

Polymer Physics Laboratories for the Undergraduate Packaging Curriculum

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ABSTRACT

Undergraduates majoring in Packaging Science at Clemson University are required to take a combined lecture/laboratory course in Applications of Polymers in Packaging in their Junior or Senior year. Over the past four semesters, new laboratory exercises have been developed to enhance the students' understanding of basic process-structure-property relationships in polymers used in packaging. This work has been enabled by new thermal analysis equipment funded by an NSF CCLI grant. This paper describes the four laboratories that have been developed to date, the cooperative team approach to executing and reporting on the labs, and the students' reactions. The laboratories include: determining the thermoforming window using elevated temperature tensile testing and DSC; understanding the effects on properties and structure from changing the film casting conditions of LLDPE films; understanding the hot fill behavior of PET bottles using DSC and TMA; and understanding the methodology and use of time-temperature superposition for predicting long term polymer behavior.

BACKGROUND

One of the core requirements for the B.S. degree in Packaging Science at Clemson University is an advanced combined lecture/laboratory course in Applications of Polymers in Packaging. Over the past four semesters, this course has been restructured to focus on essential concepts of polymer science applied to the solution of application related problems typically encountered in packaging. The underlying philosophy of this approach is that equipping students with an understanding of how the properties of polymers are related to their structure and processing history will better enable them to solve the practical problems using polymers that they will encounter in their future careers.

The lecture portion of the course consists of a series of twenty PowerPoint presentations, reinforced by the text recently published by our Michigan State colleagues, Plastics Packaging: Properties, Processing, Applications and Regulations [1]. Web sites such as Macrogalleria [2] and others are used during lecture and assigned to supplement the presentations and reading material. The course is organized in four approximately equal sections: Structure and Properties; Extrusion and Film Making; Thermoforming, Injection and Blow Molding; and Polymerization and Major Plastics.

The laboratory portion of the course has been designed to provide real experiences in relating measured properties and structural characteristics to processing. The laboratory redesign has been greatly facilitated by new thermal analysis equipment funded by an NSF CCLI grant to a group of the Packaging Science faculty and an upgraded tensile testing machine funded internally.

To date, four laboratory sequences have been implemented to realize these objectives:

- Thermoforming and the thermoforming window
- Structure-process-property relationships for PET bottles
- Structure-process-property relationships for LLDPE cast films
- Long term polymer behavior using time-temperature superposition

During scheduled laboratory classes, students have the opportunity to use each piece of processing and analytical equipment and generate some of the data for analysis. More extensive data collected using the same techniques is provided to include in the analysis. The students work in pre-selected teams of three throughout the semester to perform the experiments, analyze the data and prepare formal reports. Collaboration is emphasized to provide each student an equal opportunity to participate and contribute. The team receives one grade for their work on each report. To provide individual accountability, each student keeps his own laboratory notebook that is graded for format and completeness at the end of the semester.

THE LABORATORIES

Thermoforming

1. The students determine the optimum thermoforming conditions for PVC, APET and PETG sheet using a small bench top pressure/vacuum former. They are instructed to try a range of times to ensure that at least one set of conditions produces whitening of the APET sheet as it starts crystallizing.
2. The students learn the principles and operation of the Differential Scanning Calorimeter (DSC) by running an APET sample through a heat-cool-heat cycle between room temperature and 300°C (above the melting point). They observe the glass transition temperature, cold crystallization, the melting endotherm, crystallization from the melt (on cooling) and then a smaller T_g effect, no cold crystallization and then re-melting on the second heating.
3. The students are given DSC data for the PVC and PETG sheets.
4. In their analysis and reports, the students conclude that PVC and PETG have much wider thermoforming windows because they don't crystallize, while thermoforming of APET is limited by cold crystallization.
5. Next semester, we plan to expand this laboratory by incorporating elevated temperature stress-strain data that will allow the students to fully understand the concept of thermoforming window.

PET Bottles

1. The students compare the dimensions and design of two hot filled 20 ounce PET bottles with a 20 oz. carbonated soft drink (CSD) bottle. They then measure the volume change of each bottle on filling with 90°C water.
2. The students learn the principles and operation of the Thermo Mechanical Analyzer by measuring the linear shrinkage of a CSD bottle wall compared with that of a heat-set biaxially oriented PET film.
3. The students are given DSC data (finish, wall and base) and TMA data (vertical and circumferential) for each of the three bottles.
4. The students observe the heavier weight and thicker finish and walls of the hot fill bottles. They also note the vacuum relief panels. From the thermal analysis data, they draw several conclusions:
 - a. The bottles are made from similar copolymers (the melting points and glass transition temperatures are identical within experimental error).
 - b. All three bottles have similar crystallinity in the oriented walls.
 - c. The two hot fill bottles have experienced more heat history (the finish and base areas are more crystalline than the CSD bottle).
 - d. The CSD bottle that shrank a great deal when filled with hot water begins shrinking in the TMA about 5°C above its T_g, while the hot fill bottles (that showed no shrinkage on 90°C filling) begin shrinking about 20°C above their T_g.

- e. The hot fill bottles are made from polymers that have been modified to increase their crystallization rate (cold crystallization begins 15-20°C below that of the CSD bottle).
- f. Hot fill bottles require heat setting and heavier walls to perform effectively.

LLDPE Cast Films

1. Working with the lab assistant, students operate the 1 inch extruder with an 8 inch wide die to cast LLDPE films on a chill roll at two different chill roll speeds and two different die to chill roll distances. They observe the changes in width and appearance accompanying the process changes.
2. Students learn the operation of the tensile testing machine using samples of typical brittle amorphous, semi-crystalline and rubbery polymers.
3. Students are given stress-strain and DSC data for film samples made at the four process conditions.
4. Students conclude from the DSC data that at the short die-to-roll distance, there is no effect of roll speed on crystallinity, while the tensile properties reveal slight preferential MD orientation that is marginally greater at the higher casting speed. The longer die-to-roll distance provides more time for changes in orientation and crystallinity and considerable imbalance in properties, corresponding to much higher neck-in and molecular relaxation.

Time-Temperature Superposition

1. Using the tensile tester fitted with a temperature-controlled furnace, students measure the stress-relaxation of PETG samples below, at and above T_g for 5-minute periods at each of six temperatures. They experience the problems of heat loss resulting from opening and closing the furnace door to mount samples.
2. The students recalculate and replot their data as relaxation modulus vs. log time and attempt unsuccessfully to construct a master curve using time-temperature superposition. This exercise gives them the experience of acquiring stress relaxation data, performing the calculations and understanding the temperature intervals and time required for full data acquisition for a useful stress relaxation study.
3. Using data provided from the literature, students construct a master curve and use the data to predict the long-term behavior of a package stored in a hot warehouse.

STUDENT RESPONSE

Two indicators of student response are being used to monitor the pedagogical effectiveness of the new labs: an end-of-semester anonymous survey and comparison of results on final exam questions related to the laboratory sequences. To date, the exam question comparison reveals that the labs benefit C students more than A or B students. The surveys reveal very positive student response to the laboratories. 88% felt involved; 70% felt the labs contributed greatly to their understanding of the course; 84% felt the teams functioned well in both doing and writing up (78%) the labs; and 80% felt that working in a team rather than individually helped their understanding of the labs. In Fall 2001, only one out of the four teams reported that one or two team members did most of the work.

FUTURE WORK

The applied polymer laboratories will continue to evolve, especially as new equipment becomes available. One of the NSF CCLI grant objectives was to extend the approach discussed here to the sophomore level laboratory courses. This effort will begin this summer.

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REFERENCES

1. R. Hernandez, S.E.M. Selke and J. Culter, *Plastics Packaging*, Hanser Gardner, Cincinnati, OH (2000).
2. Dept. of Polymer Science, Univ. of Southern Mississippi, *The Macrogalleria*, <http://www.psrc.usm.edu/macrog/index.htm> (2000)

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