EXAM 1 REVIEW

MET 4501

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CHAPTER 1 – INTRODUCTION TO MECHANICAL ENGINEERING DESIGN

- Phases & interactions of the design process
- Design tools & resources
- Professional responsibilities
- Standard & codes
- Factors of safety

Professional responsibilities of engineers include all of the following EXCEPT:

A. Upholding public safety

C. Prioritizing cost over safety

B. Complying with industry standards

D. Maintaining ethical conduct

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B. The ratio of a maximum allowable parameter to the loss-of-function value of that parameter

C. The difference between design load and failure load

D. The ratio of design load to ultimate strength

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PRACTICE PROBLEM

You are tasked with designing a steel support beam for a new structure. The beam must support a concentrated load of 50 kN at its center and span 6 meters between two supports. The allowable stress for the material is 150 MPa. Using a factor of safety of 2, calculate the minimum required section modulus *Z* for the beam.

Hint: Use the bending stress formula σ=M/Z, where M is the maximum bending moment.

1. Calculate the maximum bending moment for a simply supported beam with a center load.

$$M_{\text{max}} = \frac{PL}{4} = \frac{(50{,}000\ \text{N})(6\ \text{m})}{4} = 75{,}000\ \text{N} \cdot \text{m}$$

2. Factor in the allowable stress with the factor of safety.

$$\sigma_{\text{allowed}} = \frac{150\ \text{MPa}}{2} = 75\ \text{MPa}$$

3. Solve for the section modulus *Z*.

$$Z = \frac{M_{\text{max}}}{\sigma_{\text{allowed}}} = \frac{75 \cdot 10^3\ \text{N} \cdot \text{m}}{75 \cdot 10^6\ \text{N/m}^2} = 1 \cdot 10^{-3}\ \text{m}^3$$

- Typical tensile test
- AISI/SAE Steel Numbering System
- Hot working (HR) and cold drawing (CD)
- Material hardness
- Heat treatments
- Materials selection
  - Ashby Charts
  - Deflection-limited vs. Strength-limited design

Which of the following types of steel is easiest to machine?

A. Low-carbon steel

C. High-carbon steel

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A. Yield strength

B. Modulus of elasticity

C. Toughness

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A. Yield strength vs. density

C. Yield strength vs. thermal conductivity

B. Young's modulus vs. density

D. Hardness vs. toughness

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CHAPTER 3 – LOAD & STRESS ANALYSIS

- Equilibrium and Free Body Diagrams
- Shear force and bending moment diagrams
- Stress components
- Mohr's circle
- Stresses in beams
  - Normal stresses for beams in bending
  - Shear stresses for beams in bending
  - Torsion

Mohr's circle is used to determine:

A. Principal stresses and maximum shear stresses

B. Normal and shear forces in beams

C. Maximum bending moment

D. Axial stress in tension members

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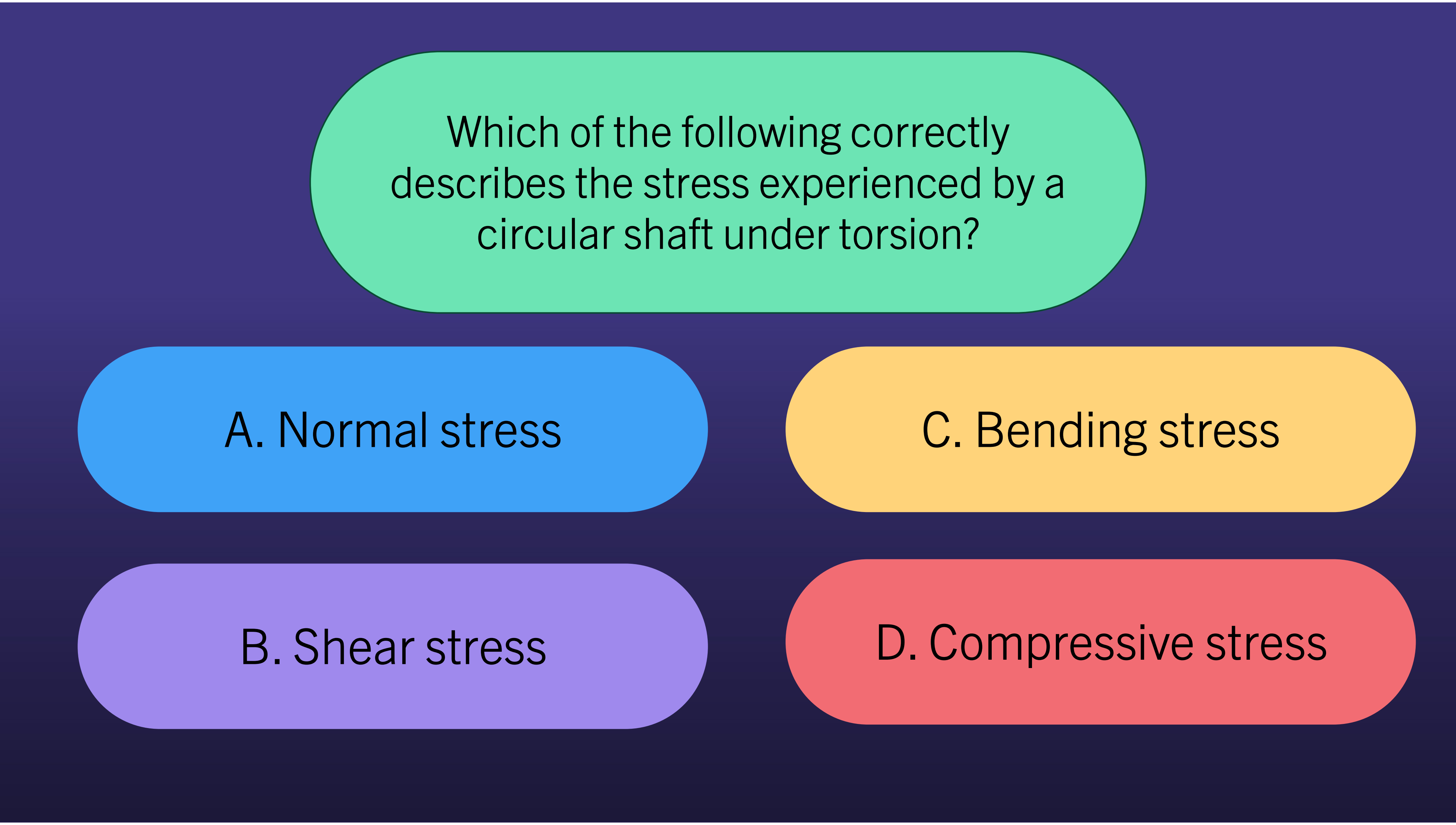
Which of the following correctly describes the stress experienced by a circular shaft under torsion?
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C. The centroid

B. The outermost fibers

D. The point of application of the load

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PRACTICE PROBLEM

A cylindrical shaft with a diameter of 50 mm is subjected to a torque of 1,000 N·m. Calculate the maximum shear stress in the shaft.

1. Calculate the polar moment of inertia for a solid circular shaft:

$$J = \frac{\pi d^4}{32} = \frac{\pi (0.05\ \mathrm{m})^4}{32} = 3.07 \cdot 10^{-7}\ \mathrm{m}^4$$

2. Use the torsion formula to solve for maximum shear stress:

$$\tau = \frac{Tr}{J} = \frac{(1000\ \mathrm{N} \cdot \mathrm{m})(\frac{0.05}{2}\ \mathrm{m})}{3.07 \cdot 10^{-7}\ \mathrm{m}^4} = 81.4 \cdot 10^6 \frac{\mathrm{N}}{\mathrm{m}^2} = 81.4\ \mathrm{MPa}$$

- Failure theories for ductile materials:
  - Maximum Shear Stress (MSS) for ductile materials
  - Distortion-Energy (DE) for ductile materials
  - Ductile Coulomb-Mohr (DCM) theory
- Failures theories for brittle materials:
  - Maximum-Normal-Stress (MNS) theory for brittle materials
  - Modifications of the Mohr Theory for brittle materials
    - Brittle Coulomb-Mohr (BCM) theory
    - Modified Mohr (MM) theory
- Introduction to fracture mechanics

Which of the following failure theories is most suitable for brittle materials?

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For ductile materials under static loading, which of the following failure theories is most conservative?

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For brittle materials, failure typically occurs when:

A. The maximum shear stress reaches the shear strength of the material

C. The strain energy exceeds the yield strength

B. The maximum normal stress reaches the tensile strength of the material

D. The material experiences significant plastic deformation

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PRACTICE PROBLEM

A ductile steel bar is subjected to a combined loading of 80 MPa in tension and 40 MPa in shear. Determine if the bar will fail according to the Maximum Shear Stress (MSS) failure theory. The yield strength of the material is 250 MPa.

1. Calculate the principal stresses:

$$\sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$= \frac{80 \text{ MPa}}{2} \pm \sqrt{\left(\frac{80 \text{ MPa}}{2}\right)^2 + (40 \text{ MPa})^2} = 40 \pm 56.6 \text{ MPa}$$

$$\sigma_1 = 96.6 \text{ MPa}$$

$$\sigma_3 = -16.6 \text{ MPa}$$

$$\tau_{\max} = 56.6 \text{ MPa}$$

2. Use the MSS theory to calculate a factor of safety:

$$n = \frac{S_y}{2\tau_{\max}} = \frac{250 \text{ MPa}}{2(56.6 \text{ MPa})} = 2.2$$

Since $n > 1$, we do not predict that the bar will fail.

EXTRA SLIDES

Which of the following is NOT a phase in the design process?

A. Problem definition

C. Prototype development

B. Conceptual design

D. Material selection

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Which source do engineers use to determine required safety and performance standards?

A. Free body diagrams

C. Mohr’s circle

B. Standards and codes

D. Shear force diagrams

CHAPTER 6 – FATIGUE FAILURE RESULTING FROM VARIABLE LOADING

- Introduction to fatigue
- Overview of fatigue analysis methods
  - Linear-elastic fracture mechanics
  - Strain-life method
  - Stress-life method
- The stress-life method in detail
  - The S-N diagram
  - Endurance limit modifying factors
  - Stress concentration & notch sensitivity
  - Characterizing fluctuating stresses
  - Fatigue failure criteria
    - Yield (Langer)
    - Goodman
    - Morrow
  - Fatigue failure analysis recipe for:
    - Completely reversing simple loading
    - Fluctuating simple loading
    - Combination of loading modes

The S-N diagram is used to represent:

A. Strain versus number of cycles

C. Stress versus strain

B. Stress versus number of cycles to failure

D. Shear stress versus normal stress

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A. Surface finish

C. Material brittleness

B. Temperature

D. Size of the component

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In fatigue failure analysis, which criterion accounts for the effect of mean stress on the fatigue strength of a material?

A. Goodman criterion

B. Langer criterion

C. Mohr’s circle

D. Maximum Normal Stress theory

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PRACTICE PROBLEM

A rotating shaft made of steel is subjected to an alternating bending stress with a maximum value of 300 MPa and a minimum value of 100 MPa. Using the Goodman criterion, determine if the shaft will fail, assuming a factor of safety of 1.5. The ultimate tensile strength of the material is 700 MPa, and the fully corrected endurance limit is 300 MPa.

1. Calculate the mean and alternating stresses:

$$\sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2} = \frac{300\ \text{MPa} - 100\ \text{MPa}}{2} = 100\ \text{MPa}$$

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{300\ \text{MPa} + 100\ \text{MPa}}{2} = 200\ \text{MPa}$$

2. Apply the Goodman criterion (for $\sigma_m \geq 0$):

$$n = \left[\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}\right]^{-1} = \left[\frac{100}{300} + \frac{200}{700}\right]^{-1} = 1.6$$

The calculated safety factor is greater than 1.5, so failure is not predicted.

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C. Mohr’s circle

B. Standards and codes

D. Shear force diagrams