LABORATORY EXPERIMENT 4

Structural Origins of the Mechanical Properties of Materials

PreLab Questions:

1. We are testing several materials under identical conditions (strain rate, maximum load, environment). Why must we note the dimensions of each sample to compute and compare mechanical properties among these materials?
2. How do true stress and true strain differ from engineering stress and engineering strain, in terms of both physical meaning and equations?

NOTE:

- Bring a calculator.

I. Introduction

The uniaxial tensile and compression tests are one of the simplest and most widely used experiments to characterize the mechanical properties (e.g., strength, stiffness, ductility, and toughness) of a material. The engineering stress vs. engineering strain data obtained from such tests have direct design implications, and thus uniaxial tension and compression tests are used routinely to compare the mechanical properties of different materials, to assist in the development of new materials, and for quality control.

__Relevant definitions and equations:__

In uniaxial testing, typically the displacement is controlled at a desired rate, and the displacement and resulting load are recorded continuously. The load is measured via a "load cell" which is in fact a series of strain gages. For precise measurements of mechanical properties, strain gages are fixed to the "gage section" of the specimen; for less precise measurements, the engineering strain is inferred directly from the normalized change in displacement:

$$\varepsilon_e = \Delta L/L_o \qquad (1)$$

where ΔL is the measured displacement and L_o is the initial gage length of the sample. Engineering stress can be calculated directly from the measured load P as:

$$\sigma_e = P/A_o \qquad (2)$$

where A_o is the initial cross sectional area of the sample (area normal to the loading direction).

However, the true stress and strain differ from these engineering expressions during plastic deformation, due to the continuous change in cross-sectional area and conservation of material volume. True stress and strain are related directly to engineering stress and strain as:

$$\varepsilon_t = \ln(1 + \varepsilon_e) \qquad (3)$$

$$\sigma_t = \sigma_e (1 + \varepsilon_e) \qquad (4)$$

By determining specific mechanical properties from the stress-strain response, materials can be compared directly without reference to geometry. For example, resilience, or the capacity of a material to elastically absorb energy, is quantified by the modulus of resilience U_R:

$$U_R = ½\, \sigma_y\varepsilon_y = ½\, \sigma_y{*}[\sigma_y/E] = \sigma_y^2/2E \qquad (5)$$

which is just the strain energy density (area under the <u>elastic portion</u> of the stress-strain curve). Similarly, the toughness, or the capacity of a material to plastically absorb energy, is quantified by the modulus of toughness U_T:

$$U_T \sim (\sigma_u + \sigma_y)/2 * \varepsilon_f \qquad (6)$$

which is a crude estimate of the energy or total area under the <u>plastic portion</u> of the engineering stress-strain curve. Thus, toughness includes both strength and ductility. Finally, strain hardening is a measure of the incremental resistance to plastic deformation after yielding. Although the strict definition of the strain hardening exponent n in terms of true stress and true strain is:

$$\sigma_t = K\varepsilon_t^n \qquad (7)$$

(where K is an empirical value called the strength coefficient) and n is determined as the slope of the log(σ_t) vs. log(ε_t), the degree of strain hardening is readily apparent from the engineering stress-strain curve as the difference between the yield stress and maximum stress.

In this lab, you will compare the bulk mechanical properties of several classes of materials, measured via uniaxial mechanical testing. These materials include pure metals and alloys, ceramic, polymers, and natural composites.

II. Objectives

The objectives of this experiment are to:

1. Gain experience in uniaxial testing of a wide range of materials.
2. Calculate the relevant elastic, plastic, and fracture properties of these materials from the stress-strain responses.
3. Compare elastoplastic properties measured under uniaxial loading to those predicted from local surface tests (hardness and indentation).
4. Interpret these results in the context of the nano- to micro- to macroscopic mechanisms of deformation.