



# Overview of Mechanical Properties and Testing

An Online Continuing Education Course for Engineers

**Course Number: MA-3004**  
**Credit: 3 Hours / 3 PDH / 3 CPD**

# Overview of Mechanical Properties and Testing

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This course teaches the following knowledge and skills:

- a. Fundamental concepts of stress, strain, elastic and plastic deformation, ductile and brittle behavior
- b. Different methods to perform mechanical property testing
- c. Mechanical properties that can be measured by different types of testing
- d. Differences in mechanical properties and testing of metals, ceramics, polymers, and composites
- e. Relevant industry standards for mechanical property testing of metals, ceramics, polymers, and composites

## 1. Introduction

Materials such as **metals, ceramics, polymers, and composites** are subjected to static and dynamic loads in service. Although these materials are all different, their characteristics that allow them to resist deformation and failure during loading must be known in order to make good design decisions, perform materials selection, and ensure quality. For example, the steel used in a car frames, the silicon carbide used in ballistic vests, the polyethylene (PE) used in food packaging, and the carbon fiber reinforced polymer (CFRP) composite used in sporting equipment are all defined by their characteristics or properties that in turn determines their ability to meet the requirements for the listed applications. The mechanical properties and behavior of a material defines its deformation response to an applied load. Furthermore, the mechanical properties of each material define its suitability for use in a specific application. Additionally, mechanical properties permit comparative evaluation of materials for selection in a design and also provide criteria to conduct quality control. Mechanical properties of materials are determined by performing standardized tests in order to ensure consistency between different testing facilities. The standards are published by professional societies, e.g., ASTM International, and in some cases government agencies. Some important mechanical properties include stiffness, yield strength, hardness, ductility, and impact toughness.

Many engineers require knowledge of mechanical properties and testing in order to ensure that undesirable deformation and failure in a component or structure does not occur. For example, civil and structural engineers must select steels with sufficiently high strength for bridges so that deformation does not occur. Similarly, an aerospace engineer must select an aluminum alloy or composite material that does not excessively deflect for use in a wing spar. A mechanical engineer may decide between stainless steels with different strengths for use in a corrosion resistant pressure vessel. On the other hand, ceramic, chemical, materials, and metallurgical engineers must understand mechanical properties, testing, and the appropriate standards in order to process and fabricate materials that meet the requirements of a specific application.

In this course, an overview of mechanical properties and testing is presented. The course first introduces the concept of stress and strain relevant for tensile testing. Testing of metals, ceramics, polymers, and composites is covered. For metals, ceramics, and polymers, each section starts with an overview of how the atomic structure influences mechanical properties and then discusses tensile testing and three-point and four-point bend testing in detail. In the case of composites, we first review the different classifications of composites and then discuss testing. For each class of material, the mechanical property test is discussed from the perspective of procedures, specimens, properties to be measured, and relevant industry standards. The stress-strain curve is covered along with differences between elastic and plastic deformation, and brittle and ductile behavior and fracture. In the next part of the course, hardness testing is examined for metals, ceramics, and polymers in the context of procedures, specimens, advantages, and disadvantages. Testing from the perspective of industry standards is addressed. In the third part of the course, impact toughness testing is covered for metals, ceramics, and polymers. The important concept of ductile-to-brittle transition (DBTT) temperature is discussed. Tables of mechanical properties of some important engineering materials are included and equations relevant to each type of testing are covered in the course. A partial list of relevant ASTM industry mechanical property testing standards is included at the end of the course.

## 2. Stress and Strain

A load that does not change with time is a static load and one that changes only very slowly with time is a quasi-static load. The mechanical behavior under these conditions can be determined by stress versus strain testing. Depending on the material class, testing may be performed for tension, compression, torsion (shear), or bending. Although the basic concepts of stress and strain are similar for metals, ceramics, polymers, and composites, differences do exist in the practical application of testing, specimens, properties, and mechanical behavior.

### 2.1. Stress Concepts

Stress,  $\sigma$ , is defined as the applied external load,  $P$ , divided by the cross-sectional area,  $A$ , as in equation (1)

$$\sigma = \frac{P}{A} \quad (1)$$

This equation assumes that the stress is uniformly distributed over the cross-sectional area and is normal or perpendicular to the area. The load is expressed in units of newtons (N) or pounds force (lbf) and the area is  $\text{m}^2$  or  $\text{in}^2$ , and thus the stress is expressed in units of pascals (Pa) or pounds per square inch (psi). Conceptually, stress can be thought of as the internal resisting force to an applied external load. If the original cross-sectional area,  $A_o$ , is used in equation (1) then the calculated stress is termed the engineering stress. However, the cross-sectional area decreases during deformation due to necking. If the instantaneous cross-sectional area,  $A_i$ , is used in equation (1) then the calculated stress is termed the true stress,  $\sigma_t$ . The true stress is equal to the engineering stress until necking and it is greater in magnitude after necking. The engineering stress is more commonly used due to the difficulty in measuring the instantaneous area. For practical purposes, this is a valid and conservative assumption during deformation. If no volume change occurs during deformation, then the true stress and engineering stress are related by

$$\sigma_t = \sigma(1 + \varepsilon) \quad (2)$$

where  $\varepsilon$  is the engineering strain, defined below. Equation (2) is only valid until the onset of necking.

## 2.2. Strain Concepts

Engineering strain,  $\varepsilon$ , is defined as the elongation (or change in length) due to deformation caused by the applied load divided by the original length,  $l_o$ , as in equation (3)

$$\varepsilon = \frac{\Delta l}{l_o} = \frac{l - l_o}{l_o} \quad (3)$$

The units of strain are dimensionless but are sometimes expressed as mm/mm or in./in. The true strain is determined by

$$\varepsilon_t = \ln \frac{l_i}{l_o} \quad (4)$$

where  $l_i$  is the instantaneous length. If no volume change occurs during deformation, then the true strain and engineering strain are related by

$$\varepsilon_t = \ln(1 + \varepsilon) \quad (5)$$

## 2.3. Metals

A metal is one of the primary classes of materials. From an atomic perspective, metals and alloys consist of positively charged ion cores surrounded by a sea of valence electrons that are not bound to any single atom. Valence electrons are the electrons in an outer shell of an atom. These free valence electrons act as glue to hold the ion cores together but also prevent the ion

cores from repelling each other. This type of bonding is known as metallic bonding. The strength of the bond or binding energy determines the magnitude of the melting temperature. The presence of free electrons also makes metals good conductors of electricity and heat.

The mechanical properties and failure characteristics of metals and alloys are also determined by the nature of metallic bonding. At room (or ambient) temperature, many metals and alloys fail in a ductile manner after plastic deformation during tensile testing, which is explained by the nature of metallic bonding. The concept of dislocations and their motion is the fundamental mechanism of plastic deformation. This characteristic of metals and alloys permits them to be strong but ductile and leads to their use in structural applications. However, if the motion of dislocations is hindered, then the metal or alloy will become stronger and harder but may lose ductility. If plastic deformation is limited further, then the metal or alloy will behave in a brittle manner with little ductility.

### ***2.3.1. Tensile Testing***

The **uniaxial tension test** of standardized metallic specimens is one of the most commonly performed tests. The results can be used to determine several important mechanical properties such as Young's modulus, yield strength, ultimate tensile strength, and ductility that are important for engineering design, materials selection, and quality control. Testing is performed using a test frame with a calibrated load cell, which is commonly referred to as a universal testing machine. A picture of an example machine is shown in Figure 1. A test specimen is uniaxially deformed in one direction in response to a quasi-static load. The load is slowly increased at a controlled constant rate until the specimen fractures.

