotropic materials

IES-29. An orthotropic material, under plane stress condition will have:  [IES-2006]
(a) 15 independent elastic constants  (b) 4 independent elastic constants
(c) 5 independent elastic constants  (d) 9 independent elastic constants

IES-30. Match List-I (Properties) with List-II (Units) and select the correct answer using the codes given below the lists:  [IES-2001]

<table>
<thead>
<tr>
<th>List I</th>
<th>List II</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Dynamic viscosity</td>
<td>1. Pa</td>
</tr>
<tr>
<td>B. Kinematic viscosity</td>
<td>2. m²/s</td>
</tr>
<tr>
<td>C. Torsional stiffness</td>
<td>3. Ns/m²</td>
</tr>
<tr>
<td>D. Modulus of rigidity</td>
<td>4. N/m</td>
</tr>
</tbody>
</table>

Codes: A B C D  A B C D  (a) 3 2 4 1  (b) 5 2 4 3  (c) 5 4 2 1  (d) 5 4 2 1

IES-31. Young's modulus of elasticity and Poisson's ratio of a material are \(1.25 \times 10^5\) MPa and 0.34 respectively. The modulus of rigidity of the material is:  [IAS 1994, IES-1995, 2001, 2002, 2007]
(a) 0.4025 \(\times 10^5\) Mpa  (b) 0.4664 \(\times 10^5\) Mpa
(c) 0.8375 \(\times 10^5\) MPA  (d) 0.9469 \(\times 10^5\) MPA

IES-32. In a homogenous, isotropic elastic material, the modulus of elasticity E in terms of G and K is equal to  [IAS-1995, IES - 1992]
(a) \(\frac{G+3K}{9KG}\)  (b) \(\frac{3G+K}{9KG}\)  (c) \(\frac{9KG}{G+3K}\)  (d) \(\frac{9K}{K+3G}\)
IES-33. What is the relationship between the linear elastic properties Young's modulus (E), rigidity modulus (G) and bulk modulus (K)? [IES-2008]

(a) \( \frac{1}{E} = \frac{9}{K} + \frac{3}{G} \)  
(b) \( \frac{3}{E} = \frac{9}{K} + \frac{1}{G} \)  
(c) \( \frac{9}{E} = \frac{3}{K} + \frac{1}{G} \)  
(d) \( \frac{9}{E} = \frac{1}{K} + \frac{3}{G} \)

IES-34. What is the relationship between the linear elastic properties Young's modulus (E), rigidity modulus (G) and bulk modulus (K)? [IES-2009]

(a) \( E = \frac{KG}{9K + G} \)  
(b) \( E = \frac{9KG}{K + G} \)  
(c) \( E = \frac{9KG}{K + 3G} \)  
(d) \( E = \frac{9KG}{3K + G} \)

IES-35. If E, G and K denote Young's modulus, Modulus of rigidity and Bulk Modulus, respectively, for an elastic material, then which one of the following can be possibly true? [IES-2005]

(a) G = 2K   
(b) G = E   
(c) K = E   
(d) G = K = E

IES-36. If a material had a modulus of elasticity of \( 2.1 \times 10^6 \) kgf/cm² and a modulus of rigidity of \( 0.8 \times 10^6 \) kgf/cm² then the approximate value of the Poisson's ratio of the material would be: [IES-1993]

(a) 0.26   
(b) 0.31   
(c) 0.47   
(d) 0.5

IES-37. The modulus of elasticity for a material is 200 GN/m² and Poisson's ratio is 0.25. What is the modulus of rigidity? [IES-2004]

(a) 80 GN/m²   
(b) 125 GN/m²   
(c) 250 GN/m²   
(d) 320 GN/m²

IES-38. Consider the following statements: [IES-2009]

1. Two-dimensional stresses applied to a thin plate in its own plane represent the plane stress condition.
2. Under plane stress condition, the strain in the direction perpendicular to the plane is zero.
3. Normal and shear stresses may occur simultaneously on a plane.

Which of the above statements is/are correct?

(a) 1 only   
(b) 1 and 2   
(c) 2 and 3   
(d) 1 and 3

IES-39. Eight bolts are to be selected for fixing the cover plate of a cylinder subjected to a maximum load of 980·175 kN. If the design stress for the bolt material is 315 N/mm², what is the diameter of each bolt? [IES-2008]

(a) 10 mm   
(b) 22 mm   
(c) 30 mm   
(d) 36 mm

IES-40. For a composite consisting of a bar enclosed inside a tube of another material when compressed under a load 'w' as a whole through rigid collars at the end of the bar. The equation of compatibility is given by (suffixes 1 and 2) refer to bar and tube respectively [IES-1998]
IES-41. When a composite unit consisting of a steel rod surrounded by a cast iron tube is subjected to an axial load.  

Assertion (A): The ratio of normal stresses induced in both the materials is equal to the ratio of Young's moduli of respective materials.  

Reason (R): The composite unit of these two materials is firmly fastened together at the ends to ensure equal deformation in both the materials.  

(a) Both A and R are individually true and R is the correct explanation of A  
(b) Both A and R are individually true but R is NOT the correct explanation of A  
(c) A is true but R is false  
(d) A is false but R is true

IES-42. The figure below shows a steel rod of 25 mm² cross sectional area. It is loaded at four points, K, L, M and N.  

Assume \( E_{\text{steel}} = 200 \text{ GPa} \). The total change in length of the rod due to loading is:  

(a) 1 \( \mu \text{m} \)  
(b) -10 \( \mu \text{m} \)  
(c) 16 \( \mu \text{m} \)  
(d) –20 \( \mu \text{m} \)

IES-43. The reactions at the rigid supports at A and B for the bar loaded as shown in the figure are respectively.  

(a) \( \frac{20}{3} \text{ kN}, \frac{10}{3} \text{ kN} \)  
(b) \( \frac{10}{3} \text{ kN}, \frac{20}{3} \text{ kN} \)  
(c) 5 kN, 5 kN  
(d) 6 kN, 4 kN

IES-44. Which one of the following is correct?  

When a nut is tightened by placing a washer below it, the bolt will be subjected to:  

(a) Compression only  
(b) Tension
IES-45. Which of the following stresses are associated with the tightening of nut on a bolt? [IES-1998]
1. Tensile stress due to the stretching of bolt
2. Bending stress due to the bending of bolt
3. Crushing and shear stresses in threads
4. Torsional shear stress due to frictional resistance between the nut and the bolt.

Select the correct answer using the codes given below
Codes: (a) 1, 2 and 4  (b) 1, 2 and 3  (c) 2, 3 and 4  (d) 1, 3 and 4

Thermal effect

IES-46. A 100 mm × 5 mm × 5 mm steel bar free to expand is heated from 15°C to 40°C. What shall be developed? [IES-2008]
(a) Tensile stress  (b) Compressive stress  (c) Shear stress  (d) No stress

IES-47. Which one of the following statements is correct? [GATE-1995; IES 2007]
If a material expands freely due to heating, it will develop
(a) Thermal stress  (b) Tensile stress  (c) Compressive stress  (d) No stress

IES-48. A cube having each side of length a, is constrained in all directions and is heated uniformly so that the temperature is raised to T°C. If γ is the thermal coefficient of expansion of the cube material and E the modulus of elasticity, the stress developed in the cube is: [IES-2003]

(a) \( \frac{\alpha TE}{\gamma} \)  
(b) \( \frac{\alpha TE}{1-2\gamma} \)  
(c) \( \frac{\alpha TE}{2\gamma} \)  
(d) \( \frac{\alpha TE}{1+2\gamma} \)

IES-49. Consider the following statements: [IES-2002]
Thermal stress is induced in a component in general, when a temperature gradient exists in the component the component is free from any restraint it is restrained to expand or contract freely

Which of the above statements are correct?
(a) 1 and 2  
(b) 2 and 3  
(c) 3 alone  
(d) 2 alone

IES-50. A steel rod 10 mm in diameter and 1m long is heated from 20°C to 120°C, E = 200 GPa and \( \alpha = 12 \times 10^{-6} \) per °C. If the rod is not free to expand, the thermal stress developed is: [IAS-2003, IES-1997, 2000, 2006]
(a) 120 MPa (tensile)  
(b) 240 MPa (tensile)  
(c) 120 MPa (compressive)  
(d) 240 MPa (compressive)

IES-51. A cube with a side length of 1 cm is heated uniformly 1°C above the room temperature and all the sides are free to expand. What will be the increase in volume of the cube? (Given coefficient of thermal expansion is \( \alpha \) per °C)
IES-52. A bar of copper and steel form a composite system. They are heated to a temperature of 40 °C. What type of stress is induced in the copper bar?  
(a) Tensile  (b) Compressive  (c) Both tensile and compressive  (d) Shear

IES-53. \( \alpha = 12.5 \times 10^{-6/\circ C}, \ E = 200 \ \text{GPa}. \) If the rod fitted strongly between the supports as shown in the figure, is heated, the stress induced in it due to 20°C rise in temperature will be:  
(a) 0.07945 MPa  (b) -0.07945 MPa  (c) -0.03972 MPa  (d) 0.03972 MPa

IES-54. The temperature stress is a function of  
1. Coefficient of linear expansion  
2. Temperature rise  
3. Modulus of elasticity
The correct answer is:  
(a) 1 and 2 only  (b) 1 and 3 only  (c) 2 and 3 only  (d) 1, 2 and 3

Impact loading

IES-55. Assertion (A): Ductile materials generally absorb more impact loading than a brittle material  
Reason (R): Ductile materials generally have higher ultimate strength than brittle materials
(a) Both A and R are individually true and R is the correct explanation of A  
(b) Both A and R are individually true but R is NOT the correct explanation of A  
(c) A is true but R is false  
(d) A is false but R is true

IES-56. Assertion (A): Specimens for impact testing are never notched.  
Reason (R): A notch introduces tri-axial tensile stresses which cause brittle fracture.
(a) Both A and R are individually true and R is the correct explanation of A  
(b) Both A and R are individually true but R is NOT the correct explanation of A  
(c) A is true but R is false  
(d) A is false but R is true
Tensile Test

IES-57. During tensile-testing of a specimen using a Universal Testing Machine, the parameters actually measured include [IES-1996]
(a) True stress and true strain  (b) Poisson’s ratio and Young’s modulus
(c) Engineering stress and engineering strain  (d) Load and elongation

IES-58. In a tensile test, near the elastic limit zone [IES-2006]
(a) Tensile stress increases at a faster rate
(b) Tensile stress decreases at a faster rate
(c) Tensile stress increases in linear proportion to the stress
(d) Tensile stress decreases in linear proportion to the stress

IES-59. Match List-I (Types of Tests and Materials) with List-II (Types of Fractures) and select the correct answer using the codes given below the lists:

List I List-II [IES-2002; IAS-2004]
(Types of Tests and Materials) (Types of Fractures)
A. Tensile test on CI 1. Plain fracture on a transverse plane
B. Torsion test on MS 2. Granular helicoidal fracture
C. Tensile test on MS 3. Plain granular at 45° to the axis
D. Torsion test on CI 4. Cup and Cone

Codes:
(a) 4 2 3 1  (c) 4 1 3 2
(b) 5 1 4 2  (d) 5 2 4 1

IES-60. Which of the following materials generally exhibits a yield point? [IES-2003]
(a) Cast iron  (b) Annealed and hot-rolled mild steel
(c) Soft brass  (d) Cold-rolled steel

IES-61. For most brittle materials, the ultimate strength in compression is much larger than the ultimate strength in tension. This is mainly due to [IES-1992]
(a) Presence of flaws × microscopic cracks or cavities
(b) Necking in tension
(c) Severity of tensile stress as compared to compressive stress
(d) Non-linearity of stress-strain diagram

IES-62. What is the safe static tensile load for a M36 × 4C bolt of mild steel having yield stress of 280 MPa and a factor of safety 1.5? [IES-2005]
(a) 285 kN  (b) 190 kN  (c) 142.5 kN  (d) 95 kN

IES-63. Which one of the following properties is more sensitive to increase in strain rate? [IES-2000]
(a) Yield strength  (b) Proportional limit  (c) Elastic limit  (d) Tensile strength
IES-64. A steel hub of 100 mm internal diameter and uniform thickness of 10 mm was heated to a temperature of 300°C to shrink-fit it on a shaft. On cooling, a crack developed parallel to the direction of the length of the hub. Consider the following factors in this regard:

1. Tensile hoop stress
2. Tensile radial stress
3. Compressive hoop stress
4. Compressive radial stress

The cause of failure is attributable to

(a) 1 alone  (b) 1 and 3  (c) 1, 2 and 4  (d) 2, 3 and 4

IES-65. If failure in shear along 45° planes is to be avoided, then a material subjected to uniaxial tension should have its shear strength equal to at least

(a) Tensile strength
(b) Compressive strength
(c) Half the difference between the tensile and compressive strengths.
(d) Half the tensile strength.

IES-66. Select the proper sequence


(a) 2, 3, 1, 4  (b) 2, 1, 3, 4  (c) 1, 3, 2, 4  (d) 1, 2, 3, 4

---

**Stress in a bar due to self-weight**

IAS-1. A heavy uniform rod of length 'L' and material density 'δ' is hung vertically with its top end rigidly fixed. How is the total elongation of the bar under its own weight expressed?

(a) \( \frac{2\delta L^2 g}{E} \)  (b) \( \frac{\delta L^2 g}{E} \)  (c) \( \frac{\delta L^2 g}{\sqrt{2E}} \)  (d) \( \frac{\delta L^2 g}{2E} \)

IAS-2. A rod of length 'l' and cross-section area 'A' rotates about an axis passing through one end of the rod. The extension produced in the rod due to centrifugal forces is (w is the weight of the rod per unit length and \( \omega \) is the angular velocity of rotation of the rod).

(a) \( \frac{\omega w l^5}{gE} \)  (b) \( \frac{\omega^2 w l^3}{3gE} \)  (c) \( \frac{\omega^2 w l^3}{gE} \)  (d) \( \frac{3gE}{\omega^2 w l^3} \)

**Elongation of a Taper Rod**

IAS-3. A rod of length, "1" tapers uniformly from a diameter "D1" to a diameter "D2" and carries an axial tensile load of "P". The extension of the rod is (E represents the modulus of elasticity of the material of the rod)

(a) \( \frac{4P1}{\pi ED1D2} \)  (b) \( \frac{4PE1}{\pi D1D2} \)  (c) \( \frac{\pi EP1}{4D1D2} \)  (d) \( \frac{\pi P1}{4ED1D2} \)
**Poisson’s ratio**

**IAS-4.** In the case of an engineering material under unidirectional stress in the $x$-direction, the Poisson's ratio is equal to (symbols have the usual meanings)  

$$\frac{\varepsilon_y}{\varepsilon_x}$$  

[IAS 1994, IES-2000]

**IAS-5.** Assertion (A): Poisson's ratio of a material is a measure of its ductility.  
Reason (R): For every linear strain in the direction of force, Poisson's ratio of the material gives the lateral strain in directions perpendicular to the direction of force.  

(a) Both A and R are individually true and R is the correct explanation of A  
(b) Both A and R are individually true but R is **NOT** the correct explanation of A  
(c) A is true but R is false  
(d) A is false but R is true  

**IAS-6.** Assertion (A): Poisson's ratio is a measure of the lateral strain in all direction perpendicular to and in terms of the linear strain.  
Reason (R): The nature of lateral strain in a uni-axially loaded bar is opposite to that of the linear strain.  

(a) Both A and R are individually true and R is the correct explanation of A  
(b) Both A and R are individually true but R is **NOT** the correct explanation of A  
(c) A is true but R is false  
(d) A is false but R is true

**Elasticity and Plasticity**

**IAS-7.** A weight falls on a plunger fitted in a container filled with oil thereby producing a pressure of 1.5 N/mm$^2$ in the oil. The Bulk Modulus of oil is 2800 N/mm$^2$. Given this situation, the volumetric compressive strain produced in the oil will be:  

(a) $400 \times 10^{-6}$  
(b) $800 \times 10^{-6}$  
(c) $268 \times 10^{-6}$  
(d) $535 \times 10^{-6}$  

[IAS-1997]

**Relation between the Elastic Moduli**

**IAS-8.** For a linearly elastic, isotropic and homogeneous material, the number of elastic constants required to relate stress and strain is:  

(a) Two  
(b) Three  
(c) Four  
(d) Six  

[IAS 1994; IES-1998]

**IAS-9.** The independent elastic constants for a homogenous and isotropic material are  

(a) $E, G, K, v$  
(b) $E, G, K$  
(c) $E, G, v$  
(d) $E, G$  

[IAS-1995]

**IAS-10.** The unit of elastic modulus is the same as those of  

(a) Stress, shear modulus and pressure  
(b) Strain, shear modulus and force  
(c) Shear modulus, stress and force  
(d) Stress, strain and pressure.  

[IAS 1994]
IAS-11. Young’s modulus of elasticity and Poisson’s ratio of a material are $1.25 \times 10^5$ MPa and 0.34 respectively. The modulus of rigidity of the material is:

(a) $0.4025 \times 10^5$ MPa  
(b) $0.4664 \times 10^5$ MPa  
(c) $0.8375 \times 10^5$ MPa  
(d) $0.9469 \times 10^5$ MPa

IAS-12. The Young's modulus of elasticity of a material is 2.5 times its modulus of rigidity. The Poisson's ratio for the material will be:

(a) 0.25  
(b) 0.33  
(c) 0.50  
(d) 0.75

IAS-13. In a homogenous, isotropic elastic material, the modulus of elasticity $E$ in terms of $G$ and $K$ is equal to:

(a) $G + 3K$  
(b) $3G + K$  
(c) $9K$  
(d) $G + 3K$

IAS-14. The Elastic Constants $E$ and $K$ are related as ($\mu$ is the Poisson's ratio)[IAS-1996]

(a) $E = 2k (1 - 2\mu)$  
(b) $E = 3k (1 - 2\mu)$  
(c) $E = 3k (1 + \mu)$  
(d) $E = 2k (1 + 2\mu)$

IAS-15. For an isotropic, homogeneous and linearly elastic material, which obeys Hooke’s law, the number of independent elastic constant is:

(a) 1  
(b) 2  
(c) 3  
(d) 6

IAS-16. The moduli of elasticity and rigidity of a material are 200 GPa and 80 GPa, respectively. What is the value of the Poisson's ratio of the material? [IAS-2007]

(a) 0.30  
(b) 0.26  
(c) 0.25  
(d) 0.24

**Stresses in compound strut**

IAS-17. The reactions at the rigid supports at A and B for the bar loaded as shown in the figure are respectively.

(a) 20/3 kN, 10/3 kN  
(b) 10/3 kN, 20/3 kN  
(c) 5 kN, 5 kN  
(d) 6 kN, 4 kN

**Thermal effect**

IAS-18. A steel rod 10 mm in diameter and 1m long is heated from 20°C to 120°C, $E = 200$ GPa and $a = 12 \times 10^{-6}$ per °C. If the rod is not free to expand, the thermal stress developed is:

(a) $1.8 \times 10^6$ MPa  
(b) $1.2 \times 10^6$ MPa  
(c) $2 \times 10^6$ MPa  
(d) $3 \times 10^6$ MPa
(a) 120 MPa (tensile)    (b) 240 MPa (tensile)
(c) 120 MPa (compressive)    (d) 240 MPa (compressive)

IAS-19. A steel rod of diameter 1 cm and 1 m long is heated from 20°C to 120°C. Its
$\alpha = 12 \times 10^{-6} / K$ and $E = 200$ GN/m². If the rod is free to expand, the thermal
stress developed in it is: [IAS-2002]
(a) $12 \times 10^4$ N/m²    (b) 240 kN/m²    (c) Zero    (d) Infinity

IAS-20. Which one of the following pairs is NOT correctly matched? [IAS-1999]
(E = Young's modulus, $\alpha =$ Coefficient of linear expansion, $T =$ Temperature
rise, $A =$ Area of cross-section, $l =$ Original length)
(a) Temperature strain with permitted expansion $\delta$ .... $\alpha T l - \delta$
(b) Temperature stress .... $\alpha T E$
(c) Temperature thrust .... $\alpha T E A$
(d) Temperature stress with permitted expansion .... $E(\alpha T l - \delta) / l$

Impact loading
IAS-21. Match List I with List II and select the correct answer using the codes given
below the lists: [IAS-1995]
List I (Property)    List II (Testing Machine)
A. Tensile strength 1. Rotating Bending Machine
B. Impact strength 2. Three-Point Loading Machine
C. Bending strength 3. Universal Testing Machine
D. Fatigue strength 4. Izod Testing Machine
Codes: A B C D  A B C D
(a) 4 3 2 1 (b) 3 2 1 4
(c) 2 1 4 3 (d) 3 4 2 1

Tensile Test
IAS-22. A mild steel specimen is tested in tension up to fracture in a Universal Testing
Machine. Which of the following mechanical properties of the material can be
evaluated from such a test? [IAS-2007]
4. Tensile strength 5. Modulus of rigidity
Select the correct answer using the code given below:
(a) 1, 3, 5 and 6    (b) 2, 3, 4 and 6    (c) 1, 2, 5 and 6    (d) 1, 2, 3 and 4

IAS-23. In a simple tension test, Hooke's law is valid up to the [IAS-1998]
(a) Elastic limit    (b) Limit of proportionality    (c) Ultimate stress    (d) Breaking point
IAS-24. Lueder' lines on steel specimen under simple tension test is a direct indication of yielding of material due to slip along the plane
(a) Of maximum principal stress   (b) Off maximum shear
(c) Of loading   (d) Perpendicular to the direction of loading

IAS-25. The percentage elongation of a material as obtained from static tension test depends upon the
(a) Diameter of the test specimen   (b) Gauge length of the specimen
(c) Nature of end-grips of the testing machine   (d) Geometry of the test specimen

IAS-26. Match List-I (Types of Tests and Materials) with List-II (Types of Fractures) and select the correct answer using the codes given below the lists:

List I List-II
[IES-2002; IAS-2004]

<table>
<thead>
<tr>
<th>(Types of Tests and Materials)</th>
<th>(Types of Fractures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Tensile test on CI</td>
<td>1. Plain fracture on a transverse plane</td>
</tr>
<tr>
<td>B. Torsion test on MS</td>
<td>2. Granular helicoidal fracture</td>
</tr>
<tr>
<td>C. Tensile test on MS</td>
<td>3. Plain granular at 45° to the axis</td>
</tr>
<tr>
<td>D. Torsion test on CI</td>
<td>4. Cup and Cone</td>
</tr>
<tr>
<td></td>
<td>5. Granular fracture on a transverse plane</td>
</tr>
</tbody>
</table>

Codes:
(a) 4 2 3 1
(b) 5 1 4 2

IAS-27. Assertion (A): For a ductile material stress-strain curve is a straight line up to the yield point.
Reason (R): The material follows Hooke's law up to the point of proportionality.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Reason (R): Brittle materials fail without yielding.
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IAS-29. Match List I (Materials) with List II (Stress-Strain curves) and select the correct answer using the codes given below the Lists:

[IES-2001]
IAS-30. The stress-strain curve of an ideal elastic strain hardening material will be as

IAS-31. An idealised stress-strain curve for a perfectly plastic material is given by

IAS-32. Match List I with List II and select the correct answer using the codes given below the Lists:
List I
A. Ultimate strength  
B. Natural strain  
C. Conventional strain  
D. Stress

Codes: A B C D
(a) 1 2 3 4
(c) 1 3 2 4

List II
1. Internal structure  
2. Change of length per unit instantaneous length  
3. Change of length per unit gauge length  
4. Load per unit area

Codes: A B C D
(b) 4 3 2 1
(d) 4 2 3 1

IAS-33. What is the cause of failure of a short MS strut under an axial load?  
(a) Fracture stress  
(b) Shear stress  
(c) Buckling  
(d) Yielding

IAS-34. Match List I with List II and select the correct answer using the codes given  
the lists:
List I
A. Rigid-Perfectly plastic  
B. Elastic-Perfectly plastic  
C. Rigid-Strain hardening  
D. Linearly elastic

List II
1. \( \sigma - \varepsilon \) relation
2. \( \sigma - \varepsilon \) relation
3. \( \sigma - \varepsilon \) relation
4. \( \sigma - \varepsilon \) relation

Codes: A B C D
(a) 3 1 4 2  
(c) 3 1 2 4

IAS-35. Which one of the following materials is highly elastic?  
(a) Rubber  
(b) Brass  
(c) Steel  
(d) Glass

IAS-36. Assertion (A): Hooke's law is the constitutive law for a linear elastic material.  
Reason (R) Formulation of the theory of elasticity requires the hypothesis that  
there exists a unique unstressed state of the body, to which the body returns  
whenever all the forces are removed.  
(a) Both A and R are individually true and R is the correct explanation of A  
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IAS-37. Consider the following statements: [IAS-2002]
1. There are only two independent elastic constants.
2. Elastic constants are different in orthogonal directions.
3. Material properties are same everywhere.
4. Elastic constants are same in all loading directions.
5. The material has ability to withstand shock loading.
Which of the above statements are true for a linearly elastic, homogeneous and isotropic material?
(a) 1, 3, 4 and 5  (b) 2, 3 and 4  (c) 1, 3 and 4  (d) 2 and 5

IAS-38. Which one of the following pairs is NOT correctly matched? [IAS-1999]
(a) Uniformly distributed stress .... Force passed through the centred of the cross-section
(b) Elastic deformation .... Work done by external forces during deformation is dissipated fully as heat
(c) Potential energy of strain .... Body is in a state of elastic deformation
(d) Hooke's law .... Relation between stress and strain

IAS-39. A tensile bar is stressed to 250 N/mm² which is beyond its elastic limit. At this stage the strain produced in the bar is observed to be 0.0014. If the modulus of elasticity of the material of the bar is 205000 N/mm² then the elastic component of the strain is very close to [IAS-1997]
(a) 0.0004  (b) 0.0002  (c) 0.0001  (d) 0.00005
GATE-1. Ans. (c)  
\[ \delta L = \frac{PL}{AE} \quad \text{or} \quad \delta L \propto \frac{1}{E} \quad [\text{As } P, L \text{ and } A \text{ is same}] \]

\[ \frac{(\delta L)_{\text{mild steel}}}{(\delta L)_{\text{AI}}} = \frac{E_{\text{CT}}}{E_{\text{MS}}} = \frac{100}{206} \quad : (\delta L)_{\text{CT}} > (\delta L)_{\text{MS}} \]

GATE-2. Ans. (a)  
\[ \delta L = \frac{PL}{AE} = \frac{(200 \times 1000) \times 2}{(0.04 \times 0.04) \times 200 \times 10^6} = 1.25 \text{ mm} \]

GATE-3. Ans. (c)  
A true stress – true strain curve in tension \( \sigma = k \varepsilon^n \)

- \( k = \text{Strength co-efficient} = 400 \times (1.35) = 540 \text{ MPa} \)
- \( n = \text{Strain – hardening exponent} = 0.35 \)

GATE-4. Ans. (d)  

A cantilever-loaded rotating beam, showing the normal distribution of surface stresses (i.e., tension at the top and compression at the bottom).

The residual compressive stresses induced.
Net stress pattern obtained when loading a surface treated beam. The reduced magnitude of the tensile stresses contributes to increased fatigue life.

GATE-5. Ans. (d)
GATE-6. Ans. (d)
GATE-7. Ans. (d) For longitudinal strain we need Young's modulus and for calculating transverse strain we need Poisson's ratio. We may calculate Poisson's ratio from 
\[ E = 2G(1+\mu) \] for that we need Shear modulus.

GATE-8. Ans. (a)
GATE-9. Ans. (a) Remember 
\[ E = 2G(1+\mu) = 3K(1-2\mu) = \frac{9KG}{3K+G} \]
GATE-10. Ans. (c) \[ T = F \times r = 2200 \times \frac{0.004}{2\pi} \text{ Nm} = 1.4 \text{ Nm} \]
GATE-11. Ans. (b) First draw FBD of all parts separately then

Total change in length = \[ \sum \frac{PL}{AE} \]

GATE-12. Ans. (a)

Frictional force required = 2000 N
Force needed to produce 2000 N frictional force at Y – Y section = \[ \frac{2000}{0.1} = 20000 \text{ N} \]. So for each side we need \( F_y = 10000 \text{ N} \) force.

Taking moment about PIN
\[ F_y \times 50 = F \times 100 \quad \text{or} \quad F = \frac{F_y \times 50}{100} = \frac{10000 \times 50}{100} = 5000 \text{ N} \]

GATE-13. Ans. (a) No calculation needed it is pre-compressed by 100 mm from its free state. So it can’t move more than 100 mm. choice (b), (c) and (d) out.

GATE-14. Ans. (d)
GATE-15. Ans. (a) Thermal stress will develop only when you prevent the material to contrast/elongate. As here it is free no thermal stress will develop.

GATE-16. Ans. (b)

![Diagram of stress and strain](chart.png)

GATE-17. Ans. (a)
GATE-18. Ans. (d)

IES-1. Ans. (a) \[ \delta = \frac{WL}{2AE} = \frac{WL}{2 \times \pi D^2 / 4} \therefore \delta \times L \quad \text{and} \quad \frac{\delta}{D} \times \frac{1}{E} \]

IES-2. Ans. (c)
IES-3. Ans. (b)
IES-4. Ans. (d)
IES-5. Ans. (c)
IES-6. Ans. (c)
IES-7. Ans. (a)

IES-8. Ans. (b) Elongation of a taper rod \( (\delta l) = \frac{PL}{\pi d_1 d_2 E} \)

\( \frac{(\delta l)_A}{(\delta l)_B} = \frac{(d_2)_A}{(d_2)_B} = \frac{D/3}{D/2} = \frac{2}{3} \)

IES-9. Ans. (c) Actual elongation of the bar \( (\delta l)_{act} = \frac{PL}{\pi d_1 d_2 E} = \frac{PL}{\pi d_2 E} \times 1.1 \times 0.9 D \)

Calculated elongation of the bar \( (\delta l)_{cal} = \frac{PL}{\pi d_2 E} \times \frac{D^2}{4} \)

\[ \therefore \text{Error} \% = \left( \frac{(\delta l)_{cal} - (\delta l)_{act}}{(\delta l)_{act}} \right) \times 100 = \left( \frac{1.1 D \times 0.9 D}{D^2} - 1 \right) \times 100 = -1\% \]

IES-10. Ans. (d) Actual elongation of the bar \( (\delta l)_{act} = \frac{PL}{\pi d_1 d_2 E} \)

IES-11. Ans. (b)
IES-12. Ans. (a)
IES-13. Ans. (c) Theoretically $-1 < \mu < 1/2$ but practically $0 < \mu < 1/2$
IES-14. Ans. (c)
IES-15. Ans. (a) If Poisson's ratio is zero, then material is rigid.
IES-16. Ans. (a)
IES-17. Ans. (d) Note: Modulus of elasticity is the property of material. It will remain same.
IES-18. Ans. (a)
IES-19. Ans. (a) Strain energy stored by a body within elastic limit is known as resilience.
IES-20. Ans. (c)
IES-21. Ans. (b)
IES-22. Ans. (c)
IES-23. Ans. (d)
IES-24. Ans. (c) A polished surface by grinding can take more number of cycles than a part with rough surface. In Hammer peening residual compressive stress lower the peak tensile stress.
IES-25. Ans. (a)
IES-26. Ans. (c)
IES-27. Ans. (c)
IES-28. Ans. (d)
IES-29. Ans. (d)
IES-30. Ans. (a)
IES-31. Ans. (b) $E = 2G(1 + \mu)$ or $1.25 \times 10^5 = 2G(1 + 0.34)$ or $G = 0.4664 \times 10^5$ MPa
IES-32. Ans. (c)
IES-33. Ans. (d) $E = 2G(1 + \mu) = 3K(1 - 2\mu) = \frac{9KG}{3K + G}$
IES-34. Ans. (d) $E = 2G(1 + \mu) = 3K(1 - 2\mu) = \frac{9KG}{3K + G}$
IES-35. Ans. (c) $E = 2G(1 + \mu) = 3K(1 - 2\mu) = \frac{9KG}{3K + G}$

The value of $\mu$ must be between 0 to 0.5, so $E$ never equal to $G$ but if $\mu = \frac{1}{3}$, then $E = k$ so Ans. is (c).
IES-36. Ans. (b) Use $E = 2G(1 + \mu)$
IES-37. Ans. (a) \( E = 2G(1 + \mu) \) or \( G = \frac{E}{2(1 + \mu)} = \frac{200}{2 \times (1 + 0.25)} = 80 \text{ GN/m}^2 \)

IES-38. Ans. (d) Under plane stress condition, the strain in the direction perpendicular to the plane is not zero. It has been found experimentally that when a body is stressed within elastic limit, the lateral strain bears a constant ratio to the linear strain.

IES-39. Ans. (b) Total load \( (P) = 8 \times \sigma \times \frac{\pi d^2}{4} \) or \( d = \sqrt{\frac{\sigma P}{2 \pi \sigma}} = \sqrt{\frac{980175}{2 \pi \times 315}} = 22.25 \text{ mm} \)

IES-40. Ans. (c) Compatibility equation insists that the change in length of the bar must be compatible with the boundary conditions. Here (a) is also correct but it is equilibrium equation.

IES-41. Ans. (a)

IES-42. Ans. (b) First draw FBD of all parts separately then

IES-43. Ans. (a) Elongation in AC = length reduction in CB

\[
\frac{R_A \times 1}{AE} = \frac{R_B \times 2}{AE}
\]

And \( R_A + R_B = 10 \)

IES-44. Ans. (b)

IES-45. Ans. (d)

IES-46. Ans. (d) If we resist to expand then only stress will develop.

IES-47. Ans. (d)

IES-48. Ans. (b) \[
\frac{\Delta V}{V} = \frac{\sigma}{K} = \frac{a^2 (1 + \alpha T)^3 - a^2}{a^3} \quad \text{or} \quad \frac{P}{E} = \frac{3\alpha T}{3(1 - 2\gamma)}
\]

IES-49. Ans. (c)

IES-50. Ans. (d) \[
\alpha E \Delta t = (12 \times 10^{-3}) \times (200 \times 10^3) \times (120 - 20) = 240 \text{ MPa}
\]

It will be compressive as elongation restricted.

IES-51. Ans. (a) Co-efficient of volume expansion

\( \gamma = 3 \times \text{co-efficient of linear expansion} (\alpha) \)

IES-52. Ans. (b)

IES-53. Ans. (b) Let compression of the spring = \( x \) m

Therefore spring force = \( kx \) kN

Expansion of the rod due to temperature rise = \( La\Delta t \)
Reduction in the length due to compression force = \( \frac{(kx) \times L}{AE} \)

Now \( L \alpha \Delta t - \frac{(kx) \times L}{AE} = x \)

or \( x = \frac{0.5 \times 12.5 \times 10^{-6} \times 20}{1 + \frac{50 \times 0.5}{\pi \times 0.010^2 \times 200 \times 10^6}} = 0.125 \text{mm} \)

\[ \therefore \text{Compressive stress} = - \frac{kx}{A} = - \frac{50 \times 0.125}{\pi \times 0.010^2} = -0.07945 \text{MPa} \]

IES-54. Ans. (d) Stress in the rod due to temperature rise = \((a \Delta t) x E\)

IES-55. Ans. (c)

IES-56. Ans. (d) A is FALSE but R is correct.

IES-57. Ans. (d)

IES-58. Ans. (b)

IES-59. Ans. (d)

IES-60. Ans. (b)

IES-61. Ans. (a)

IES-62. Ans. (b) \( \sigma_e = \frac{W}{\pi d^2} \) or \( W = \sigma_e \times \frac{\pi d^2}{4} \);

\[ W_{safe} = \frac{W}{f_{os}} = \frac{\sigma_e \times \pi \times d^2}{f_{os} \times 4} = \frac{280 \times \pi \times 36^2}{1.5 \times 4} = 190 \text{ kN} \]

IES-63. Ans. (b)

IES-64. Ans. (a) A crack parallel to the direction of length of hub means the failure was due to tensile hoop stress only.

IES-65. Ans. (d)

IES-66. Ans. (d)
IAS-1. Ans. (d) Elongation due to self weight \[ \frac{WL}{2AE} = \frac{\delta Alg}{2AE} = \frac{\delta L^2 g}{2E} \]

IAS-2. Ans. (b)

IAS-3. Ans. (a) The extension of the taper rod \[ \frac{P l}{\pi D_1 D_2}E \]

IAS-4. Ans. (a)

IAS-5. Ans. (d)

IAS-6. Ans. (b)

IAS-7. Ans. (d) Bulk modulus of elasticity \( K \) \[ \frac{P}{K} \] or \[ \frac{P}{K} = \frac{1.5}{2800} = 535 \times 10^{-6} \]

IAS-8. Ans. (a)

IAS-9. Ans. (d)

IAS-10. Ans. (a)

IAS-11. Ans. (b) \( E = 2G (1 + \mu) \) or \( 1.25 \times 10^6 = 2G (1 + 0.34) \) or \( G = 0.4664 \times 10^6 \) MPa

IAS-12. Ans. (a) \( E = 2G (1 + \mu) \Rightarrow 1 + \mu = \frac{E}{2G} \Rightarrow \mu = \left( \frac{E}{2G} - 1 \right) = \left( \frac{2.5}{2} - 1 \right) = 0.25 \)

IAS-13. Ans. (c)

IAS-14. Ans. (b) \( E = 2G (1 + \mu) = 3k (1 - 2\mu) \)

IAS-15. Ans. (b) \( E, G, K \) and \( \mu \) represent the elastic modulus, shear modulus, bulk modulus and poisons ratio respectively of a 'linearly elastic, isotropic and homogeneous material.' To express the stress – strain relations completely for this material; at least any two of the four must be known. \( E = 2G (1 + \mu) = 3K (1 - 3\mu) = \frac{9KG}{3K + G} \)

IAS-16. Ans. (c) \( E = 2G (1 + \mu) \) or \( \mu = \frac{E}{2G} - 1 = \frac{200}{2 \times 80} - 1 = 0.25 \)

IAS-17. Ans. (a) Elongation in \( AC \) = length reduction in \( CB \)
\[ \frac{R_A \times 1}{AE} = \frac{R_B \times 2}{AE} \]
And \( R_A + R_B = 10 \)

IAS-18. Ans. (d) \( \alpha E \Delta t = \left( 12 \times 10^{-6} \right) \times \left( 200 \times 10^3 \right) \times \left( 120 - 20 \right) = 240 \) MPa
It will be compressive as elongation restricted.
IAS-19. Ans. (c) Thermal stress will develop only if expansion is restricted.
IAS-20. Ans. (a) Dimensional analysis gives (a) is wrong
IAS-21. Ans. (d)
IAS-22. Ans. (d)
IAS-23. Ans. (b)
IAS-24. Ans. (b)
IAS-25. Ans. (b)
IAS-26. Ans. (d)
IAS-27. Ans. (d)
IAS-28. Ans. (a) Up to elastic limit.
IAS-29. Ans. (b)
IAS-30. Ans. (d)
IAS-31. Ans. (a)
IAS-32. Ans. (a)
IAS-33. Ans. (d) In compression tests of ductile materials fractures is seldom obtained. Compression is accompanied by lateral expansion and a compressed cylinder ultimately assumes the shape of a flat disc.
IAS-34. Ans. (a)
IAS-35. Ans. (c) Steel is the highly elastic material because it is deformed least on loading, and regains its original from on removal of the load.
IAS-36. Ans. (a)
IAS-37. Ans. (a)
IAS-38. Ans. (b)
IAS-39. Ans. (b)
### Conventional Question GATE

**Question:** The diameters of the brass and steel segments of the axially loaded bar shown in figure are 30 mm and 12 mm respectively. The diameter of the hollow section of the brass segment is 20 mm.

**Determine:** (i) The maximum normal stress in the steel and brass (ii) The displacement of the free end; Take $E_s = 210 \text{ GN/m}^2$ and $E_b = 105 \text{ GN/m}^2$

**Answer:**

(i) The maximum normal stress in steel and brass:

$\sigma_s = \frac{10 \times 10^3}{36\pi \times 10^{-6}} \times 10^6 \text{ MN/m}^2 = 88.42 \text{ MN/m}^2$

$\sigma_b = \frac{5 \times 10^3}{225\pi \times 10^{-6}} \times 10^6 \text{ MN/m}^2 = 7.07 \text{ MN/m}^2$

$\sigma_b = \frac{5 \times 10^3}{125\pi \times 10^{-6}} \times 10^6 \text{ MN/m}^2 = 12.73 \text{ MN/m}^2$

(ii) The displacement of the free end:

$\delta l = (\delta l_{AB} + (\delta l_{BC}) + (\delta l_{CD})$

$= \frac{88.42 \times 0.15}{210 \times 10^9 \times 10^{-6}} + \frac{7.07 \times 0.2}{105 \times 10^9 \times 10^{-6}} + \frac{12.73 \times 0.125}{105 \times 10^9 \times 10^{-6}}$

$= 9.178 \times 10^{-7} \text{ m} = 0.09178 \text{ mm}$

$\therefore \delta l = \frac{\sigma l}{E}$
**Conventional Question IES-1999**

**Question:** Distinguish between fatigue strength and fatigue limit.

**Answer:** Fatigue strength as the value of cyclic stress at which failure occurs after N cycles. And fatigue limit as the limiting value of stress at which failure occurs as N becomes very large (sometimes called infinite cycle).

---

**Conventional Question IES-1999**

**Question:** List at least two factors that promote transition from ductile to brittle fracture.

**Answer:**

(i) With the grooved specimens only a small reduction in area took place, and the appearance of the fracture was like that of brittle materials.

(ii) By internal cavities, thermal stresses and residual stresses may combine with the effect of the stress concentration at the cavity to produce a crack. The resulting fracture will have the characteristics of a brittle failure without appreciable plastic flow, although the material may prove ductile in the usual tensile tests.

---

**Conventional Question IES-1999**

**Question:** Distinguish between creep and fatigue.

**Answer:** Fatigue is a phenomenon associated with variable loading or more precisely to cyclic stressing or straining of a material, metallic, components subjected to variable loading get fatigue, which leads to their premature failure under specific conditions.

When a member is subjected to a constant load over a long period of time it undergoes a slow permanent deformation and this is termed as "Creep". This is dependent on temperature.

---

**Conventional Question IES-2008**

**Question:** What different stresses set-up in a bolt due to initial tightening, while used as a fastener? Name all the stresses in detail.

**Answer:**

(i) When the nut is initially tightened there will be some elongation in the bolt so tensile stress will develop.

(ii) While it is tightening a torque across some shear stress. But when tightening will be completed there should be no shear stress.

---

**Conventional Question IES-2008**

**Question:** A Copper rod 6 cm in diameter is placed within a steel tube, 8 cm external diameter and 6 cm internal diameter, of exactly the same length. The two pieces are rigidly fixed together by two transverse pins 20 mm in diameter, one at each end passing through both rod and the tube.

Calculated the stresses induced in the copper rod, steel tube and the pins if the temperature of the combination is raised by 50°C.

[Take $E_s=210$ GPa, $\alpha_s = 0.0000115 / ^\circ C$; $E_c=105$ GPa, $\alpha_c = 0.000017 / ^\circ C$]
\[
\frac{\sigma_c}{E_c} + \frac{\sigma_s}{E_s} = \Delta t (\alpha_c - \alpha_s)
\]

Area of copper rod \(A_c = \frac{\pi d^2}{4} = \frac{\pi (6/100)^2}{4} \text{m}^2 = 2.8274 \times 10^{-3} \text{m}^2\)

Area of steel tube \(A_s = \frac{\pi d^2}{4} = \frac{\pi (8/100)^2}{4} \left[\frac{6}{100}\right]^2 \text{m}^2 = 2.1991 \times 10^{-3} \text{m}^2\)

Rise in temperature, \(\Delta t = 50^\circ\text{C}\)
Free expansion of copper bar = \(\alpha_c L \Delta t\)
Free expansion of steel tube = \(\alpha_s L \Delta t\)
Difference in free expansion = \((\alpha_c - \alpha_s)L \Delta t\)

\[
= (17 - 11.5) \times 10^{-6} \times L \times 50 = 2.75 \times 10^{-4} \text{Lm}
\]

A compressive force \((P)\) exerted by the steel tube on the copper rod opposed the extra expansion of the copper rod and the copper rod exerts an equal tensile force \(P\) to pull the steel tube. In this combined effect reduction in copper rod and increase in length of steel tube equalize the difference in free expansions of the combined system.

Reduction in the length of copper rod due to force \(P\) Newton =

\[
(\Delta L)_c = \frac{PL}{A_c E_c} \left(2.8275 \times 10^{-3}\right) \left(105 \times 10^6\right) \text{m}
\]

Increase in length of steel tube due to force \(P\)

\[
(\Delta L)_s = \frac{PL}{A_s E_s} \left(2.1991 \times 10^{-3}\right) \left(210 \times 10^6\right) \text{m}
\]

Difference in length is equated

\[
(\Delta L)_c + (\Delta L)_s = 2.75 \times 10^{-4} L
\]

or \(P = 2.75 \times 10^4 \left[2.8275 \times 10^5 + 2.1991 \times 210\right] \times 10^6 \text{N} = 208652 \text{N} = 0.208652 \text{MN}\)

Stress in copper rod, \(\sigma_c = \frac{P}{A_c} = \frac{0.208652}{2.8275 \times 10^{-3}} \text{MPa} = 73.79 \text{MPa}\)
Stress in steel tube, \( \sigma = \frac{P}{A} = \frac{0.208652}{2.1991 \times 10^{-3}} \) MPa = 94.88 MPa

Since each of the pin is in double shear, shear stress in pins \( (\tau_{pin}) \)

\[
\tau_{pin} = \frac{P}{2 \times A_{pin}} = \frac{0.208652}{2 \times \frac{\pi}{4} (0.02)^2} = 332 \text{ MPa}
\]

**Conventional Question IES-2002**

**Question:** Why are the bolts, subjected to impact, made longer?

**Answer:** If we increase length its volume will increase so shock absorbing capacity will increased.

**Conventional Question IES-2007**

**Question:** Explain the following in brief:

(i) Effect of size on the tensile strength

(ii) Effect of surface finish on endurance limit.

**Answer:**

(i) When size of the specimen increases, tensile strength decrease. It is due to the reason that if size increases there should be more change of defects (voids) into the material which reduces the strength appreciably.

(ii) If the surface finish is poor, the endurance strength is reduced because of scratches present in the specimen. From the scratch crack propagation will start.

**Conventional Question IES-2004**

**Question:** Mention the relationship between three elastic constants i.e. elastic modulus \( (E) \), rigidity modulus \( (G) \), and bulk modulus \( (K) \) for any Elastic material. How is the Poisson’s ratio \( (\mu) \) related to these moduli?

**Answer:**

\[
E = \frac{9KG}{3K + G}
\]

\[
E = 3K(1 - 2\mu) = 2G(1 + \mu) = \frac{9KG}{3K + G}
\]

**Conventional Question IES-1996**

**Question:** The elastic and shear moduli of an elastic material are \(2 \times 10^{11} \) Pa and \(8 \times 10^{10} \) Pa respectively. Determine Poisson’s ratio of the material.

**Answer:**

We know that \( E = 2G(1 + \mu) = 3K(1 - 2\mu) = \frac{9KG}{3K + G} \)

or, \( 1 + \mu = \frac{E}{2G} \)

or \( \mu = \frac{E}{2G} - 1 = \frac{2 \times 10^{11}}{2 \times (8 \times 10^{10})} - 1 = 0.25 \)
Conventional Question IES-2003

Question: A steel bolt of diameter 10 mm passes through a brass tube of internal diameter 15 mm and external diameter 25 mm. The bolt is tightened by a nut so that the length of tube is reduced by 1.5 mm. If the temperature of the assembly is raised by 40°C, estimate the axial stresses the bolt and the tube before and after heating. Material properties for steel and brass are:

\[ E_s = 2 \times 10^5 \text{ N/mm}^2 \quad \alpha_s = 1.2 \times 10^{-5} / \text{°C} \quad \text{and} \quad E_b = 1 \times 10^5 \text{ N/mm}^2 \quad \alpha_b = 1.9 \times 10^{-15}/\text{°C} \]

Answer:

Area of steel bolt \( A_s = \frac{\pi}{4} \times (0.010)^2 = 7.854 \times 10^{-5} \text{ m}^2 \)

Area of brass tube \( A_b = \frac{\pi}{4} \times ((0.025)^2 - (0.015)^2) = 3.1416 \times 10^{-4} \text{ m}^2 \)

Stress due to tightening of the nut

Compressive force on brass tube = tensile force on steel bolt

or, \( \sigma_s A_s = \sigma_b A_b \)

or, \( E_b \frac{\Delta L}{\ell} A_b = \sigma_b A_b \)

\[ \therefore \sigma = \frac{E}{\varepsilon} = \frac{\sigma}{\Delta L/L} \]

Let assume total length \( (\ell) = 1 \text{ m} \)

Therefore \( (1 \times 10^5 \times 10^6) \times \frac{\Delta L}{L} = \frac{1.5 \times 10^{-5}}{1} \times 3.1416 \times 10^{-4} = \sigma_s \times 7.854 \times 10^{-5} \)

or \( \sigma_s = 600 \text{ MPa (tensile)} \)

and \( \sigma_b = E_b \frac{\Delta L}{\ell} = (1 \times 10^5) \times \frac{1.5 \times 10^{-5}}{1} = 150 \text{ MPa (Compressive)} \)

So before heating

Stress in brass tube \( (\sigma_b) = 150 \text{ MPa (compressive)} \)

Stress in steel bolt \( (\sigma_s) = 600 \text{ MPa (tensile)} \)
Stress due to rise of temperature

Let stress $\sigma_b$ & $\sigma_s$ are due to brass tube and steel bolt.

If the two members had been free to expand,
Free expansion of steel = $\alpha_s \times \Delta t \times 1$
Free expansion of brass tube = $\alpha_b \times \Delta t \times 1$

Since $\alpha_b > \alpha_s$ free expansion of copper is greater than the free expansion of steel. But they are rigidly fixed so final expansion of each members will be same. Let us assume this final expansion is $\delta$. The free expansion of brass tube is greater than $\delta$, while the free expansion of steel is less than $\delta$. Hence the steel rod will be subjected to a tensile stress while the brass tube will be subjected to a compressive stress.

For the equilibrium of the whole system,

Total tension (Pull) in steel = Total compression (Push) in brass tube.

$\sigma_s A_s = \sigma_b A_b$ or, $\sigma_s = \frac{\sigma_b A_b}{A_s} = 7.854 \times 10^{-5} \times \frac{3.14 \times 10^{-6}}{0.25} \sigma_b = 0.25 \sigma_b$

Final expansion of steel = final expansion of brass tube

$\alpha_s (\Delta t) \times 1 + \frac{\sigma_s}{E_s} \times 1 = \alpha_b (\Delta t) \times 1 - \frac{\sigma_b}{E_b} \times 1$

or, $\left(1.2 \times 10^{-5}\right) \times 40 \times 1 + \frac{\sigma_s}{2 \times 10^{-10}} = \left(1.9 \times 10^{-5}\right) \times 40 \times 1 - \frac{\sigma_b}{1 \times 10^{-2} \times 10^{6}}$ - (ii)

From (i) & (ii) we get

$\sigma_s \left[ \frac{1}{2 \times 10^{11}} + \frac{0.25}{10^{11}} \right] = 2.8 \times 10^3$

or, $\sigma_s = 37.33$ MPa (Tensile stress)

or, $\sigma_b = 9.33$ MPa (compressive)

Therefore, the final stresses due to tightening and temperature rise
Stress in brass tube = $\sigma_b + \sigma_b = 150 + 9.33$ MPa = 159.33 MPa
Stress in steel bolt = $\sigma_s + \sigma_s = 600 + 37.33 = 637.33$ MPa.

Conventional Question IES-1997

Question: A Solid right cone of axial length h is made of a material having density $\rho$ and elasticity modulus $E$. It is suspended from its circular base. Determine its elongation due to its self weight.

Answer: See in the figure MNH is a solid right cone of length 'h'.

Let us assume its wider end of diameter'd'

fixed rigidly at MN.

Now consider a small strip of thickness dy at a
distance \( y \) from the lower end.
Let 'ds' is the diameter of the strip.

\[ \therefore \text{Weight of portion UVH} = \frac{1}{3} \left( \frac{\pi d_s^2}{4} \right) y \times \rho g - (i) \]

From the similar triangles MNH and UVH,

\[ \frac{MN}{UV} = \frac{d}{d_s} = \frac{\ell}{y} \]

or, \( d_s = \frac{\ell y}{d} \) - - - - (ii)

\[ \therefore \text{Stress at section UV} = \frac{\text{force at UV}}{\text{cross-section area at UV}} = \frac{\text{Weight of UVH}}{\frac{\pi d_s^2}{4}} \]

\[ = \frac{\frac{1}{3} \frac{\pi d_s^2}{4} y \rho g}{\frac{\pi d_s^2}{4}} = \frac{1}{3} y \rho g \]

So, extension in dy = \( \frac{\left( \frac{1}{3} y \rho g \right) dy}{E} \)

\[ \therefore \text{Total extension of the bar} = \int \frac{1}{3} y \rho g dy = \frac{\rho g h^2}{6E} \]

From stress-strain relationship

\[ E = \frac{\delta \ell}{\delta} = \frac{\delta}{d} \text{ or, } \frac{\delta}{E} \]

**Conventional Question IES-2004**

**Question:** Which one of the three shafts listed here has the highest ultimate tensile strength? Which is the approximate carbon content in each steel?

(i) Mild Steel (ii) cast iron (iii) spring steel

**Answer:** Among three steel given, spring steel has the highest ultimate tensile strength.

Approximate carbon content in

(i) Mild steel is (0.3% to 0.8%)
(ii) Cost iron (2% to 4%)
(iii) Spring steel (0.4% to 1.1%)
**Conventional Question IES-2003**

*Question:* If a rod of brittle material is subjected to pure torsion, show with help of a sketch, the plane along which it will fail and state the reason for its failure.

*Answer:* Brittle materials fail in tension. In a torsion test the maximum tensile test occurs at 45° to the axis of the shaft. So failure will occur along a 45° helix.

![Sketch of failure plane](image)

So failures will occur according to 45° plane.

**Conventional Question IAS-1995**

*Question:* The steel bolt shown in Figure has a thread pitch of 1.6 mm. If the nut is initially tightened up by hand so as to cause no stress in the copper spacing tube, calculate the stresses induced in the tube and in the bolt if a spanner is then used to turn the nut through 90°. Take $E_c$ and $E_s$ as 100 GPa and 209 GPa respectively.

*Answer:* Given: $p = 1.6$ mm, $E_c = 100$ GPa; $E_s = 209$ GPa.

Stresses induced in the tube and the bolt, $\sigma_c, \sigma_s$:

\[
A_s = \frac{\pi}{4} \left( \frac{18}{1000} \right)^2 = 7.584 \times 10^{-5} \text{m}^2
\]

\[
A_s = \frac{\pi}{4} \left( \frac{18}{1000} \right)^2 - \left( \frac{12}{1000} \right)^2 = 14.14 \times 10^{-5} \text{m}^2
\]

Tensile force on steel bolt, $P_s = $ compressive force in copper tube, $P_c = P$

Also, Increase in length of bolt + decrease in length of tube = axial displacement of nut.

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### Conventional Question AMIE-1997

**Question:** A steel wire 2 m long and 3 mm in diameter is extended by 0.75 mm when a weight W is suspended from the wire. If the same weight is suspended from a brass wire, 2.5 m long and 2 mm in diameter, it is elongated by 4.64 mm. Determine the modulus of elasticity of brass if that of steel be $2.0 \times 10^5$ N/mm$^2$.

**Answer:** Given, $l_s = 2$ m, $d_s = 3$ mm, $\delta l_s = 0.75$ mm; $E_s = 2.0 \times 10^5$ N/mm$^2$; $l_b = 2.5$ m, $d_b$ = 2 mm $\delta l_b = 4.64$ mm and let modulus of elasticity of brass $= E_b$

Hooke’s law gives, $\delta l = \frac{P}{AE}$ [Symbol has usual meaning]

#### Case I: For steel wire:

\[
\delta l_s = \frac{P}{A_s E_s}
\]

or

\[
0.75 = \frac{P \times (2 \times 1000)}{\left(\frac{\pi}{4} \times 3^2\right) \times 2.0 \times 10^5 \times \frac{1}{2000}}
\]

#### Case II: For brass wire:

\[
\delta l_b = \frac{P}{A_b E_b}
\]

\[
4.64 = \frac{P \times (2.5 \times 1000)}{\left(\frac{\pi}{4} \times 2^2\right) \times E_b}
\]

or

\[
P = 4.64 \times \left(\frac{\pi}{4} \times 2^2\right) \times E_b \times \frac{1}{2500}
\]

From (i) and (ii), we get

\[
0.75 \times \left(\frac{\pi}{4} \times 3^2\right) \times 2.0 \times 10^5 \times \frac{1}{2000} = 4.64 \times \left(\frac{\pi}{4} \times 2^2\right) \times E_b \times \frac{1}{2500}
\]

or

\[
E_b = 0.909 \times 10^5 \text{ N/mm}^2
\]
**Conventional Question AMIE-1997**

**Question:** A steel bolt and sleeve assembly is shown in figure below. The nut is tightened up on the tube through the rigid end blocks until the tensile force in the bolt is 40 kN. If an external load 30 kN is then applied to the end blocks, tending to pull them apart, estimate the resulting force in the bolt and sleeve.

![Image of bolt and sleeve assembly](https://via.placeholder.com/150)

**Answer:**

Area of steel bolt, \( A_b = \left( \frac{25}{1000} \right)^2 = 4.908 \times 10^{-3} \text{m}^2 \)

Area of steel sleeve, \( A_s = \pi \left( \frac{62.5}{1000} \right)^2 - \left( \frac{50}{1000} \right)^2 = 1.104 \times 10^{-3} \text{m}^2 \)

**Forces in the bolt and sleeve:**

(i) Stresses due to tightening the nut:

Let \( \sigma_b \) = stress developed in steel bolt due to tightening the nut; and \( \sigma_s \) = stress developed in steel sleeve due to tightening the nut.

Tensile force in the steel bolt = 40 kN = 0.04 MN

\[ \sigma_b \times A_b = 0.04 \]

or \( \sigma_b \times 4.908 \times 10^{-3} = 0.04 \)

\[ \therefore \sigma_b = \frac{0.04}{4.908 \times 10^{-3}} = 81.5 \text{ MN/m}^2 \text{ (tensile)} \]

Compressive force in steel sleeve = 0.04 MN

\[ \sigma_s \times A_s = 0.04 \]

or \( \sigma_s \times 1.104 \times 10^{-3} = 0.04 \)

\[ \therefore \sigma_s = \frac{0.04}{1.104 \times 10^{-3}} = 36.23 \text{ MN/m}^2 \text{ (compressive)} \]

(ii) Stresses due to tensile force:

Let the stresses developed due to tensile force of 30 kN = 0.03 MN in steel bolt and sleeve be \( \sigma_b' \) and \( \sigma_s' \) respectively.

Then, \( \sigma_b' \times A_b + \sigma_s' \times A_s = 0.03 \)
\[ \sigma'_b \times 4.908 \times 10^{-4} + \sigma'_s \times 1.104 \times 10^{-3} = 0.03 \quad - - - (i) \]

In a compound system with an external tensile load, elongation caused in each will be the same.

\[ \delta l_b = \frac{\sigma'_b}{E_b} \times l_b \]

or \[ \delta l_b = \frac{\sigma'_b}{E_b} \times 0.5 \quad \text{(Given,} l_b = 500\text{mm} = 0.5) \]

and \[ \delta l_s = \frac{\sigma'_s}{E_s} \times 0.4 \quad \text{(Given,} l_s = 400\text{mm} = 0.4) \]

But \[ \delta l_b = \delta_s \]

\[ \therefore \frac{\sigma'_b}{E_b} \times 0.5 = \frac{\sigma'_s}{E_s} \times 0.4 \]

\[ E \sigma'_b = 0.8 \sigma'_s \quad \text{(Given,} E_b = E_s) \quad - - - (2) \]

Substituting this value in (1), we get

\[ 0.8 \sigma'_s \times 4.908 \times 10^{-4} + \sigma'_s \times 1.104 \times 10^{-3} = 0.03 \]

gives \[ \sigma'_s = 20\text{MN/m}^2 \text{ (tensile)} \]

and \[ \sigma'_b = 0.8 \times 20 = 16\text{MN/m}^2 \text{ (tensile)} \]

Resulting stress in steel bolt,

\[ (\sigma'_b)_b = \sigma'_b + \sigma'_s = 81.5 + 16 = 97.5\text{MN/m}^2 \]

Resulting stress in steel sleeve,

\[ (\sigma'_s)_s = \sigma'_s + \sigma'_s = 36.23 + 20 = 16.23\text{MN/m}^2 \text{ (compressive)} \]

Resulting force in steel bolt \((\sigma'_b)_b \times A_b = 97.5 \times 4.908 \times 10^{-4} = 0.0478\text{MN (tensile)}\)

Resulting force in steel sleeve \((\sigma'_s)_s \times A_s = 16.23 \times 1.104 \times 10^{-3} = 0.0179\text{MN (compressive)} \)