LABORATORY MANUAL: TENSILE TESTING OF MATERIALS

Course: Engineering Materials I

Experiment Title: Uniaxial Tensile Test & Mechanical Property Determination

1. OBJECTIVES

- To understand the mechanical behavior of materials subjected to uniaxial tensile loading.
- To convert raw experimental data (**Load–Displacement**) into standard engineering and true stress-strain relationships (**Engineering Stress–Strain** and **True Stress–Strain**).
- To graphically determine key mechanical properties including **Young's Modulus (Stiffness)**, **Yield Strength**, **Ultimate Tensile Strength**, **Fracture Strength**, **Modulus of Resilience**, **Toughness**, and **Total Energy to Fracture**.
- To analyze and compare the fundamental differences between engineering and true stress-strain curves.

2. THEORETICAL BACKGROUND

During a tensile test, a standardized specimen is subjected to an increasing axial load (F) while its elongation (ΔL) is continuously recorded.

2.1. Basic Definitions & Formulas

1. **Engineering Stress (σ) & Engineering Strain (ϵ):**

$$\sigma = \frac{F}{A_0} \quad \text{[MPa]}$$

$$\epsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

Where A_0 is the initial cross-sectional area and L_0 is the original gauge length.

2. **True Stress (σ_t) & True Strain (ϵ_t):**

$$\sigma_t = \sigma(1 + \epsilon) \quad \text{[MPa]} \quad \text{(valid up to necking)}$$

$$\epsilon_t = \ln(1 + \epsilon)$$

3. **Stiffness / Young's Modulus (E):**

$$E = \frac{\Delta\sigma}{\Delta\epsilon} \quad \text{[GPa or MPa]} \quad \text{(Slope of the linear elastic region)}$$

4. **Modulus of Resilience (U_r):** Capacity of a material to absorb energy when deformed elastically. Represented by the area under the elastic region of the Engineering Stress–Strain curve:

$$U_r \approx \frac{1}{2}\sigma_y \cdot \epsilon_y = \frac{\sigma_y^2}{2E} \quad \text{[J/m}^3\text{]}$$

5. **Toughness (U_t):** The total energy absorbed per unit volume up to fracture. Represented by the total area under the Engineering Stress–Strain curve:

$$U_t = \int_0^{\epsilon_f} \sigma \, d\epsilon \quad [\text{J/m}^3]$$

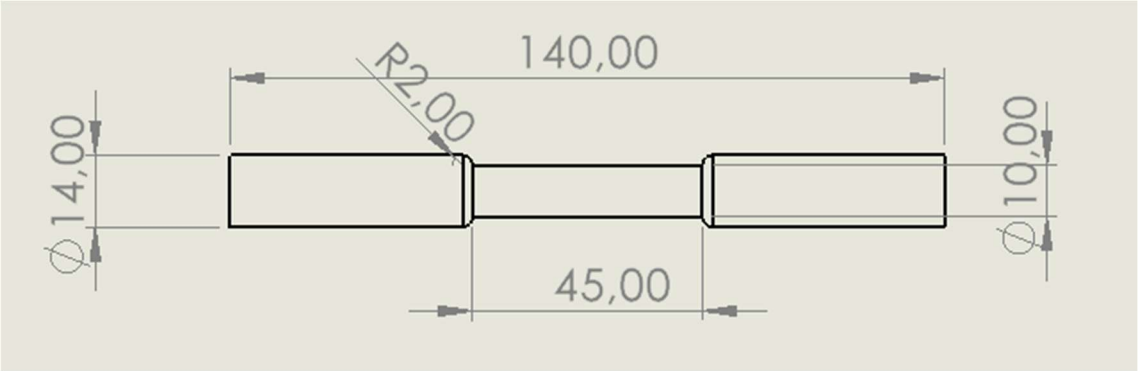
6. **Total Energy to Fracture (W_{total}):** The overall mechanical work done on the specimen, calculated from the area under the **Load–Displacement** ($F - \Delta L$) curve:

$$W_{total} = \int_0^{\Delta L_f} F \, d(\Delta L) \quad [\text{J}]$$

3. SPECIMEN SPECIFICATIONS & EXPERIMENTAL DATA

3.1. Specimen Geometry (Round Dog-Bone Specimen)

The tensile specimen is machined according to standard proportions (similar to ASTM E8/E8M round tension test specimens).



Overall Length (L_T): 140 mm

Grip Section Diameter (D): 14 mm

Gauge Section Diameter (d_0): 10 mm *(Nominal)*

Gauge Length (L_0): 45 mm

Fillet Radius (R): Transition radius between the grip sections and gauge section.

4. REQUIRED CALCULATIONS & GRAPHICAL WORK

Part A: Graph Plotting (To be drawn side-by-side on millimeter grid paper)

Using millimeter grid paper (graph paper), construct **two graphs side-by-side** using identical scales for the strain axis:

1. **Graph 1: Engineering Stress (σ) vs. Engineering Strain (ϵ)**
2. **Graph 2: True Stress (σ_t) vs. True Strain (ϵ_t)**

Note on Graphing Standards:

- Label all axes with parameter names, variable symbols, and units.
- Use clear grid divisions to allow accurate counting for area calculations.
- Clearly identify and mark the following **5 Key Points/Regions**:
    1. Elastic Region
    2. Plastic Region
    3. Yield Point (σ_y, ϵ_y) — *Use the 0.2% offset method if no distinct yield point is observed.*
    4. Ultimate Tensile Strength / UTS (σ_u, ϵ_u)
    5. Fracture Point (σ_f, ϵ_f)

Part B: Parameter Calculations

Calculate and report the following properties. Show all working steps, including units and area counting methods:

1. **Stiffness (E):** Calculate the slope of the elastic region on the Engineering Stress–Strain curve.
2. **Yield Strength (σ_y):** Identify the stress value where plastic deformation initiates.
3. **Ultimate Tensile Strength (σ_u):** Maximum stress value on the Engineering Stress–Strain curve.
4. **Fracture Strength (σ_f):** Stress value at the point of final specimen failure.
5. **Modulus of Resilience (U_r):** Calculate the area under the elastic region of the Engineering Stress–Strain curve.
6. **Toughness (U_t):** Calculate the total area under the entire Engineering Stress–Strain curve (e.g., using grid counting or trapezoidal approximation).
7. **Total Energy to Fracture (W_{total}):** Calculate the total area under the raw **Load–Displacement** curve. Verify the relation $W_{total} = U_t \times V_0$ (where $V_0 = A_0 \cdot L_0$ is the initial gauge volume).

6. DISCUSSION QUESTIONS

Address the following points thoroughly in the **Discussion** section of your laboratory report:

1. **Engineering vs. True Stress–Strain Curves:**
    - Why do the engineering and true stress-strain curves diverge after yielding?
    - Why does the engineering stress decrease after the UTS point, whereas the true stress continues to increase until fracture? Explain in terms of instantaneous cross-sectional area (A) and necking.
2. **Energy Relations:**

- Explain the physical difference between **Toughness (U_t)** and **Total Energy to Fracture (W_{total})**. What are their respective units, and why is one geometry-independent while the other depends on specimen size?

3. **Material Failure Analysis:**
    - Based on the shape of the stress-strain curve and the magnitude of total elongation to failure (ϵ_f), classify the tested material as **ductile** or **brittle**. Justify your answer.
    - Briefly describe the expected fracture surface appearance for this specimen type (e.g., cup-and-cone, flat cleavage surface, shear bands).

Student Name: Date:

Student ID: Group:

6. TENSILE TEST RAW DATA & CALCULATED STRESS-STRAIN VALUES

Fill in the table below using the 20 raw data points (F and ΔL) provided from the Universal Testing Machine (UTM). Perform all calculations to complete the table.

Point	**Load (N)**	**Displacement (mm)**	**Eng. Stress (MPa)**	**Eng. Strain (mm)**	**True Stress (MPa)**	**True Strain(mm)**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						