Teacher Instructions for PETE Processing Activity

Material and Equipment List: 12 oz. PETE (Recycling #1) clear plastic cups, free from ridges or markings on the cups' walls; scissors; permanent markers; dog-bone style template; digital calipers; safety glasses, for all students and instructors; mechanical tensile testing machine; laptop or in-classroom computer with spread-sheet software for data recording and analysis.

Activity Preparation: It is suggested to perform some preliminary tensile tests with the plastic cups to determine their typical stress-strain response. It was found during the design of this activity that cups from different manufacturers will have slightly different stress-strain responses. For example, PETE cups of different sizes (6 oz., 10 oz., 12 oz.) donated from a local cafe displayed relatively flat plateau regions in their stress-strain curves following the yield point whereas the data including in this activity (e.g., Figure 4) was from cups purchased at a local grocery store which displayed significant strain stiffening. What remained constant between all the PETE cups that were tested (at least 4 different brands and 2 different sizes) is that parallel-cut specimens displayed ductile behavior with greater strength and elongation while perpendicular-cut specimens displayed brittle behavior with reduced strength and elongation.

Activity Instructions:

1. As a group, discuss the "Pre-Activity Handout" with the students.
2. Introduce the students to the general use and operation of the mechanical testing machine.
    a. Explain how specimens of a material are loaded into the machine and how these specimens are created and quantified (by measuring gauge thickness and gauge length for dog-done style samples).
    b. Explain how the specimens are deformed (by cross-head displacement) and how the data is collected (by load cell) and analyzed (by engineering stress and engineering strain, to calculate small-strain Young's Modulus, yield stress, elongation, and stress and strain at failure).
3. Provide each student with a plastic cup and ask them to brainstorm a way to test the mechanical properties of the plastic cup.
    a. Questions to ask: What section(s) of the cup should you test? Do you think the mechanical properties will be the same in every area of the cup? How should you create the specimens that you will test? How many specimens should you test?
    b. The teacher should encourage the students to test specimens of the cups' walls, with separate specimens oriented parallel and perpendicular to the thermoforming direction (refer to Figure 2). Ask the students why these specimens are important to test, relating back to the content and discussion questions in the "Pre-Activity Handout".
    c. As a group, determine the list of specimens to prepare for testing. Note: the number of specimens that should be prepared is dependent on the amount of time allotted for this activity, the number of students and the number of tensile testers. For a 1-hour activity, it is suggested to prepare at least 2-3 parallel-cut specimens and 2-3 perpendicular-cut specimens. Each specimen will take less than 5 minutes to load and test (see videos for example of this) in a typical tensile testing machine. When performed previously with a group of 6 undergraduate students, students were asked to form pairs and each pair was given a different plastic cup and asked to prepare two specimens from their cup for

testing (1 parallel-cut specimen and 1 perpendicular-cut specimen). The 6 specimens were then tested during the 1-hour time block (testing took approximately 25 minutes).

4. Provide the students with scissors, markers, and the dog-bone style template. Ask them to trace and cut out different specimens from their cups.
    a. Safety note: Students should be careful when cutting out the specimens as some regions of the cups will be more difficult to cut and could result in sharp edges. Safety glasses should be worn and cutting should be performed slowly.
    b. Label each specimen and record the orientation of the specimen (parallel or perpendicular), using Table 1 if desired.
    c. The cut specimens do not have to be perfectly identical in size and shape, with smooth edges and exact dimensions. In the design and implementation of this activity, it was found that the stress-strain responses and quantitative data were largely independent of minor flaws and differences in specimen preparation and dimension.
5. Provide the students with digital calipers. Ask the students to measure, calculate, and record the cross-sectional area of the section of the specimen that will be deformed. For dog-bone style specimens, this would be the cross-sectional area of the narrowed gauge region. Add the appropriate dimensions to Table 1.

Table 1: Sample preparation data table.

Specimen ID	Specimen Orientation	Cross-Sectional Area (mm^2)	Length (mm)

6. Once the specimens are prepared and Table 1 is completed, the specimens can be tested and the resulting force and displacement data recorded for each specimen.
    a. Use a common loading procedure and testing rate for all specimens, such as 1 mm/s or 1 in/min. Test until failure.
    b. Safety note: Everyone should wear impact-resistant safety glasses during testing, as some specimens may shatter upon failure.
    c. The students can either be trained to operate the machine by themselves (if time allows) or the teacher or a student assistant could help the students operate the machine.
    d. Depending on the machine that is used, the data might be recorded as tensile force in units of Newtons (N) or pound force (lb-f), and the displacement might be recorded as millimeters (mm) or inches (in). Conversion to SI units is recommended.
7. Once the data is collected, have the students prepare a computer spreadsheet and input the force and displacement data into the spreadsheet. The spreadsheet can be organized as shown in Table 2 (with additional columns for unit conversions if necessary).

Table 2: Sample testing results (strain rate = xxx).

Specimen ID	Specimen Orientation	Cross-Sectional	Length (mm)	Force (N)	Displacement (mm)	Stress (P)	Strain (mm/mm)	E (MPa)

		Area (mm^2)						

8. As a group with help from the teacher or student assistant, have the students complete the following tasks for each sample:
    a. Convert the force values to engineering stress values with units of Pascals (P).
    b. Convert the displacement values to engineering strain values (mm/mm).
    c. Plot the data for all of the specimens on a series of stress-strain graphs, combining data series into a single plot when appropriate.
    d. Calculate the elastic modulus (E, Young's modulus) for each specimen.
    e. If time allows, can also ask the students to calculate/determine the yield stress, percent elongation, and failure stress and strain.

Post-Activity Discussion: As a group, discuss why the different specimen displayed different mechanical properties, with a focus on the relative differences in stress-strain behavior, elastic modulus values, yield stress, and percent elongation of the parallel-cut specimens and the perpendicular-cut specimens. To aid in this discussion, the following questions inspired by the "Pre-Activity Handout" may be useful to pose to the students (depending on their level):

- Comparing the stress-strain response of the parallel-cut specimens to the perpendicular-cut specimens, which sample displayed a more ductile response and which displayed a more brittle response?
- If you could "zoom-in" and directly view the microstructure of each sample BEFORE deformation, what would the microstructure look like? How would the microstructure change DURING deformation but before failure? Note: To be consistent with the discussion questions in the handout, students could be encouraged to draw a sketch of the general microstructure of each sample before and during deformation.
- In each sample, how was the applied tensile stress being supported (or resisted) by the PETE polymer molecules? Note: this could lead to a discussion of the relative strength of intrachain covalent bonds vs. interchain Van der Waals bonds.