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#15 Elastomers: The Best Bungee Cord

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I. INTRODUCTION

Description

Students will determine the strength of a single rubber band, the strength of two rubber bands working in parallel, and the strength of three rubber bands working in parallel. A simple tensile strength testing apparatus will be set up using 2 L containers, string, and a sturdy ring stand. The students will use this apparatus to determine the tensile strength, percent elongation, and plot stress vs strain graphs for each experiment. The students will design a small bungee cord, giving a rationale for the design. After submitting their design, the students will take a bungee cord apart and see how their design compares to the bungee cords on the market today.

<u>Student Audience</u>

This investigation is intended for chemical technology students or undergraduate chemistry students.

Goals for the Experiment

<u>In this exercise the students will:</u>

- determine the percent that the original length of a material can be stretched without breaking (percent elongation),
- determine the tensile strength of a single rubber band, two rubber bands in parallel, and three rubber bands in parallel,
- make a plot of stress vs strain for each of the experiments,
- describe creep and how it occurs, and
- design a bungee cord.

Recommended Placement in the Curriculum

This lab would be best implemented during a section on elastomeric polymers. It should occur after the basic types of polymers have been introduced.

II. STUDENT HANDOUT

Elastomers: The Best Bungee Cord

Scenario

You work for a company that is involved in the manufacturing of bungee cords. The company currently manufactures bungee cords that are composed of several links of paired rubber bands. The company feels that it would be more cost effective to change the design so that single rubber bands are linked together instead of pairs. They have also considered combining three rubber bands together to get more strength. You have been given the responsibility to determine if this is indeed a good move for the company.

Safety, Handling, and Disposal

Everyone is required to have safety goggles on at all times. If the rubber band breaks it could snap back or be projected in any direction.

Materials

Per group

- 6 identical rubber bands (3 mm wide)
- heavy string
- a pair of 2-L soda pop bottles
- ring stand, large and heavy
- test tube clamp
- graduated cylinders, 50- and/or 100-mL
- large plastic basin or bucket
- water
- bungee cord

Procedure

CAUTION: All involved in the experiment should have safety goggles on at all times. The rubber band will snap back at failure.

1. Tie each end of a 25–30 cm piece of heavy string around the top of an empty 2-liter bottle.
2. Weigh the two bottles and string on a balance and record the combined mass.
3. Take a rubber band and draw a line across its width. Measure the width of the rubber band.
4. Starting at the line you just drew, continue 2 cm up along the length of the rubber band, and draw a second line across the width of the rubber band. You should now have two lines the width of the rubber band which are 2 cm apart. Record the distance between the two lines as the length of the rubber band.
5. Lay the rubber band on the table. Lay the string across the width of the rubber band. Fold the rubber band in half and then loop the rubber band through itself. This will knot the rubber band to the string. Make sure that the 2 lines you drew on the rubber band are halfway between the string and the top end of the rubberband.
6. Fasten the test tube clamp to the ring stand. Loop the rubberband over the test tube clamp. Your apparatus should now look similar to that shown in Figure 1.

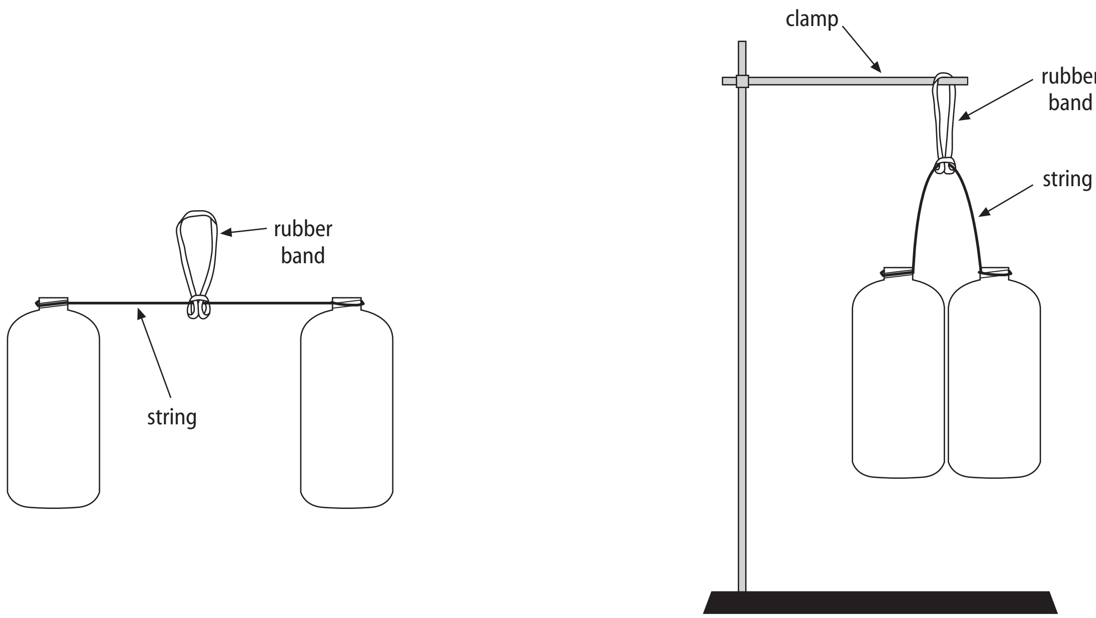


Figure 1 Experimental apparatus

7. Place a large basin or bucket under the apparatus so that when the rubber band fails, the water-filled bottles will fall into the container.
8. Using a graduated cylinder add 50 mL of water to each 2-L bottle for a combined volume of 100 mL.
9. Record the mass pulling on the rubber band (mass of the two bottles, string, and 100 mL of water).
10. The rubber band will stretch and the two lines will become farther apart. Measure the distance between the two marks you made on the rubber band. Record this as the length.
11. Repeat Steps 8–10 (adding increments of 100 mL of water) until the rubber band fails (breaks).
12. Retrieve the broken rubber band and once again measure the distance between the two marks.
13. Repeat the procedure above using 2 rubber bands connected in parallel.
14. Repeat using 3 rubber bands connected in parallel.

Calculations

1. How much mass was needed to break the rubber band?
2. Calculate the force (in Newtons) necessary to break the rubber band. Remember F = ma or F = mg, where “m” is the mass in kg and “g” is gravity (9.8 m/s^2).
3. Determine the percent elongation by using the formula below:

$$\text{percent elongation} = \frac{l - l_0}{l_0} \times 100$$

4. Determine the ultimate tensile strength in N/m^2

$$\textit{ultimate tensile strength} = \frac{\textit{force required to break the rubber band (N)}}{\textit{cross sectional area of the rubber band } (m^2)}$$

5. Make a plot of stress vs strain.

$$\textit{stress} = \frac{\textit{force applied (N)}}{\textit{cross sectional area } (m^2)}$$

$$\textit{strain} = \frac{l - l_0}{l_0}$$

Questions

1. Which design produced the greatest percent elongation?
2. Which design had the greatest tensile strength.
3. Was the measured distance between marks on the rubber band the same after failure as it was at the beginning. Explain.
4. Write a paragraph explaining how you would design a 2-foot long bungee cord that could withstand between 2 and 3 kg of dead weight.
5. Ask your instructor to see a bungee cord purchased locally. You may want to cut the nylon lining off to examine how the rubber bands are attached to form the bungee cord. Explain how your design of the bungee cord compares to the store bought one.
6. What do you hypothesize would be the effect of extremes in temperature on the rubber band?
7. Name at least five other applications where the tensile strength of the material is important.

References

Carraher, C. E. Jr. *Polymer Chemistry, an Introduction, 4th Ed.*; Marcel Dekker, Inc. New York, 1996.

Rodriguez, F. *Principles of Polymer Systems, 2nd Ed.*; McGraw-Hill, 201-206.

Tock, R. Wm.; Dinivahi, M.V.R.N.; Chew, C.H. *Advances in Polymer Technology.* 1988, 8(3), 317-324.

Tock, R. Wm.; *Elastomers: The Materials That Stretch*, The Ohio Academy of Science, 1996, 83-85.

III. INSTRUCTOR NOTES

Elastomers: The Best Bungee Cord

Purpose

The purpose of this lab is to investigate the characteristics of a rubber band in terms of percent elongation, tensile strength, and elastic modulus.

Time Required

This lab will take 2-3 hours. It can be done more quickly if the single, double, and triple rubber bands are tested by different groups.

Group Size

Students can work in groups of 2-4 students.

Safety, Handling, and Disposal

Everyone is required to have safety goggles on at all times. If the rubber band breaks it could snap back or be projected in many directions.

Materials

Per group

- 6 rubber bands (3 mm wide)
- heavy string
- a pair of 2–L soda pop bottles
- ring stand, large and heavy
- test tube clamp
- graduated cylinders, 50- and/or 100-mL
- large plastic basin or bucket
- water
- bungee cord

Points to Cover in Pre-Lab

Elastomers should be discussed. The following terms should be reviewed or introduced. These definitions were taken from Carraher, but any polymer chemistry textbook will have them listed.

Tensile strength - a measure of the ability of a polymer to withstand pulling stresses.

Elastic modulus - the ratio of the applied stress to the strain it produces within the region where the relationship between stress and strain is linear.

Ultimate tensile strength - the force required to cause failure divided by the minimum cross-sectional area of the test sample.

Percent elongation - change in length divided by the original length of the specimen multiplied by 100%.

Creep - the irreversible elongation caused by the application of force over a specified time.

Procedural Tips and Suggestions

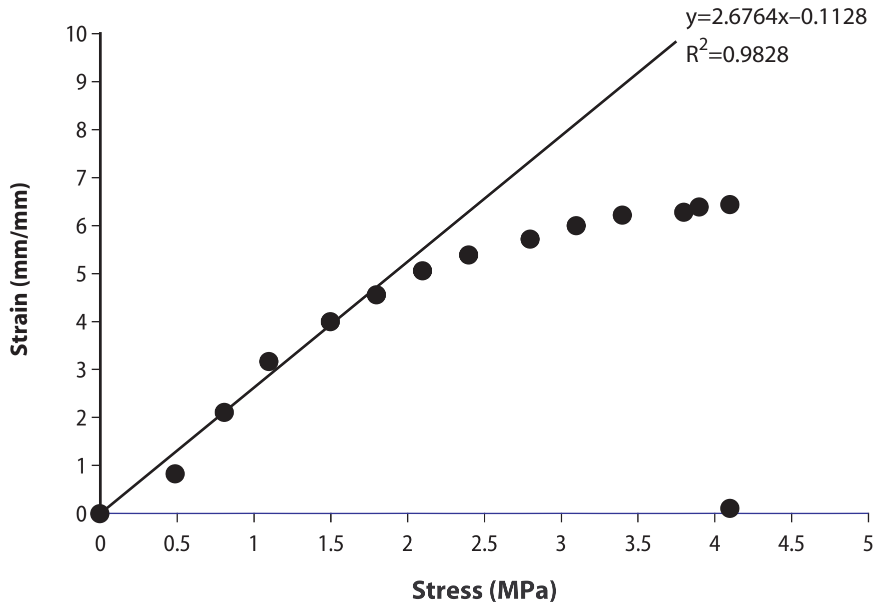
- The graphs can be done by using a computer program such as graphical analysis, or by using a spreadsheet such as Lotus 1-2-3.

Sample Results

The following graphs are for a single rubber band, two rubber bands connected in parallel, and three rubber bands connected in parallel.

One Rubber Band					
Cross Sectional Area	Mass (g)	Length (cm)	Stress (MPa)	Strain (mm/mm)	Strain (mm/mm)
0.030	0	1.80	0.00	0.00	
0.030	149	3.30	0.49	0.83	
0.030	249	5.60	0.81	2.11	
0.030	349	7.50	1.1	3.17	
0.030	449	9.00	1.5	4.00	
0.030	559	10.00	1.8	4.56	
0.030	649	10.90	2.1		5.06
0.030	749	11.50	2.4		5.39
0.030	849	12.10	2.8		5.72
0.030	949	12.60	3.1		6.00
0.030	1049	13.00	3.4		6.22
0.030	1149	13.10	3.8		6.28
0.030	1199	13.30	3.9		6.39
0.030	1249	13.40	4.1		6.44
0.030	1250	2.00	4.1		0.11

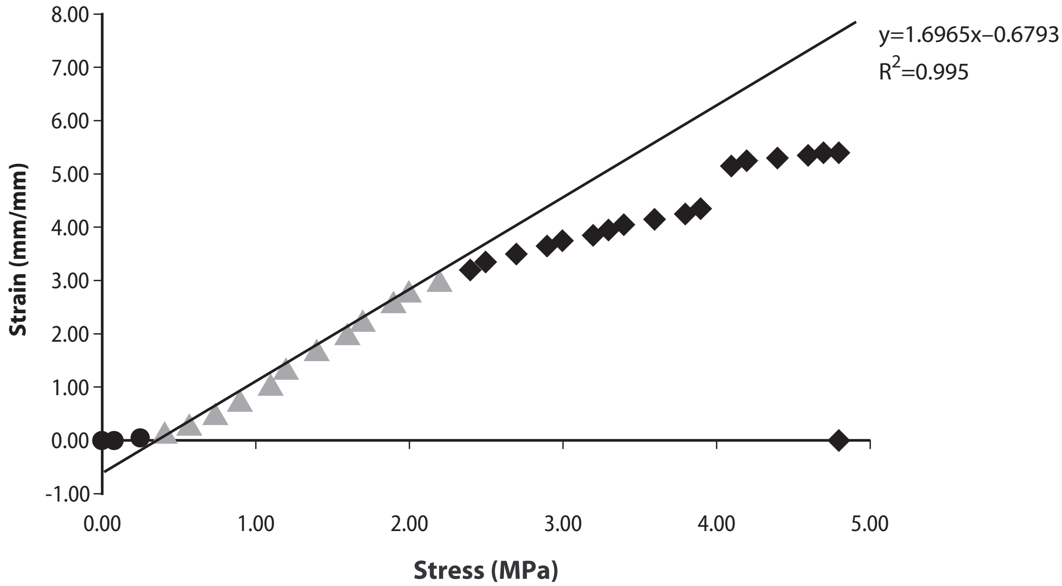
One Rubber Band



Percent Elongation	644%
Ultimate Tensile Strength	4.1 MPa
Elastic Modulus	2.7 MPa

Two Rubber Bands						
Cross Sectional Area (cm2)	Mass (g)	Length (cm)	Stress (MPa)	Strain (mm/mm)	Strain (mm/mm)	Strain (mm/mm)
0.060	0	2.00	0.00	0.00		
0.060	50	2.00	0.08	0.00		
0.060	150	2.10	0.25	0.05		
0.060	250	2.30	0.41		0.15	
0.060	350	2.60	0.57		0.30	
0.060	450	3.00	0.74		0.50	
0.060	550	3.50	0.90		0.75	
0.060	650	4.10	1.1		1.05	
0.060	750	4.70	1.2		1.35	
0.060	850	5.40	1.4		1.70	
0.060	950	6.00	1.6		2.00	
0.060	1050	6.50	1.7		2.25	
0.060	1150	7.20	1.9		2.60	
0.060	1250	7.60	2.0		2.80	
0.060	1350	8.00	2.2		3.00	
0.060	1450	8.40	2.4			3.20
0.060	1550	8.70	2.5			3.35
0.060	1650	9.00	2.7			3.50
0.060	1750	9.30	2.9			3.65
0.060	1850	9.50	3.0			3.75
0.060	1950	9.70	3.2			3.85
0.060	2050	9.90	3.3			3.95
0.060	2100	10.10	3.4			4.05
0.060	2200	10.30	3.6			4.15
0.060	2300	10.50	3.8			4.25
0.060	2400	10.70	3.9			4.35
0.060	2500	12.30	4.1			5.15
0.060	2600	12.50	4.2			5.25
0.060	2700	12.60	4.4			5.30
0.060	2800	12.70	4.6			5.35
0.060	2900	12.80	4.7			5.40
0.060	2949	12.80	4.8			5.40
0.060	2949	2.00	4.8			0.00

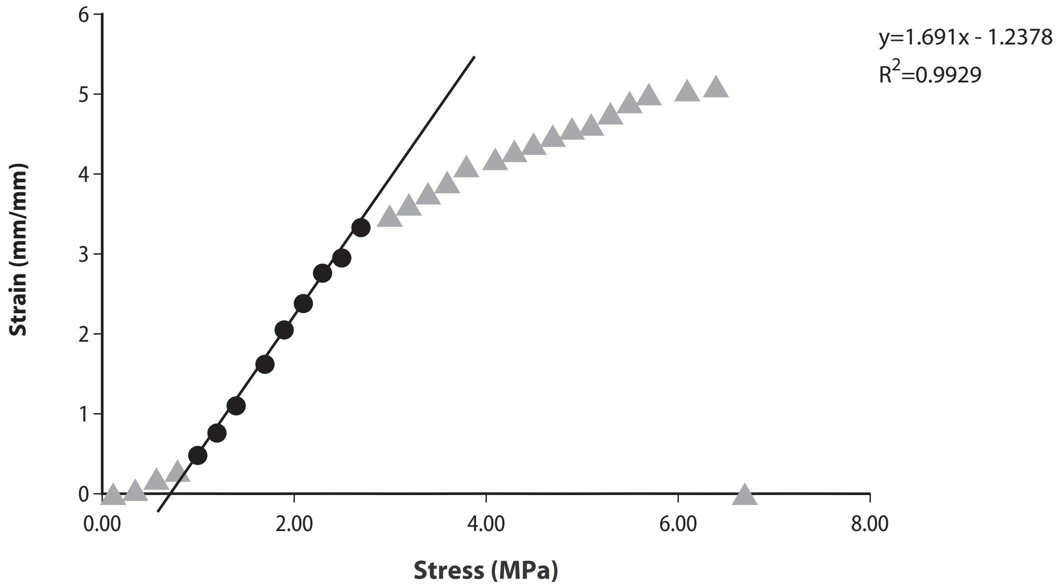
Two Rubber Bands



Percent Elongation	540%
Ultimate Tensile Strength	4..8 MPa
Elastic Modulus	1.7 MPa

Three Rubber Bands					
Cross Sectional Area (cm2)	Mass (g)	Length (cm)	Stress (MPa)	Strain (mm/mm)	Strain (mm/mm)
0.090	114	2.10	0.12		0.00
0.090	324	2.20	0.35		0.05
0.090	524	2.50	0.57		0.19
0.090	724	2.70	0.79		0.29
0.090	924	3.10	1.0	0.48	
0.090	1124	3.70	1.2	0.76	
0.090	1324	4.40	1.4	1.10	
0.090	1524	5.50	1.7	1.62	
0.090	1724	6.40	1.9	2.05	
0.090	1924	7.10	2.1	2.38	
0.090	2124	7.90	2.3	2.76	
0.090	2324	8.30	2.5	2.95	
0.090	2524	9.10	2.7	3.33	
0.090	2724	9.40	3.0		3.48
0.090	2924	9.70	3.2		3.62
0.090	3124	10.00	3.4		3.76
0.090	3324	10.30	3.6		3.90
0.090	3524	10.70	3.8		4.10
0.090	3724	10.90	4.1		4.19
0.090	3924	11.10	4.3		4.29
0.090	4124	11.30	4.5		4.38
0.090	4279	11.50	4.7		4.48
0.090	4479	11.70	4.9		4.57
0.090	4679	11.80	5.1		4.62
0.090	4879	12.10	5.3		4.76
0.090	5079	12.40	5.5		4.90
0.090	5279	12.60	5.7		5.00
0.090	5579	12.70	6.1		5.05
0.090	5879	12.80	6.4		5.10
0.090	6179	2.10	6.7		0.00

Three Rubber Bands



Percent Elongation	510%
Ultimate Tensile Strength	6.7 MPa
Elastic Modulus	1.7 MPa

Plausible Answers to Calculations

1. How much mass was needed to break the rubber band?

A: It took about 1.2 kg for the single rubber band.

2. Calculate the force (in Newtons) necessary to break the rubber band. Remember F=ma or F=mg, where the mass is in kg and g is gravity (9.8 m/s^2).

A: The force was about 12 Newtons for one rubber band.

3. Determine the percent elongation by using the formula below:

$$\textit{percent elongation} = \frac{l - l_0}{l_0} \times 100$$

A: 644%, 540%, and 510% respectively (they are all similar). They should be close to the same values because essentially all that was done for the 2 rubber band experiment was to take two rubber bands and put them side by side.

4. Determine the ultimate tensile strength in MPa ($N/m^2 \times 10^{-6}$).

$$\textit{ultimate tensile strength} = \frac{\textit{force required to break the rubber band (N)}}{\textit{cross sectional area of the rubber band } (m^2)}$$

A. 1 MPa, 4.8 MPa, 6.7 MPa (These should also be essentially equal but appear to increase slightly with more rubber bands.) The width of the rubber band is directly proportional to the force being applied. If the width is doubled (2 rubber bands), the force necessary to break the rubber band should also double.

5. Make a plot of stress vs strain.

$$\text{strain} = \frac{l - l_o}{l_o} \qquad \text{stress} = \frac{\text{force applied (N)}}{\text{cross} - \text{sectional area (m}^2\text{)}}$$

A: See the plots in Sample Results. The data tables were arranged so that the strain was split into multiple columns. This enables the student to make a trend line for the straight line portion of the graph, thus determining the elastic modulus (slope).

Plausible Answers to Questions

1. Which design produced the greatest percent elongation?

A: Answers may vary but in the sample they were all pretty much the same, with the single rubber band elongating slightly more than the others.

2. Which design had the greatest tensile strength.

A: In the sample, the three rubber band design had the greatest tensile strength but they should be close to the same.

3. Was the measured distance between marks on the rubber band the same after failure as it was at the beginning. Explain.

A: No. There was about a 5 mm increase in the length. This is due to creep. This is the point where the rubber band stretched, and the bonds slid past each other forming new bonds with other carbons down the polymer chain. The rubber band will never go back to its original length after this occurs.

4. Write a paragraph explaining how you would design a 2-foot long bungee cord that could withstand between 2 and 3 kg of dead weight.

A: Answers will vary but should be in line with the student's data.

5. Ask your instructor to see a bungee cord purchased locally. You may want to cut the nylon lining off to examine how the rubber bands are attached to form the bungee cord. Explain how your design of the bungee cord compares to the store bought one.

A: Answers will vary.

6. What do you hypothesize would be the effect of extremes in temperature on the rubber band?

A: At very low temperatures, the rubber band will lose flexibility and thus break much more easily. The rubber band will melt at very high temperatures. Creep would increase as the temperature increases.

7. Name at least five other applications where the tensile strength of the material is important.

A: The answers here will vary. They might include, for example, grocery and trash bags, "rubber" gloves, hydraulic and pneumatic seals, elastic and other stretchable fabrics, fishing line, climbing rope, etc.

Extensions and Variations

1. The students could test the materials to determine how many times each material can be repeatedly stretched over a short distance and still return immediately to its original dimensions.

2. The students could test other elastomeric materials such as saran wrap, pipe thread tape, and baggies.
3. If a tensile testing machine is available, the students can use it and compare their results to those obtained using the above procedure.

Resources for Materials:

The ring stand, test tube clamp, and graduated cylinders can be purchased at any science supply store. The 2-liter bottles can be brought in by students. The heavy string, rubber bands, and bungee cord can be purchased at your local hardware or discount store.

References:

Carraher, C. E. Jr. *Polymer Chemistry, an Introduction, 4th Ed.*; Marcel Dekker, Inc. New York, 1996.

Rodriguez, F. *Principles of Polymer Systems, 2nd Ed.*; McGraw-Hill, 201-206.

Tock, R. Wm.; Dinivahi, M.V.R.N.; Chew, C.H. *Advances in Polymer Technology.* 1988, 8(3), 317-324.

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