Experiment 5

Tensile Properties of Various Polymeric Materials

Introduction

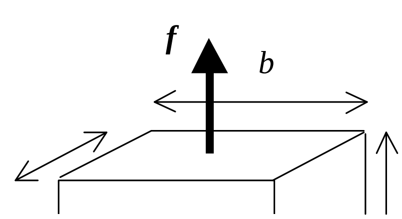
Polymeric materials find application in many industries. The automotive industry, for instance, employs plastics for many parts in cars and trucks, such as the tires, bumpers, body panels, and interior trim. Even the upholstery is often a synthetic plastic. The electronics industry uses plastics for such varied items like the electronic components and the cases in which computers are packaged. And the examples could be multiplied. Plastics are prolific.

One question that is of critical importance to any company that decides to use a plastic for a particular application is, "Which plastic material is best suited for our application?" The answer to this question is determined by the physical, chemical, optical, and/or electrical properties required for the specific application. To answer these questions, it is obvious that various parameters need to be defined for each grade of polymer (many polymers are sold as blends or composites, and contain certain modifiers, such as anti-static agents, anti-weathering agents, pigments, etc., and each recipe will have different specifications). Many parameters are governed by ASTM (American Standard and Testing Materials), although just as many are 'non-standard' in-house tests developed by various companies to meet a certain need.

One of the most common tests used for plastic materials is the tensile test. From this test, a number of important parameters can be calculated, such as the apparent modulus, the strain at break, and the ultimate elongation to rupture. While these parameters are not necessarily linked to a specific molecular property of the material (i.e. the numbers are strictly empirical, and are to be used on a comparative basis), they are often very useful to the plastics industry for determining which grade of material is best suited to their purpose.

Theory

A typical tensile test is drawn schematically in Figure 1. A material with dimensions a x b x c is subject to a uniaxial force f in the c-direction. The stress, σ, is given by f/A, where $A = a \times b$. The tensile strain, γ, is equal to the change in length, $\Delta c/c$. The tensile (Young's or Secant or 2%) modulus, E_{secant}, is given by $E_{secant} = \sigma/\gamma$. Typical stress-strain plots for different types of plastic are shown in Figure 2.



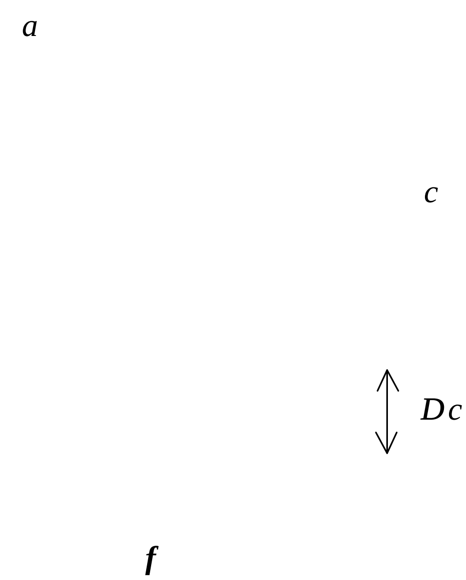


Figure 1: Tensile deformation in a three-dimensional body.

There are various parameters which can be calculated, namely initial modulus (E_{secant}), yield stress (σ_y), yield strain (γ_y), ultimate tensile strength (σ_B), and elongation at break (γ_B). Clearly, not all of these parameters are possible for each curve, since the brittle plastic does not display a yield point.

Effect of temperature and rate of testing

Temperature and strain rate can be considered simultaneously, since, in general, a reduction in temperature has the same effect as an increase in the strain rate. In the case of tensile testing, T_g is an important parameter in determining the temperature dependence of the various properties. In general, when the testing temperature is much lower than T_g ($T \ll T_g$), the elongation at break (g_B) is low and there is no yield point. At $T > T_g$, g_B is much larger, and yielding is observed.

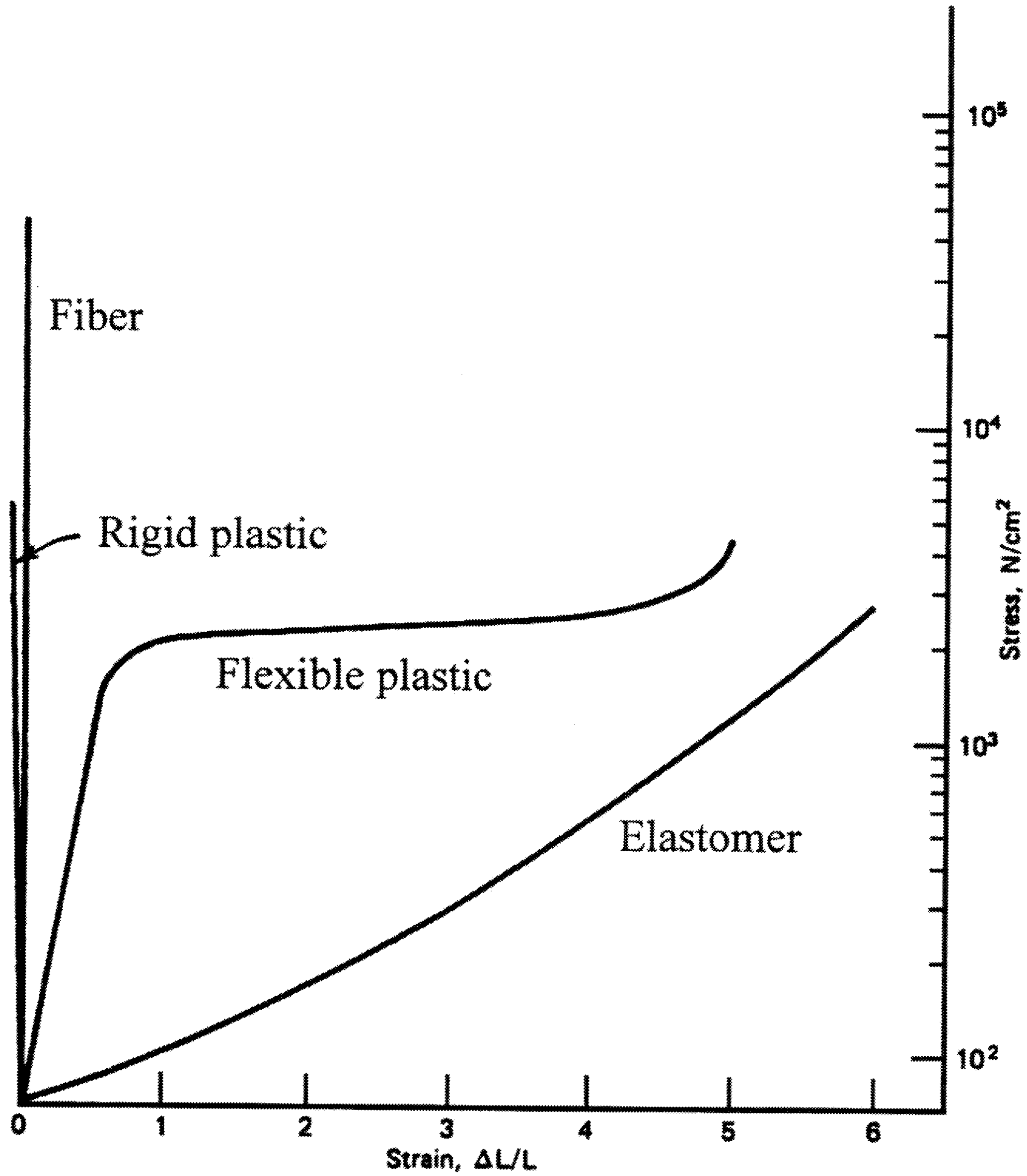


Figure 2: Stress-strain plots for a typical elastomer, flexible plastic, rigid plastic, and fiber (from Odian, G., Principles of Polymerization, Third Edition).

And at T»T_g, g_B may decrease again. As far as the yield properties are concerned, both s_y and g_y decrease as the temperature increases (near T_g, for amorphous materials). At cryogenic temperatures, nearly all polymers are glassy.

Effect of molecular weight and branching

There is no simple relationship between tensile properties and molecular weight of the polymers since the molecular weight also affects the crystalline morphology (such as lamellar thickness, spherulite size and degree of crystallinity) and chain entanglements in the amorphous region, which in turn affects the tensile properties. However, it is still possible to make some general statements. At $T > T_g$, very low M.W. polymers are viscous liquids which are unable to support a load. At sufficiently high M.W., the material becomes a solid, but has a low strength, and a low elongation at break. Once the molecular weight is above the critical molecular weight for entanglements ($M_c > 10^4$, from zero-shear viscosity data for polyisoprene), the strength and elongation increase to a limiting value as the molecular weight increases. At high M.W. ($> 10^5$), the elongation at break can be as high as 1000%. If the testing temperature is below T_g, then materials with low molecular weight are extremely brittle. For semicrystalline polymers, the same trends apply, except that the M.W. dependence is reduced somewhat.

Effect of crystallinity

A semicrystalline material is generally brittle and has a low strength at temperatures below its T_g. There are a number of possible reasons for this. It may be that the crystallites impose strain on the amorphous region, or voids may be created during the crystallization process, or the crystallites may act as stress concentrators. It is known that chain ends and low molecular weight material collect in the amorphous region. Since the strength of semicrystalline polymers comes primarily from the tie molecules between lamellae, the presence of chain ends and low molecular weight material in the inter-lamellar region may reduce the number of tie molecules, and hence the strength of the polymer.

Large spherulites result in a brittle material. An increase in crystallinity is accompanied by an increase in modulus and yield stress, but a decrease in the elongation at yield and break. These changes can be brought about in a sample during annealing or ageing, in which secondary crystallization can occur, and by varying the cooling rate from the melt.

Effect of orientation

The tensile strength of a material tested perpendicular to the molecular orientation is lower than if the test was performed parallel to the orientation. The trend applies to the modulus and to the yield strength. A load applied parallel to the orientation is borne by the strong covalent bonds, whereas the load is carried by weaker van der Waals' interaction in the perpendicular direction.

In this experiment, we will be subjecting four different plastics to tensile deformation. These materials are high density polyethylene (HDPE), low density polyethylene (LDPE), polystyrene (PS), and rubber. We will be using sample specimens called dog-bones, which will be clamped in the jaws of the Instron Tensile Tester. The lower jaw is connected to a movable crossbeam. This crossbeam can be raised or lowered at preset >crosshead= speeds using the buttons on the instrument. The top jaw is connected directly to a force transducer, which sends its signal to the computer. The computer converts the signal from volts to Newtons (N) based on the calibration constant of the force transducer, which was determined previously. The computer then plots force (in N) against time (t), which can be converted to strain because we know the crosshead speed. This information is also saved as a comma-delimited ASCII file, which can be imported into Excel or QuattroPro for data analysis. From this data we can plot the stress-strain curve for each polymer and calculate the parameters we desire. It should be noted that we will be making a simplifying assumption, namely that the cross-sectional area ($A = a \times b$) does not change during the course of the experiment. This is not necessarily valid, but determining the cross-sectional area at every point during the test is prohibitively difficult with our apparatus. To be correct, we should refer to the stress-strain plot as the 'apparent' stress-strain plot.

Experimental

You will prepare the tensile specimens with the molding press. **Your TA or senior**

demonstrator must explain to you how to operate the molding press or the Instron Tensile Tester before you may start. Twelve of HDPE, and three each of all the others will be molded. Number each dogbone, and determine the cross-sectional area of each specimen in the narrow part of the tensile dogbone using the micrometer provided. The length of the specimens are assumed to be the same, and the gauge length (distance between the jaws) on the Instron Tensile Tester has been set at 9.3 cm. The TA or the Senior Demonstrator will then show you the operation of the Instron Tensile Tester, and the associated data acquisition program.

The crosshead speed that we will use for this experiment will be ***2 inches per minute***. Test all sample specimens at this crosshead speed, except in the case of the HDPE. For the HDPE samples only use three of the dogbones at the 2 inch/min crosshead speed. The other HDPE dogbones will be tested at different crosshead speeds. Test three of them at 0.02 inch/min, three at 1 inch/minute, and three at 10 inches/min. Be sure to tabulate the names of the files that you generate, so that you can identify them later. An easy system might be LDPE_1, LDPE_2, etc., PS_1, PS_2, etc., ELAST_1, ELAST_2, etc. For the HDPE samples, another indicator must be included to identify the crosshead speed.

In all cases, be sure to make notes about what you observe for each of the samples that you tested.

Copy the files (you should have 18 files) from the data diskette to your own diskette, and make a backup copy as well, in case one copy gets corrupted. For each file, convert the force-time data into stress-strain data using the relations discussed in the **Theory** section. Plot the curves for each type of sample together (polymer type and crosshead speed; 7 plots in total). Also, for the HDPE samples, plot one representative stress-strain plot at each crosshead speed on one plot, to show the effect of crosshead speed on the stress-strain properties. [Note: Be sure to shift the data on the *x*-axis to take into account that the zero time for each run is different. Time zero is considered to be the point where the force increases above the baseline.]

For each sample, calculate the secant modulus (stress/strain at 2% strain), the stress at break and elongation (strain) at break, and for those samples that exhibited a yield point, also calculate the yield stress and yield strain. Tabulate the results. Also, calculate the average for like samples (same polymer type and crosshead speed).

Discussion

For all the samples tested at 2 inch/min, describe the stress-strain behaviour, making use of the plots you prepared. Report the relevant parameters that you obtained from the tensile experiment.

Compare the data you obtained for HDPE and LDPE at the same crosshead speed. Are there differences? Account for the differences.

Compare the data for HDPE at the different crosshead speeds. Explain any trends that you observe.

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Appendix: Operating Procedures of Instruments

Molding Press Operation:

The molding press is made of two jaws, which are temperature-controlled. A mold containing the polymer of interest is placed between the two preheated jaws, which are brought together and tightly held closed for 20 minutes. After 20 minutes at high temperature and under high pressure, the jaws are open and the polymer dogbones are obtained.

Operating the *Molding Press*:

Plug in the molding press. Set up the temperature of the two jaws to equal 180^{o}C. This is done by pressing the center of the temperature control knob and rotating it to the desired temperature.

Use the mold capable of producing four dogbones. The mold is placed on top of a metal plate, which has been covered beforehand by aluminum foil. The polymer pellets are gently spread over the mold. A second metal plate covered by aluminum foil is adjusted on top of the mold filled with polymer pellets.

The ensemble (bottom metal plate/aluminum foil/mold with polymer pellets/aluminum foil/top metal plate) is placed between the two preheated jaws of the molding press. The jaws are brought together using the handle on the right of the instrument. Upon contact, higher pressure must be applied in order to force the polymer into the mold. High pressure is obtained by lifting the handle in the upward position and gently bringing it down. Maintain the pressure constant at about 10,000lbs and let the molding process occur for 20 minutes.

When done, release the pressure using the dump valve on the left hand side of the instrument. Using the insulating glove, take out the metal plates and mold and place the ensemble on another metal plate located on the table. Pry open the two metal plates, and get the dogbones out of the mold. Clean up plates and mold for molten polymer and prepare the next batch.

Four dogbones have been obtained. The cross-section of each dogbone equals ½x1/8'.

Instron Operation:

The polymer dogbone is placed between the two clamps of the *Instron*. The lower jaw moves downwards and applies increasing stress onto the dogbone, which is recorded as a function of time on the computer. Since the crosshead speed is known, one can calculate the elongation from the time measurement.

Operating the *Instron*:

Turn on the instrument with the main power bar located behind the Instron. Turn on the main power and the amplidyne switches located on the front panel of the Instron. Open the nitrogen tank, which controls the Instron clamps. Set up your polymer dogbone in the clamps. The distance between the two clamps equals 9.3cm. Set up the desired crosshead speed (setting 1-0.1 is equivalent to a crosshead speed of 1'/min, setting 2-0.2 is equivalent to a crosshead speed of 2'/min).

On the computer, go into the *Instron Data Acquisition* Menu and choose the *configure* menu. In the *configure* menu, give your file name as "*a:filename*". This ensures that the file is saved on a 51/2' floppy disk. When done, press *Esc* to exit the *configure* menu and chose the *go* menu. Press *enter* to start the run on the computer and press *down* on the front panel of the Instron to lower the clamp. As the clamp is lowered, the dogbone is under increasing stress, which is shown on the screen.

When the run is over, **press the *stop* button on the front panel of the Instron**. Your data is automatically saved in your disk. Bring the lower clamp back up first with the *traverse up* handle and then with the *up* button at a reasonable speed (1'/min).