MECHANICAL PROPERTIES

Introduction

The concepts of stress, strain and strength of materials is employed in practically every engineering discipline. Mechanical properties such as stiffness, yield strength, tensile strength, ductility, toughness, impact resistance, creep resistance, fatigue resistance and others all influence the design, fabrication and service life of equipment. For example, the stiffness of a material is a primary factor determining the stiffness of a spring, of a bicycle frame, the wings of an airplane, even the floor you walk on while the yield strength determines how much load it can handle without being permanently deformed.

From the two above examples we can see that we usually have to consider not one but several properties when trying to match a material to an application. In some cases two properties can be combined to give us a third. For instance, the combination of yield strength and stiffness determines how much a material can be deformed elastically and how much mechanical energy it can store. In other cases one property may be dependent on another. For example, when processing a material to increase its strength one usually ends up sacrificing ductility and fracture toughness. Having established that any given material has a number of interesting and useful mechanical properties, and that these properties are often interrelated, it follows that we need be able to measure all of the them. It would be nice if one type of test could measure all of them but, unfortunately, no one test can do this. The tensile test, however, which can be used to measure a number of the most commonly used mechanical properties, is a very good place to start.

The origin of the stiffness of a material is the spring-like nature of the bonds between the atoms. Consequently, this property is strongly influenced by the composition of the material but only weakly by its heat treatment or other processing methods which do not change its composition. On the other hand, a material's yield strength is very sensitive to the material's processing history. This means that yield strength, unlike stiffness, is not a unique property of a material. It also illustrates the fact that there is a degree of versatility built into all engineering materials, that the properties of most materials can altered to fit the application. It also means that it is difficult to talk about the properties of a material without also mentioning its processing history.

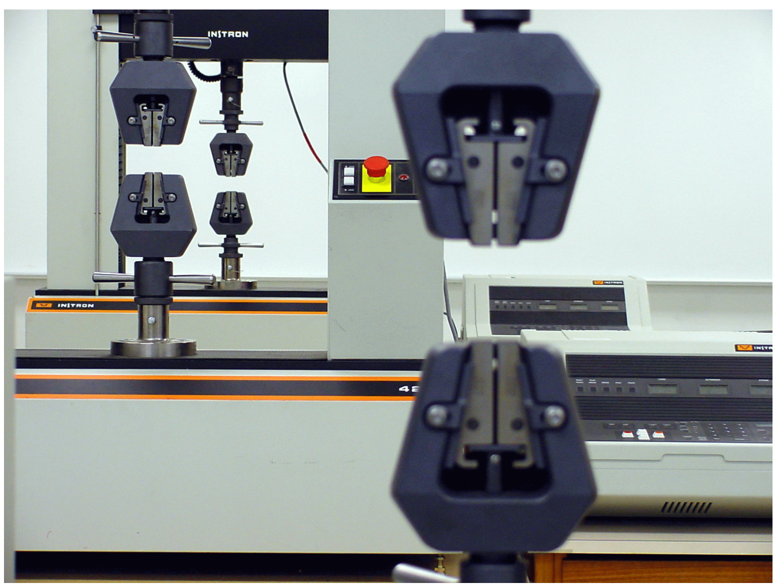

Figure 1 The three Instron 4204 tensile testers in the Materials Science teaching laboratories. They are shown with wedge-type grips installed. These are used to grip flat specimens and are rated for loads up to 11,000 pounds (50 kN).

The common tensile test is one of the simplest and straight-forward methods for measuring a host of mechanical properties. Tensile testing involves gripping a long cylindrical or rectangular specimen at both ends and pulling it at a specified rate until the specimen breaks. During the test one records force as a function of elongation, the mechanical behavior of the specimen, and from this, by considering the specimen's dimensions, one can determine the properties of the material itself. The advantages of this type of test are its simplicity, it is quick and easy to perform, and the concepts behind tensile stress and strain and the properties measured are not difficult to understand.

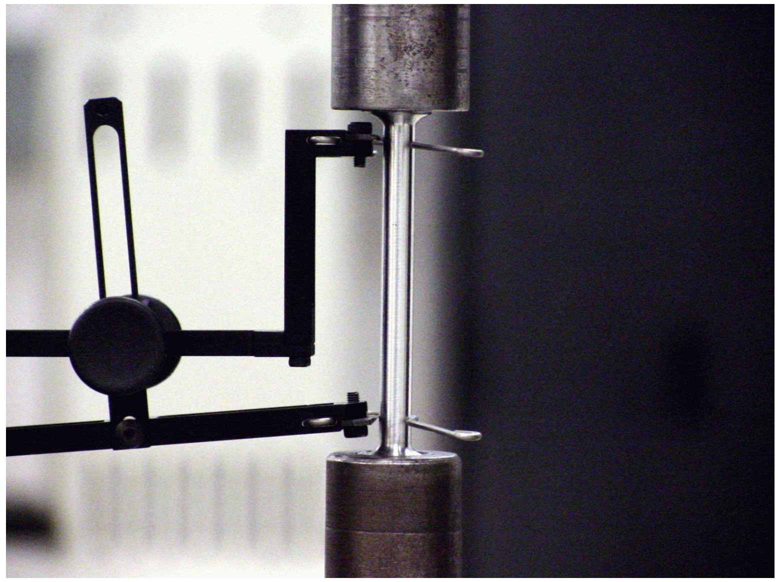

Figure 2 A close up view of an aluminum alloy specimen during the early part of a tensile test. The device attached to it, an extensometer, allows one to make accurate strain measurements.

Variations of the basic tensile test are used to study the influences of various metallurgical variables, such as grain size or impurity concentration, and can lead to better understanding of the fundamental aspects of a material's mechanical behavior. Tensile tests can also be used to evaluate a material's behavior in service-like conditions, for instance, high temperature tests conducted in air to study the behavior of superalloys that may be used in aircraft engines, or synthetic bone in a warm saline solution. There are also a number of other types of tests designed to measure properties such as the impact resistance of materials, hardness tests which are often good indications of strength but also of wear resistance, and fracture testing which involves pulling apart a specimen which has a machined notch and sharp starter crack in it. Fracture toughness is not quite the same thing as simple brute strength. Rather, it is a measure of the material's sensitivity to flaws, such as pores or pre-existing cracks, even scratches, and all materials contain flaws which reduce its fracture toughness. Flexure tests preferred for brittle materials, compression tests for concrete, and of course there are many types of tests one can use to evaluate the mechanical properties of polymers, and one of these is the tensile test.

In this experiment specimens of several widely used engineering alloys will be tensile tested to failure. The results will be analyzed to obtain measures of the properties one often finds in mechanical design handbooks. These results will then be compared to those listed in these handbooks and to the results obtained by other members of the class.

Procedure

Select a specimen to test and note its color code as it is used to identify the alloy and the specimen's processing history. Also note the type of specimen design and then carefully measure the length and cross-sectional area of the gage section of the specimen.

Tensile test the specimen to failure using one of the Instron tensile testers and the procedure given in the appendix. Ask your instructor to help you with any part of this procedure that you are not completely comfortable with.

Examine the specimen after tensile testing. Note the location and size of the necked region and see if yours has the classic cup-and-cone type of fracture. Use the microscope provided to observe the details of the fracture surface and, optionally, save the specimen, protecting the fracture surfaces from damage or contamination, so that you can examine it using a scanning electron microscope.

Finally, using the Instron Series IX software generate load-elongation and stress-strain curves from your test data and print one copy for each person in your group plus an extra copy for your instructor.

Results

Using the reports and plots generated by the Instron software determine the following mechanical properties:

1. Stiffness
   Young's Modulus__________________________psi   ___________________
___ GPa

2. Strength
   Yield Strength______________________psi   _________________________MPa

   Type of Yielding   9 Gradual   9 Sharp   9 Upper/Lower

   Ultimate Tensile Strength_____________psi   _________________________MPa

3. Ductility
   Elongation to Failure_________________%

   Reduction in Area__________________________%

4. Energy Capacity
   Energy to Yield_____________________inch-pounds   ___________________Joules

   Energy to Fracture_________________________inch-pounds   ______Joules

   Modulus of Toughness_______________ksi   ___________________MPa (J/m^3)

5. Fracture
Describe the necked region of the specimen. ____

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Describe the fracture surfaces. ____

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Analysis

1. Compare the above results with those in table 1 and in additional reference materials provided.

2. Compare your results with those of all other specimens tested.

3. Use the equations in the sample laboratory reports and the results from the tensile tests of the steel specimens to design a 3.5 inch diameter helical coil spring having a stiffness of 500±10 pounds per inch. Estimate the value of the shear modulus G using the equation G = E/2(1+<) where <=0.25 and E is Young's modulus. What would the stiffness of the spring be if you had made it out of aluminum? How much energy would these two springs be able to store?

Example

Figure 3 shows a stress-strain curve for which all prominent features are labeled. It should help you to identify these features in your results and to measure the mechanical properties using your stress-strain curve. Figure 4 shows the stress-strain curves for a number of materials.

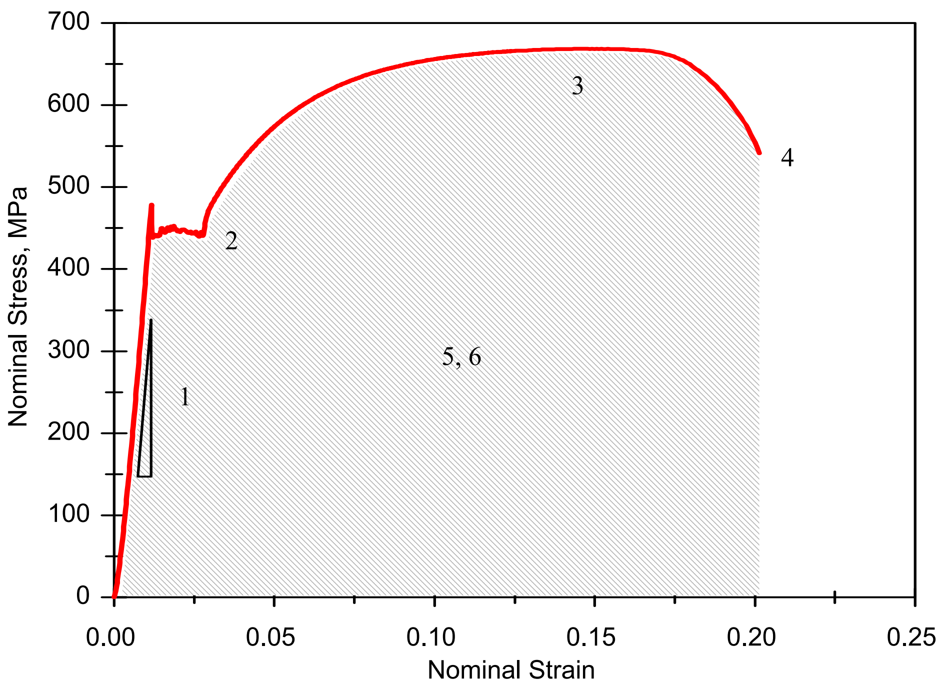

Figure 3 Typical stress-strain curve for a plain carbon steel. The numbers correspond to the mechanical properties described in this section.

1. Young's Modulus: a measure of a material's stiffness when deformed in tension. It is measured from the slope of the initial linear region on the stress-strain plot. Unfortunately, unless we use an extensometer we will not be able to measure Young's modulus. The data in the stress-strain plot in the example above yields a value of 47.8 GPa ($6.9x10^6$ psi) while the correct value is 207 MPa ($30x10^6$ psi). The difference is due to the stiffness of the testing machine itself.

2. Yield Strength: the stress where deformation changes from being mostly elastic to mostly plastic. It is taken from the end of the linear (elastic) portion of the stress-strain plot. This specimen

exhibited an upper an lower yield strength, a well known characteristic of steel. The yield strength in this case is the lower yield strength which is 441 MPa (63.9 ksi).

3. Ultimate tensile strength: this is the highest stress on the stress-strain plot. For this material the UTS is 668 MPa (96.9 ksi).

4. Ductility: there are two ways to represent this property but both are measures of the strain at fracture. One is the elongation at fracture and the other is the reduction of area in the necked region of the fractured specimen. The elongation to failure for this specimen is 20.1%. The reduction of area has to be measured directly from the specimen.

5. Energy Capacity: this represents how much work was done (how much energy was required) to pull the specimen to fracture. It is a measure of the specimen's resistance to failure in tension and is equal to the area under the load-elongation curve. For this specimen the energy capacity is 201 joules.

6. Modulus of Toughness: this is similar to energy capacity except that it is expressed in terms of the energy per volume of the specimen. It is a measure of the material's resistance to failure in tension and is equal to the area under the stress-strain curve. (Note: units of stress can be converted to units of energy per volume, i.e., 1 MPa = 1 J/m^3) For this specimen the modulus of toughness is 119 MPa = 119 J/m^3.

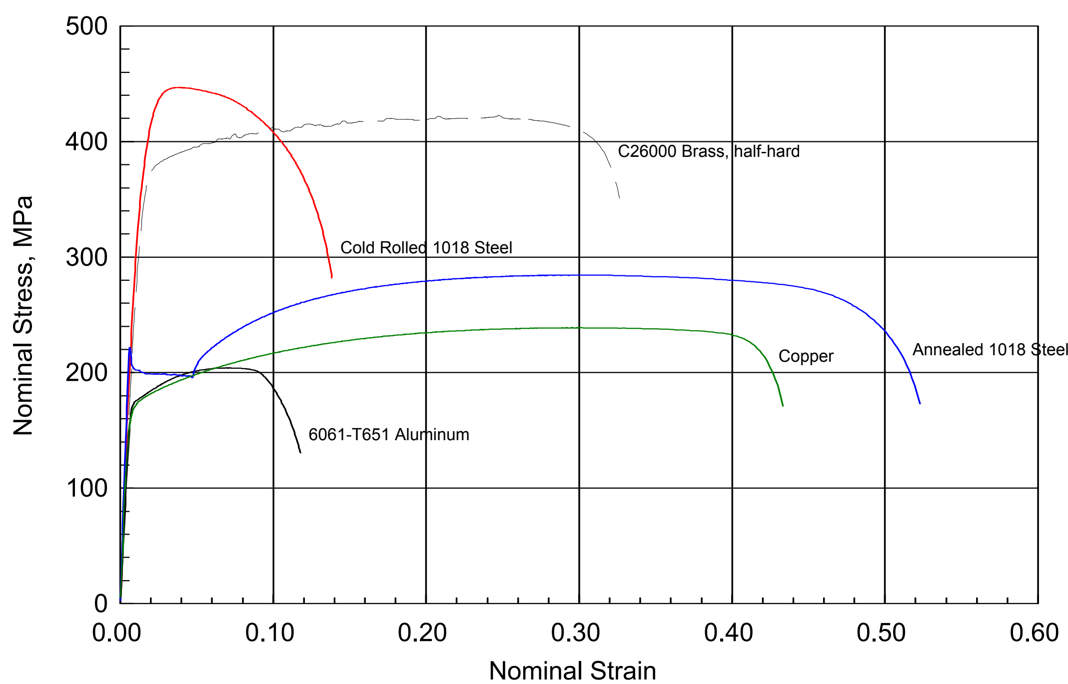

Figure 4 Examples of stress-strain curves for the types of materials tested in this laboratory.