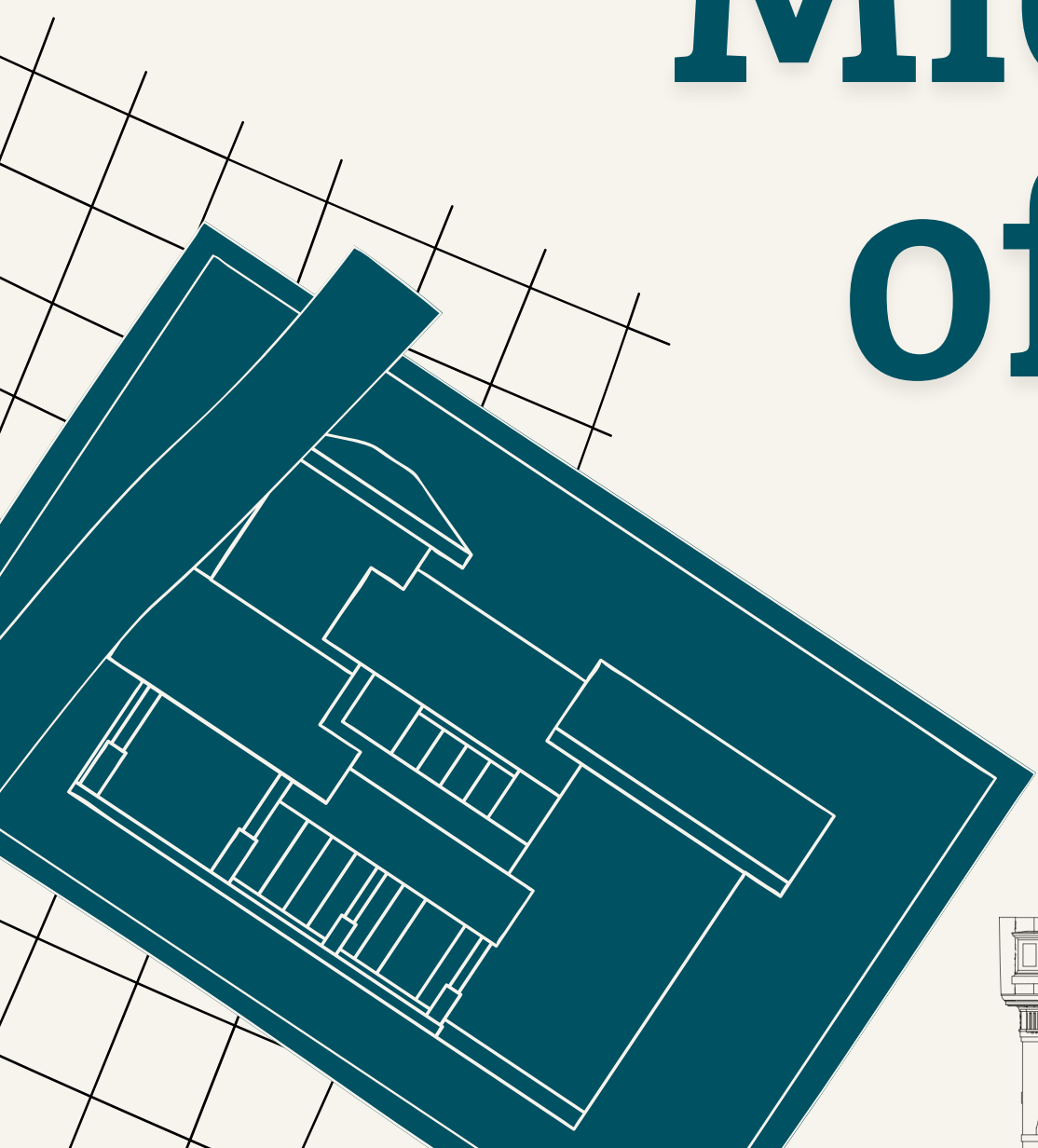
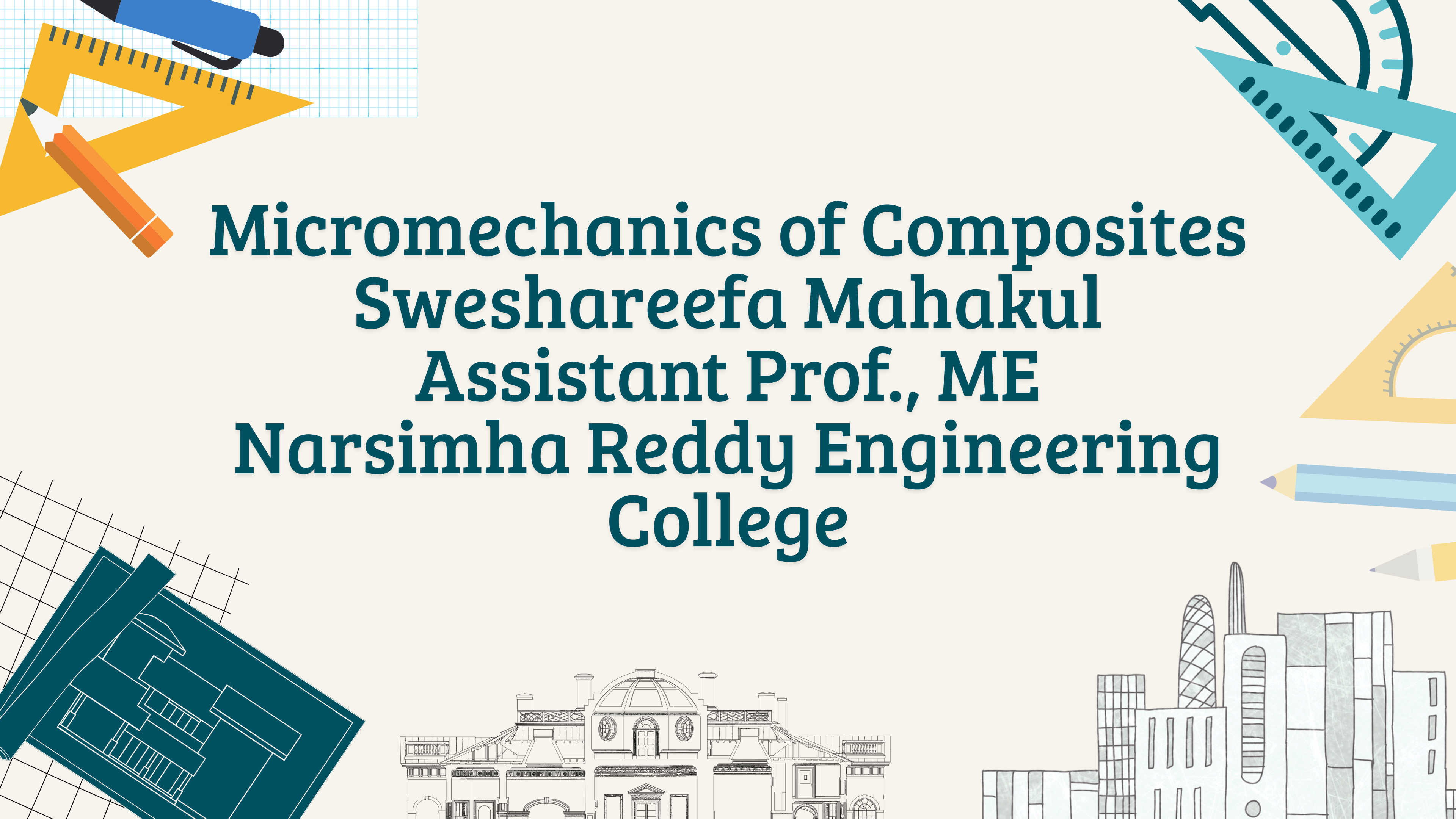


Micromechanics of Composites



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The background features a light cream color with various engineering-related illustrations. In the top left, there is a blue pen, a yellow ruler, and an orange pencil. In the top right, a blue protractor and a yellow ruler are shown. On the right side, there are two pencils, one blue and one yellow. At the bottom, there are architectural drawings: a dark blue floor plan on the left, a white line drawing of a classical building with a dome in the center, and a modern city skyline with various skyscrapers on the right.

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Micromechanics of Composites

Density

Mechanical Properties

Thermal Properties



Micromechanics of Composites

Density – Definition

The density of a composite material is the mass per unit volume of the combined constituent materials. For a composite with fiber and matrix phases, the rule of mixtures gives: $\rho_c = \rho_f V_f + \rho_m V_m$, where ρ_f and ρ_m are the densities of fiber and matrix, and V_f and V_m are their respective volume fractions ($V_f + V_m = 1$). Density is a fundamental property influencing specific strength and specific stiffness.

Density – Calculation & Importance

Experimental density is determined using Archimedes' principle or pycnometry. Void content affects actual density: $\rho_{\text{actual}} < \rho_{\text{theoretical}}$ when voids are present. Void volume fraction $V_v = (\rho_{\text{theoretical}} - \rho_{\text{actual}}) / \rho_{\text{theoretical}}$. Low density is critical in aerospace and automotive composites for achieving high specific mechanical properties. SWESHAREEFA MAHAKUL, Asst. Prof., ME | Narsimha Reddy Engineering College

Mechanical Properties

Prediction of Elastic Constants

Key Methods:

- Rule of Mixtures: Longitudinal modulus $E_1 = E_f \cdot V_f + E_m \cdot V_m$
- Transverse Modulus E_2 via inverse rule
- Poisson's ratio prediction
- Shear modulus G_{12} estimation
- Halpin–Tsai equations for improved accuracy
- Bounds: Voigt & Reuss models
- Valid for continuous fiber composites

Micromechanical Approach

Key Concepts:

- Representative Volume Element (RVE) analysis
- Fiber-matrix stress distribution
- Inclusion-based models (Eshelby)
- Concentric cylinder model
- Periodic microstructure assumption
- Transverse stress concentrations
- Accounts for fiber geometry & arrangement

Halpin-Tsai Equations

Mathematical Formulation: The Halpin-Tsai equations predict composite properties as: $P = P_m \left[\frac{1 + \xi \eta V_f}{1 - \eta V_f} \right]$, where $\eta = \frac{P_f/P_m - 1}{P_f/P_m + \xi}$. Here, P is the composite property, P_f and P_m are fiber and matrix properties, V_f is fiber volume fraction, and ξ is a reinforcing factor depending on fiber geometry and loading direction.

Applications & Predictions: Halpin-Tsai equations are widely used to predict transverse modulus (E_2), shear modulus (G_{12}), and Poisson's ratio. The parameter $\xi = 2(a/b)$ for elliptical fibers controls prediction accuracy. These semi-empirical equations bridge micromechanical and macromechanical analysis, offering reliable elastic constant predictions for unidirectional fiber-reinforced composites under transverse and shear loading conditions.

Transverse Stresses

Analysis Methods for Transverse Stresses: Transverse stresses in composite laminates arise due to mismatch in material properties between fiber and matrix. Classical lamination theory (CLT) and 3D elasticity approaches are used to predict interlaminar stresses. Free-edge effects cause significant stress concentrations at laminate boundaries, requiring detailed finite element or analytical methods for accurate evaluation.

Significance in Composite Behavior: Transverse stresses govern failure modes such as matrix cracking, delamination, and fiber-matrix debonding. In off-axis and cross-ply laminates, transverse tensile stresses can initiate damage at relatively low load levels. Understanding and controlling transverse stress distribution is critical for designing reliable, high-performance composite structures in aerospace and mechanical applications.



Micromechanics of Composites

Thermal Properties

Hydrothermal Stresses: When composite materials are subjected to changes in temperature and moisture, internal stresses known as hydrothermal stresses are induced. These stresses arise due to the mismatch in coefficients of thermal and moisture expansion between the fiber and matrix phases, leading to residual stress states that significantly affect the structural integrity and performance of the composite laminate.

Effects on Composites

Hydrothermal effects cause dimensional instability, matrix cracking, and delamination in composite structures. The combined thermal and moisture loading alters elastic moduli and strength. Analysis involves hygrothermal strain terms in constitutive equations, enabling prediction of warpage and stress distribution across plies for safe design.

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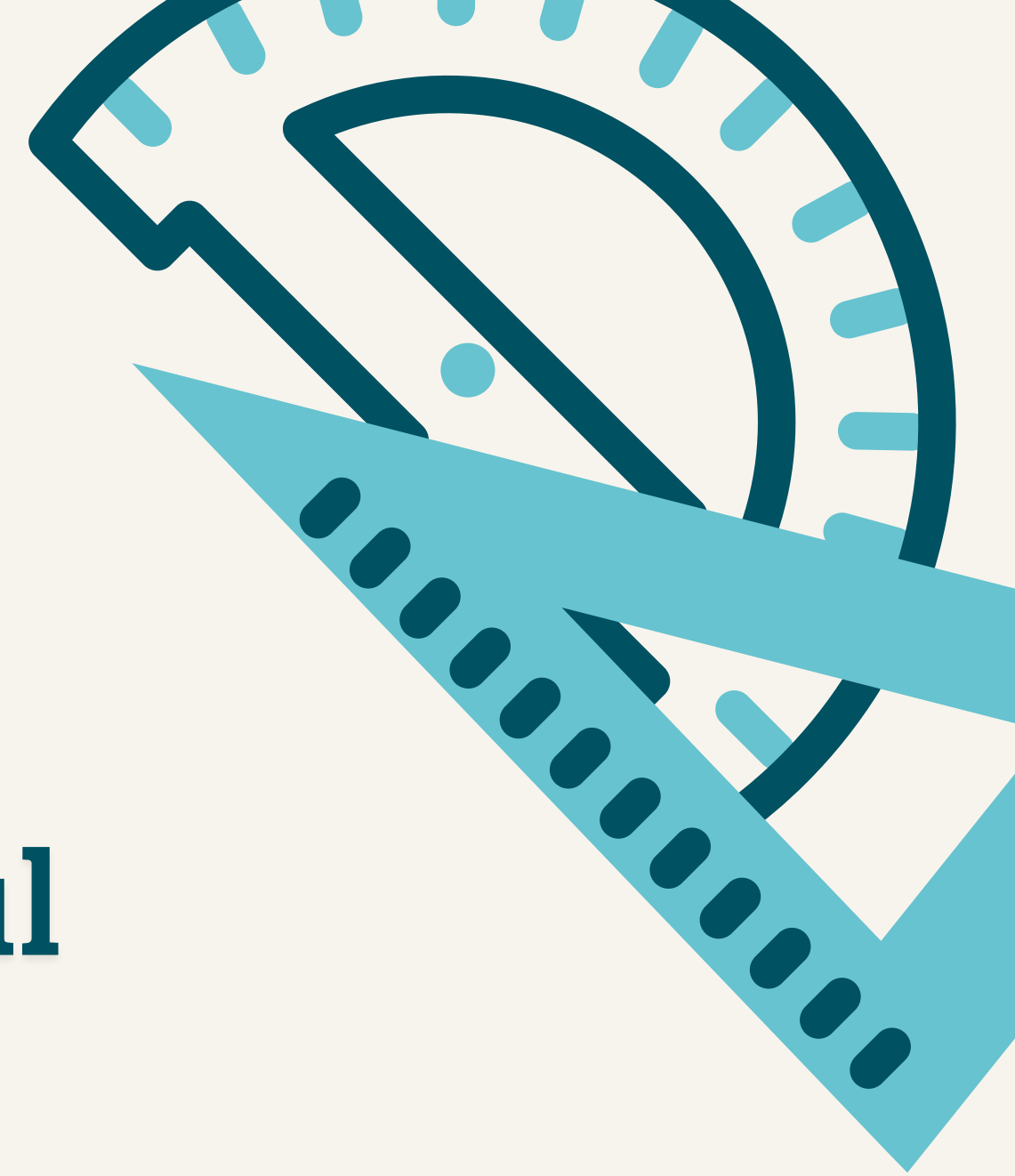
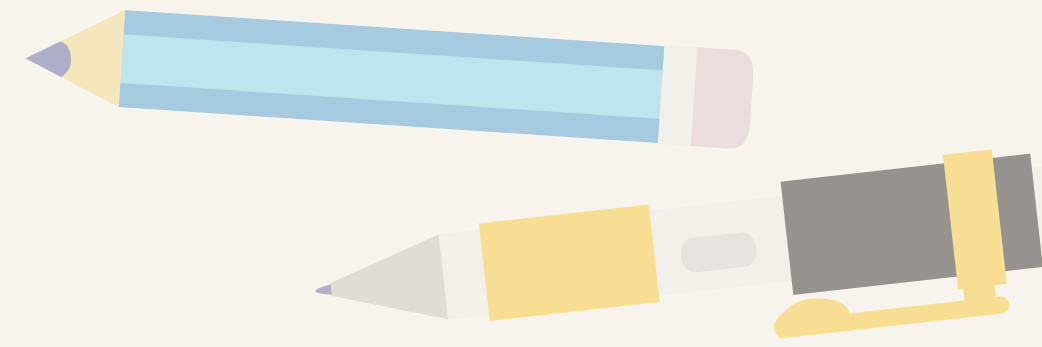
Load Transfer Mechanics

Matrix to Fiber Load Transfer Mechanisms: Load transfer from matrix to fiber occurs primarily through interfacial shear stress along the fiber-matrix interface. When external loads are applied, the matrix deforms and transfers stress to the stiffer fiber via shear lag mechanisms. The critical transfer length (l_c) defines the minimum fiber length required for effective stress transfer, given by $l_c = (\sigma_f \times d) / (2\tau_i)$, where σ_f is fiber tensile strength, d is fiber diameter, and τ_i is interfacial shear strength.

Load Transfer Efficiency: The efficiency of load transfer depends on fiber aspect ratio (l/d), interfacial bond strength, and fiber orientation. For fibers longer than l_c , full composite strengthening is achieved. Short fibers with $l < l_c$ exhibit partial load transfer, reducing composite strength. The Cox shear lag model and Kelly-Tyson model predict stress distribution along fiber length. Strong fiber-matrix adhesion, surface treatments, and coupling agents enhance interfacial shear strength, maximizing load transfer efficiency in composite systems.

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**Thank You!
Questions?
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