DETERMINING SIGNIFICANT MATERIAL PROPERTIES, A DISCOVERY APPROACH

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PREREQUISITE KNOWLEDGE: The experiment itself can be informative for persons of any age past elementary school, and even for some in elementary school. The preparation of the plastic samples is readily accomplished by persons with reasonable dexterity in the cutting of paper designs. The completion of the statistical Design of Experiments which uses Yates' Method requires basic math (addition and subtraction). Interpretive work requires plotting of data and making observations. Knowledge of statistical methods would be helpful.

OBJECTIVES: The purpose of this experiment is to acquaint students with the seven classes of recyclable plastics, and provide hands-on learning about the response of these plastics to mechanical tensile loading.

EQUIPMENT AND SUPPLIES: 1) recyclable class 1 - PETE plastic container such as a Sprite, Coca-Cola, or Pepsi 2 liter bottle large enough to make 8 samples (other recyclable plastic containers with recycle codes are listed in Appendix A and for more discussion on plastics and their properties see Smith, Askeland and Callister [1,2,3]); 2) sample templates* which follow the American Society for Testing and Materials [4] specification Part 35 D638-80 type IV style (or equivalent); 3) a utility knife for scribing out the samples; 4) a 'magic' marker to label the samples; 5) a data sheet as laid out in Appendix C for a) sample preparation, b) data tally, and c) descriptive comments; 6) a tensile testing machine with a) grips suitable to hold the thin 0.5mm +/- 20% (0.020 in. +/- 20%) samples, b) position control to specify stretch or deformation rates of 500 mm/min. (20 in/min.) and 50 mm/min. (2 in./min.), and c) a method of recording the maximum first load held by the sample (see data sheet) which could be taken from a load versus deformation graph prepared while each specimen is tested; and 7) Normal Probability paper available from a stationary store.

PROCEDURE: The procedure requires making samples from recyclable plastic containers, pulling the samples apart, and evaluating the test results to determine if the variables of specimen orientation, specimen cross-section via throat width, and rate of stretch or 'pulling-apart' are singly or jointly important. This involves a visual/descriptive review of the samples as well as the data collected.

Step I: Procure a recyclable 2 liter green Sprite PETE bottle and label the x-axis that is parallel to the base of the

*See Appendix B.

bottle and follows around the 'roundness', and the y-axis which is perpendicular to the base and which is coincident with the long axis of the bottle as shown in Appendix B - Figure B1.

Step II: Devise a way to obtain four 6.25 mm (1/4 in.) wide throat and four 12.5 mm (1/2 in.) wide throat samples so that half the 6.25 mm (1/4 in.) wide throat samples have their long axis parallel to the x-axis and half parallel to the y-axis as shown in Appendix B; Figure B1 - Bottle, Figure B2 - Bottle Sheet for 'layout' and the specimen geometry in Figure B3 - Specimen. The ends of the bottle can be removed with a pair of scissors by first carefully piercing the bottle just below the expanded neck, cutting around the bottle, cutting along the long seam parallel to the long axis of the bottle, and cutting off the base just 6 mm. (1/4 inch) above the base. Check the data sheet in Appendix C which designates the 6.25 mm (1/4 in.) wide throat samples with a "-", and the 12.5 mm (1/2 in.) wide throat samples with a "+"; and the long sample axis parallel to x-axis as "-", and parallel to y-axis as "+".

Once the layout is complete and the specimens have been located, (see Figure B2), use the correct template set and clamp the plastic between the template plates. Secure the template set with C-clamps. Next, with the utility knife gently scribe several times around the specimen until the template set with the plastic inside can be released from the bottle sheet. A template set can be made by contouring two 6.25 mm. (1/4 in.) thick steel plates to a 'dog-bone' shape following the American Society for Testing and Materials [4] specification Part 35 D638-80 type IV style. The type IV style will need to have a modified width for the 12.5 mm (1/2 in.) wide throat specimens. (Careful cutting could eliminate the use of the steel template set. However, extreme care must be exercised to <u>avoid</u> stray cuts into the throat area which can weaken the specimen.)

Step III: Label specimens as shown in Figure B3 to correspond with the run numbers in the Appendix C data table. Measure the thickness of each specimen in the vicinity of the middle of the throat area. Record the findings on the data sheet in the proper space. Check the variation in the thickness of the specimens. The thickness should be uniform across all specimens so that throat width is representative of specimen cross-section area.

Step IV: Evaluation of the specimens under load can now begin. Be sure you are working with someone who is familiar with the operation of a tensile test machine in position control so that a stretch rate of 50 mm/min.(2 inches/min.) can be set. Now run the first four specimens (numbers 1 -4) where the third factor, factor (c), of stretch (deformation) rate has been assigned a '-' in the data table. As these tests are run it is important to record on the data sheet in the proper column <u>the first maximum load reached</u> by each specimen. The <u>first maximum</u>

load reached is the highest load reading obtained usually within the first 12.5mm (half-inch) of deformation. Be sure to place the specimens in the tensile testing machine so that the numbers on the specimen ends are positioned the same way for each run so that after fracture the ends can be lined-up for comparison.

After the first four specimens have been tested, change the deformation rate to 500 mm/min. (20 inches/ min.) needed for the '+' value for the third factor. Be sure to record the first maximum load reached by each of these last four specimens. (An enhancement of the experiment is to obtain a recording of load against deformation for each tested specimen. If a scaled and labeled graph of load against deformation has been made during the test for each sample the first maximum load can be read from the graph.)

Step V-A: After the tensile tests are complete take a close look at the failed specimens. Align the specimens using the numbers on the bulb ends of each specimen (see Figure B3) and have all the top bulbs at the same level. The changes in elongation of each sample can be seen. Notice how the plastic 'curled up'! The wide throat specimens curled more than the narrow throat specimens. What can be said about the rate of stretch? How does the idea of the faster the stretching, the more brittle type failure and the lower the elongation express your observations? Express what you have discovered via a sketch and words.

Step V-B: Turn to the first maximum load held by each specimen recorded on the data sheet. A three factor, two level factorial Design Of Experiments procedure [5,6] is an efficient way to identify significant effects of the three factors of (a) specimen orientation, (b) cross-section area via throat width, and (c) stretch rate, and evaluate their interactions. The single, two, and three factor effect interactions can be assessed with the eight tests just completed.

To illustrate the Yates' Method a catapult intuitive outcome experiment influenced by three factors is shown in Appendix D. The three factors are: (a) thickness of elastic, (b) type of binding post cross-section, and (c) load on the elastic. Elastic stretch is measured to determine the impact of the three factor effects. Elastic thickness (a) and applied load (c) are found to be the major factors effects. There are no significant second and third order effects, and the cross-section of the binding post is unimportant. The same methodology is applied to the test results of the 2 liter, green PETE bottle with the three factor effects of: a) specimen orientation, b) cross-sectional area as given by the throat width and, c) rate of stretch, with your measurements of the first maximum load.

COMMENTS ON FINDINGS:

I. In the case of the green PETE bottle evaluated with the first maximum load; factor effects of specimen orientation and throat width were found to be significant based on a Yates' Method analysis and a normal probability paper plot. Significant failure features seen from the specimens are: 1) all specimens curled about the load application axis, 2) the wide throat specimens curled less at the low stretch rate and wound up tight at the high stretch rate, 3) total specimen elongation in the x-direction was minimal in contrast to the elongation of 25 mm (one inch) or more in the y-direction, and 4) all of the fracture surfaces appeared to be 'brittle' with glass-like conchoidal features.

II. For a series of specimens cut from a white, opaque, HDPE, 32 oz. Ricotta cheese container evaluated with the first maximum load, the effects of specimen width and loading rate were found to be significant in contrast to the other effects. However when evaluated with specimen elongation at fracture, all first, second and third order factor effects based on specimen orientation, throat width, and stretch rate appeared not to be significant based on a Yates' Method analysis and a normal probability paper plot. The specimens exhibited failure features as follows: 1) the specimens aligned with the x-axis tend to a) show necking and stringy fingers at the failure surface at the low stretch rate, and b) minimal necking with cleaner cleavage at the high stretch rate; 2) the samples oriented with the length of the container (y-axis) broke cleanly if the specimen elongated, and if the specimen did not elongate appreciably the fracture surface was fibrous.

III. You now have the opportunity to collect different recyclable containers, make test specimens, run tests and compare findings. Alternative methods to the Yates' algorithm which address the Design of Experiments are found in Lochner (7) and Roy (8), and may be of interest. Enjoy!

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APPENDIX A: Plastics Recycling Codes, Symbols, and Samples

Code	Symbol	and material/ sample containers
1	PETE	polyethylene terephthalate carbonated beverages, cooking oil, peanut butter, boil in bag foods
2	HDPE	high-density polyethylene milk, juice and water jugs; trash cans, laundry detergents, auto oil, dishwasher soaps
3	V or PVC	polyvinyl chloride transparent bottles, cooking oil, mouthwash, household cleaners
4	LDPE	low-density polyethylene plastic bags, garbage bags, sandwich bags, shrink wrap films, yogurt containers
5	PP	polypropylene food containers and lids, screw caps, tubs
6	PS	polystyrene brittle yogurt containers, sour cream, cottage cheese, table ware, plates, 'styrofoam' items
7	OTHER	multiresin and others not listed above: microwave packages, multilayer bottles

APPENDIX B: SPECIMEN PREPARATION

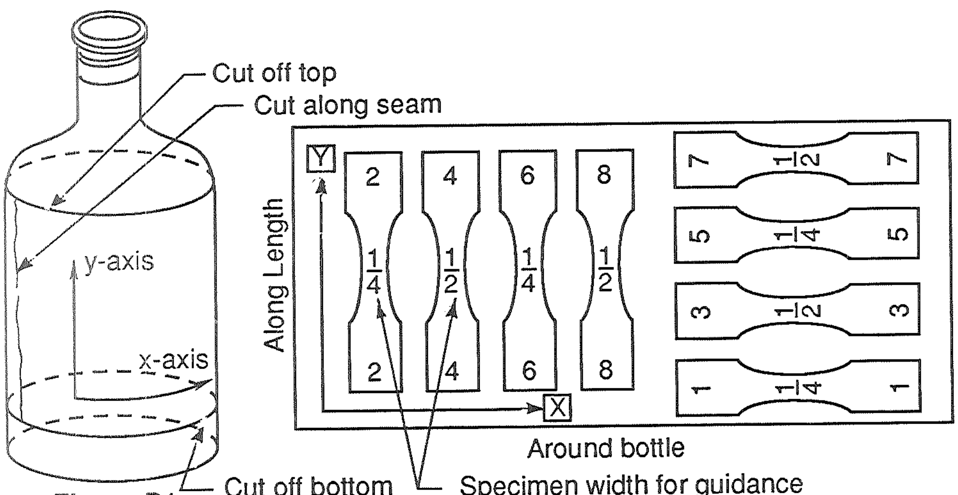

Figure B1

2-liter PETE bottle

Figure B2

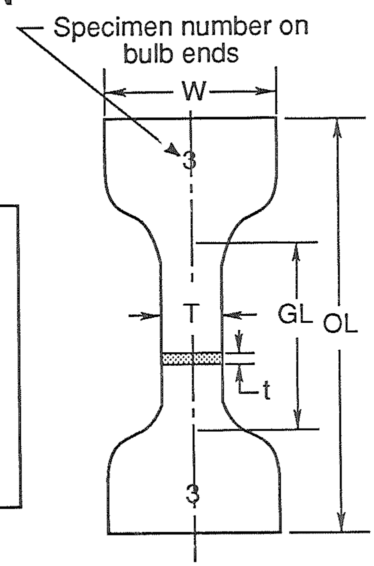

Figure B3

Specimen

W - width 25 mm (1 in.)
OL - overall length 125 mm (5 in.)
GL - gage length 25 mm (1 in.)
T - throat: thin 6.25 mm (1/4 in.)
wide 12.5 mm (1/2 in.)
t - thickness 0.5 mm (0.02 in.)

APPENDIX C: Specimen Data Sheet

Specimen Type ____________________ Team of Testers ___________

Source of Specimens ______________ ___________________________

Place of Testing _________________ Date of Test ______________

Temperature of Test Facility ____ Humidity in Test Facility ____

Factors[1] effects					Yates' Method[2]							
Run	a	b	c	Thick- ness in.	First Max. load lbs.	columns (1)	(2)	(3)	rank	PP	Factor effect	Comments
1	−	−	−								mean	
2	+	−	−								a	
3	−	+	−								b	
4	+	+	−								ab	
5	−	−	+								c	
6	+	−	+								ac	
7	−	+	+								bc	
8	+	+	+								abc	

[1]Factor effects:
(a) sample orientation: '−' means along x-axis
'+' means along y-axis

(b) throat width: 6.25 mm (1/4 in) is '−'
12.50 mm (1/2 in) is '+'

(c) stretch rate: '−' is for 50 mm/sec (2 in/min)
'+' is for 500 mm/sec (20 in/min)

[2]See Appendix D for explanation

APPENDIX D: Catapult Exercise

Three factors impacting the operation of a catapult product delivery device are considered for a three factor, two level, factorial Design of Experiments exercise using Yates' Method. The three factors, each with two levels '-' and '+', are: factor (a): same length elastic band widths (thin and wide), factor (b): major support post cross-section (round and square), and factor (c): applied load (12 oz. and 24 oz.). A sketch of the catapult is shown in Figure D1.

Eight runs are made as delineated in data Table D1, below. The elongation of the rubber band under load is measured. The factors are listed in Table D1 and the application of the Yates' Method is explained below Table D1. The column labeled rank is the sequence of column (3) ranked in order from high to low value while PP refers to plot position for the Normal Probability paper plot and is given by 100 times the ratio of rank minus one-half, divided by seven. The last column in the table relates the factor effect to the value in column (3). On Normal Probability paper you can see graphically that the first and second ranked items are outstanding in contrast to the others which plot about zero. This observation provides for the result that the effect of the elastic band width (a) and the load applied (c) are the significant factors in the experiment, while the other effects are not considered as significant.

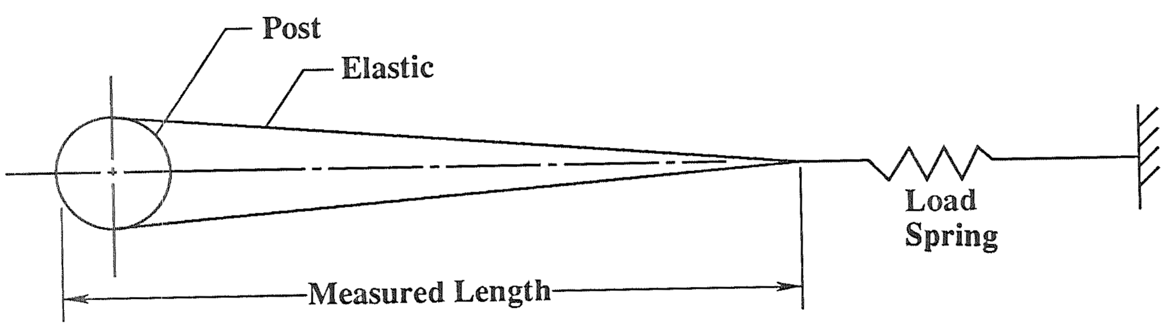

Figure D1 Catapult

Table D1 Data and Yates' Method for Catapult

	Factors[1]			Yates' Algorithm						
	a	b	c	Measured Length in.	columns[2] (1)	(2)	(3)	rank	PP[3]	Factor effect
1	-	-	-	5.375	17.375	36.375	100.00	-	---	mean
2	+	-	-	12.000	19.000	63.625	29.00	7	92.9	a
3	-	+	-	5.750	31.375	14.125	2.50	5	64.3	b
4	+	+	-	13.250	32.250	14.875	1.50	4	50.0	ab
5	-	-	+	12.125	6.625	1.625	27.25	6	78.6	c
6	+	-	+	19.250	7.500	0.875	0.75	3	35.5	ac
7	-	+	+	12.250	7.125	0.875	-0.75	1	7.1	bc
8	+	+	+	20.000	7.750	0.625	-0.25	2	21.4	abc

[1]Factor effects:

(a) elastic band width: '-' means thin No. 19 elastic
'+' means wide No. 33 elastic

(b) post cross-section: round post is '-'
square post is '+'

(c) load: '-' means 12 oz. load applied
'+' means 24 oz. load applied

[2]From the measured length column:
add 5.375 to 12.000 to get 17.375, the 1st entry
add 5.750 to 13.250 to get 19.000, the 2nd entry
add 12.125 to 19.250 to get 31.375, the 3rd entry
add 12.250 to 20.000 to get 32.250, the 4th entry
subtract from 12.000, 5.375 to find 6.625, the 5th entry
subtract from 13.250, 5.750 to find 7.500, the 6th entry
subtract from 19.250, 12.125 to find 7.125, the 7th entry and
subtract from 20.000, 12.250 to find 7.750, the 8th entry
to complete column (1). Next, use column (1) as data and compute column (2). Repeat the process for column (3) with data in column (2). The column (3) values are used to assess the factor effects for this two level, three factor, factorial design.

[3]PP or Plot Position for row 4 with the rank of 4 is 100 times rank minus one-half (4 - 0.5 = 3.5) divided by 7 to get 50.0 percent.