

TEACHER INSTRUCTIONS

How Strong is Your Chocolate?

Objective: To demonstrate how material properties, such as microstructure, can influence the strength of a material.

Background Information: Materials such as *metals* (aluminum, iron, copper, etc.), *ceramics* (porcelain, silicon carbide, etc.) and *polymers* (milk jugs made of polyethylene) are tested by scientists and engineers to reveal the material's mechanical properties. There are a range of mechanical tests that can be performed depending on the needed application of a material. One type of mechanical testing is strength testing. Strength is a measurement of the maximum stress that a material can withstand. Stress is the force applied per the unit area (usually the cross-sectional area perpendicular to the force being applied). Using this metric, an engineer can determine the strength of any object, from a tiny bobby pin to a gigantic beam for a skyscraper. Many of the materials that we see every day are subjected to a variety of stresses and must be designed to provide a certain measure of strength. For example, a concrete bridge must have enough strength to withstand vehicles driving on it day after day.

It is necessary to understand how materials respond to stresses so that the correct material can be chosen for a specific application. A material's atomic structure, the type and way that atoms are bonded to one another into different arrangements, is a major factor that influences the strength of a material. However, two materials that share all of the same atomic traits can still have different strengths if their microstructure is altered due to processing. The chocolate bars in this lab are an excellent example of how microstructure can be altered due to processing. The chocolate in all of the bars has the same atomic traits (milk chocolate), however the microstructures differ (e.g., almonds in the bar, crisped rice in the bar, etc.). See the Introductory PowerPoint Presentation for examples of how material properties can influence the strength of a material in real-world applications.

Lab Description: In this lab, different types of chocolate bars will be tested to demonstrate the influence of different microstructures on the flexural strength (i.e., stress) of the chocolate bar. The flexural strength of the chocolate bars will be measured using a conventional 3-point bending test set-up as shown in Figure 1.

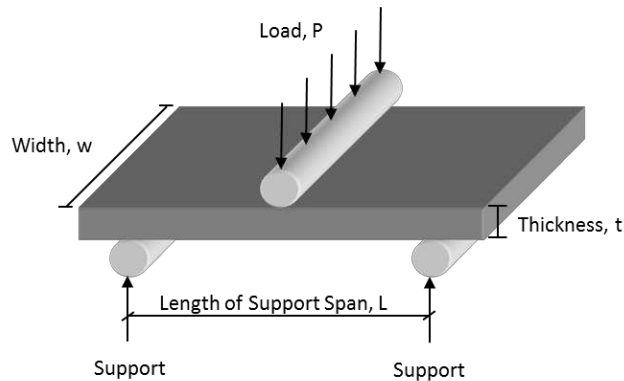


Figure 1. Test set-up for a 3-point bending test

For this test set-up, chocolate bars are placed on two supports (making two points of contact), and a force is applied to the center of the bar (making the 3rd point of contact in the 3-point bending test). The flexural strength of the bar is essentially the highest stress that the material experiences during its moment of rupture (failure) and can be calculated from the following equation:

$$\sigma = \frac{1.5PL}{wt^2}$$

where σ is the flexural strength (MPa), P is the applied force (N), L is the span length (mm), w is the width of the bar (mm), and t is the thickness of the bar (mm).

Keywords:

- mechanical properties – the description of how a material behaves in response to applied forces.
- stress – the force applied per unit area.
- 3-point bending test – a standard test used to measure the flexural strength of a material.
- microstructure – the structure of a material as observed through microscopic examination.

Materials List:

Items provided in the kit

- 5 plastic cups with twine
- 1 mass balance

Items to be purchased/provided by the teacher

- pennies – each group will need approximately 350 pennies. Alternative mass objects, such as rice, buttons, or beans, can also be used to load the chocolate bars.
- five protective mats to catch the chocolate when it falls (aluminum foil, saran wrap, etc.) – one for each group
- five rulers – one for each group

- five milk chocolate bars – one for each group
- five milk chocolate bars with almonds – one for each group
- five milk chocolate bars with crisped rice – one for each group

NOTE: try to purchase chocolate bars of approximately the same thickness.

Safety Precautions: This lab does not require any safety apparel, although standard lab rules and procedures (e.g. using the items as described in the handout, not for any other purposes) should be followed.

Instructions:

1. Measure and record the following information about the chocolate bar:
 - a. type (milk chocolate, almond, crisped rice, etc.)
 - b. width of the bar (mm), w
 - c. thickness of the bar (mm), t
2. For each type of chocolate bar, ask the students to make a prediction of how many pennies they think the chocolate bar can hold.
3. Position two desks so that the chocolate bar can span across the space between the desks. Approximately $\frac{1}{2}$ inch of the chocolate bar should be touching each desk.
4. Measure and record the length of the chocolate bar that is not supported by the desks. This is called the length of the support span, L .
5. Place the twine with the cup attached across the middle of the chocolate bar so that the cup hangs freely below the chocolate bar as shown in Figure 2.

Note: If the chocolate bar is “scored” (indents in the chocolate which make it easier to break into pieces), and the string is centered in the score as shown in Figure 2, the bar will be less strong than a bar of equal size that does not have score lines (e.g., a Crunch[®] bar). While it would be best to be consistent (either have all the bars with score lines or no score lines at all), this can be difficult to find at times in a local grocery store. It is ok to run this lab with a combination of chocolate bars with/without scores, but the point should be made to the students that this may cause some differences in the bar’s strength that has nothing to do with changes in the microstructure, but rather a difference in geometry. This is part of the reason why this lab utilizes the calculation of flexural strength rather than just comparing the chocolate bars based on the number of pennies in the cup at failure. The flexural strength calculation attempts to account for the geometry of the bar during the loading process. If the bar contains score lines, you can have students measure the thickness of the bar at a score line and away from the score line. Use each set of dimensions to calculate the flexural strength of the bar and compare the two values. The actual flexural strength of the bar is most likely an average of these values.

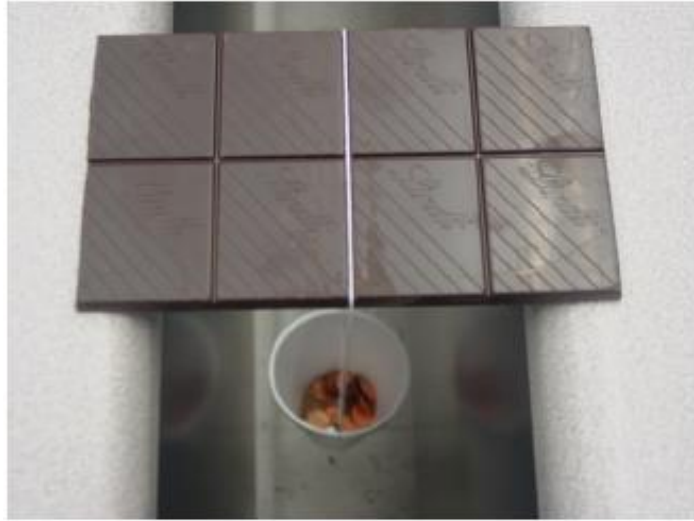


Figure 2. Chocolate bar subjected to a 3-point bending test

6. Place a mat on the floor to protect the chocolate when it falls. Plastic wrap, aluminum foil, or a Tupperware container work well for containing the chocolate and any pennies that might spill out of the cup when the chocolate bar falls.
7. Create a paper funnel by rolling a piece of paper and either stapling or taping it.
8. Using the funnel, start placing the pennies into the cup, one at a time. The pennies should be funneled in at a steady pace, ensuring that each penny lands in the cup before the next penny enters the cup (a pace of two to three pennies per second is good). Try funneling the pennies in a way that they do not fall a large distance when they enter the cup.
9. Continue placing pennies into the cup at a steady rate until the chocolate bar fractures. Be sure to note any deflections or bending of the chocolate bar during the loading process.
Note: If it is difficult to see the bar start to deflect, place the ruler across the desk just to the side of the chocolate bar to help indicate when the bar starts to deflect from a horizontal line.
10. Record the number of pennies in the cup at the time of fracture.
11. Look at the fracture surface and record any observations.
12. Find the mass (in grams) of the cup, twine, and the pennies in the cup at fracture using the mass balance. The force, P , applied to the chocolate bar can then be calculated as follows:

$$P = (\text{weight of cup, twine, and pennies}) * (\text{acceleration due to gravity} = 9.81 \text{ m/s}^2)$$

If you do not have access to a mass balance, use the following weights to approximate the mass.

- a. Weight of one penny – 2.35 grams
- b. Weight of the cup and twine – 25 grams

The force, P , applied to the chocolate bar can then be calculated as follows:

$$P = ((\text{weight of penny}) * (\# \text{ of pennies}) + \text{weight of cup and twine}) * (\text{gravity} = 9.81 \text{m/s}^2)$$

13. Use the force, P , found in step 12 to calculate the flexural strength of the chocolate bar. The formula for calculating flexural strength is found in the Description section of these instructions.
14. Repeat steps 1 - 13 for each chocolate bar to be tested.
15. Have students discuss any differences in the strength of the chocolate bars. Example questions can be found in the Student Questions Handout.

Lab Delivery Hints:

1. This lab is best done in groups of three to four students. One student should be responsible for taking the dimensions of the bar. Another student should be responsible for funneling the pennies into the cup, and one to two students should monitor any changes in the chocolate bar during the loading process. These responsibilities should be rotated as different chocolate bars are tested.
2. Chocolate can get expensive for this lab. Be creative with how you purchase and use the chocolate! For example, the 6-pack of regular size Hershey's[®] bars is often sold for almost half of what six bars would cost individually. In addition, the regular size bars can often be broken in half so that you get two tests out of each bar. That is the main reason that this lesson uses flexural strength (which takes geometry of the bar being tested into account) – it allows you the flexibility to use different size bars! Feel free to experiment with snack size or mini-size bars as well. These can often be purchased in a multi-pack which tend to include crisped rice bars, almond (or peanut) bars, and milk chocolate bars. You may even have enough left over from a multi-pack of small bars to use them as rewards later in the semester.

Troubleshooting: This lab is easy to set-up and run. It may take students a few tries to figure out how to funnel the pennies into the cup at a consistent rate. You can have the students practice funneling using a ruler in place of the chocolate bar. This will allow them plenty of time to get comfortable with their technique since the ruler would require a much heavier load to break.

Cleanup/Replacement Parts: Eat the chocolate! Clean any chocolate residue from the cup and twine with a wet paper towel and return it to the kit for later use. The chocolate bars will need to be replaced before the lab can be performed again. It is best to use fresh chocolate that has not been subjected to extreme hot or cold temperatures. Exposing the chocolate to extreme temperatures may change the strength of the bar and can cause a lot of variability in the measurements from group to group.

TEACHER DISCUSSION QUESTIONS

How Strong is Your Chocolate?

Discussion Questions to Ask Before the Lab

1. Ask students what type of materials they think that scientists and engineers test for mechanical properties.

Discussion: Emphasize that scientists and engineers look at many different types of materials such as metals, ceramics, and polymers.

2. Ask students what type of testing they think that scientists and engineers perform to determine material mechanical properties.

Discussion: Emphasize that there are a range of mechanical tests that can be performed depending on the needed application of a material. One type of mechanical testing is strength testing. Strength is a measurement of the maximum stress that a material can withstand before breaking. Common mechanical testing for strength includes compression, tension, and flexural (bending) testing. See the introductory PowerPoint presentation on the flash drive in the kit for examples of various mechanical testing methods. Many of the materials that we see every day are subjected to a variety of stresses and must be designed to provide a certain measure of strength. It is necessary to understand how these materials respond to mechanical stresses so that the correct material can be chosen for a specific application. The atomic structure of a material is a major factor that influences the strength of a material and involves the elements in the material – the way they are bonded to each other and the way the atoms are arranged to make different structures. However, two materials that share all of the same atomic traits can still have different strengths if their microstructure is altered due to processing. The chocolate bars in this lab are an excellent example of how microstructure can be altered due to processing. The chocolate in all of the bars has the same elemental make-up and atomic traits (all of the bars are milk chocolate), however the microstructures differ (e.g., almonds in the bar, crisped rice in the bar, etc.). It is important to understand how these changes in the microstructure can affect the strength of the chocolate bar.

3. Ask students why it is important for scientists and engineers to understand the mechanical properties of different materials.

Discussion: Show the video of the I-35W Mississippi River Bridge collapse in 2007. This video is available on the Wikipedia website as well as a number of other websites (<http://en.wikipedia.org/wiki/File:35wBridgecollapse.gif>). The I-35W bridge collapsed during rush hour in August 2007, killing 13 people and injuring 145.

(NOTE: The bridge collapse video was captured by a security camera that was located just to the side and below the bridge, therefore the video does not show any people. It is difficult to even see the vehicles on the bridge during collapse. However, this collapse did result in fatalities and multiple injuries. It is at the teacher's discretion whether to show the video and discuss that fatalities did occur. For younger students, this information can be "glossed" over and the point can still be made that the bridge collapsed due to loading issues).

The reason for the collapse was attributed to a design flaw coupled with additional weight, or load, on the bridge at the time of collapse. The design flaw led to the bridge being under-designed (should have used larger steel members) for the loads it would normally be carrying. In the weeks prior to collapse, construction was being done on half of the bridge. At the time of collapse, **575,000 pounds** of construction equipment and supplies were on the bridge in addition to the typical vehicle traffic expected during rush hour. This, coupled with the design flaw, led to a catastrophic failure of the bridge. It is important for scientists and engineers to understand the mechanical properties of different materials so that they can make sure that the materials are being used in an appropriate way.

4. Give students a brief description of what will be done during the lab. Ask each student to make a prediction about the number of pennies they think that each type chocolate bar can withstand.

Discussion: Encourage each student to choose a different number for each type of chocolate bar and explain why they chose that number. There is no right or wrong answer to this question – the point is to get the students thinking about how the bars are different and to make a prediction about the behavior of each bar.

Discussion Questions to Ask During the Lab







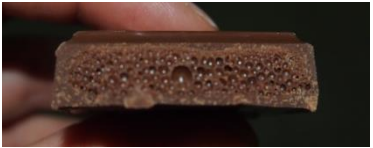

1. As each chocolate bar is tested, ask students what they noticed about the bar during the loading process. Did it sag before breaking? Did it stretch at all? Have them record their observations on the data sheet included in the Student Lab Handout.









Discussion: Students should be able to see the chocolate start to sag, or deflect, before it breaks. Have them place the ruler across the desks just to the side of the chocolate bar to help them check whether the chocolate bar has deflected.

2. After each bar is tested, ask students what they think about the performance of that particular bar. Were there any differences between the bar they just tested and the previous bars they have tested? If yes, what do they think is the cause of this difference?

Discussion: Have students test the milk chocolate bar first. This is the ‘control’ bar as nothing has been done to change the microstructure, and should be what the students use as a comparison to other chocolate bars. For the chocolate bar with almonds, the inclusion of almonds will tend to act like large defects. The almond is very strong compared to the chocolate bar, but it is also very dense and non-porous. This makes it difficult for the chocolate to achieve a strong bond with the almond. In addition, almonds are fairly large in diameter compared to the thickness of a typical chocolate bar. If the bond is already weak between the almond and chocolate bar, and this bond runs the entire thickness of the chocolate bar (meaning you can see the almond sticking out on both sides of the chocolate bar), it will influence the strength in a negative way. Depending on how close an almond is to the point of loading and the points of support, this chocolate bar should fail at a lower load (number of pennies) than the milk chocolate bar due to the failure of the bond between the almond and the chocolate. There will probably be a high variability in the max load that each group finds for the almond bar due to the fact that the almonds are spread randomly throughout the bar. In contrast, the inclusion of crisped rice in the chocolate bar is much more uniform. Crisped rice is also a very low density, high porosity material, meaning that the chocolate will tend to fill the pores of the crisped rice. This allows for a much better bond to be formed between the rice and chocolate. In addition, crisped rice is fairly small in comparison to the thickness of a chocolate bar which means that the chocolate will be spread more uniformly around the crisped rice and should allow for good load transfer across the bar. This bar typically performs the same as or better than the milk chocolate bar, and the max load that each group finds for the bar with crisped rice will probably be more consistent than for the bar with almonds. A material’s microstructure can be processed by using an additive (the crisped rice or almonds in our example), or by simply causing changes in the original microstructure (such as adding air voids or using heat treatment to produce different chemical compounds within a microstructure). Depending on the type of processing performed, the new microstructure may have properties that are different from the original microstructure. In some cases, these properties will be better, but in some cases the properties will be the same or worse than the original material. For example, in the case of adding an additive such as crisped rice to milk chocolate, perhaps this material is cheaper and substituting a percentage of the milk chocolate with crisped rice provides cost savings to the manufacturer. This allows the manufacturer to not only provide a chocolate bar that tastes different from the original and provides similar or better mechanical properties (meaning it won’t easily break into pieces during shipping and

transportation), but might also provide more profit for the company as most chocolate bars are sold at similar prices. In many real-world applications, such as adding fiber reinforcement to concrete (see the Engineered Concrete lesson for a discussion of this topic), processing of the microstructure can yield a much stronger material. In the case of processing the original microstructure, perhaps it is difficult for the manufacturer to maintain a 'pure' microstructure, so knowing that a certain percentage of change is still ok in terms of the desired material properties would allow the manufacturer to produce the material more easily. Table 1 provides a summary of the behavior of various types of milk chocolate bars. Teachers are encouraged to supplement the instructions with other types of bars to help students understand that additives/processing can cause the bar to behave differently and that it is important to understand this influence on a material's behavior so that the material can be properly designed for a given application.

Crunch® Bar	Crisped rice added	<p style="text-align: center;">Wrapper</p>  <p style="text-align: center;">Front</p>  <p style="text-align: center;">Cross-section</p>  <p style="text-align: center;">Back</p> 	95 x 42 x 8	296 (38.2 MPa)
Hershey's® Air Delight	Air bubbles added	<p style="text-align: center;">Wrapper</p>  <p style="text-align: center;">Front</p>  <p style="text-align: center;">Cross-section</p>  <p style="text-align: center;">Back</p> 	95 x 39 x 10	256 (22.9 MPa)

<p>Mr. Goodbar®</p>	<p>Peanuts added</p>	<p>Wrapper</p>  <p>Front</p>  <p>Cross-section</p>  <p>Back</p> 	<p>95 x 43 x 8</p>	<p>103 (13.8 MPa)</p>
<p>Butterfinger® Bar</p>	<p>Butterfinger pieces added</p>	<p>Wrapper</p>  <p>Front</p>  <p>Cross-section</p>  <p>Back</p> 	<p>72 x 42 x 7</p>	<p>51 (7.6 MPa)</p>
<p>*Dimensions refer to the dimensions of the bar tested. In some cases, an extra-large bar was the cheapest bar to purchase. This large bar was split into smaller pieces and tested in the 3-point bending test. **L refers to the unsupported length during the test as defined in the Lab Description section of the Teacher Instructions</p>				

Discussion Questions to Ask After the Lab

1. At the end of the lab, ask students to compare all of the chocolate bars that they tested. Have them state reasons for any differences in the flexural strength of the bars tested and why they think those differences occurred. Encourage discussion among the groups. Did everyone see the same thing? Did bars of the same type perform differently for different groups?

Discussion: Should be the same as what was discussed in questions 5 and 6, but have the students actually write down their reasoning in the Student Questions Handout and discuss what the other groups found as well.

2. Have students determine the average number of pennies that each type of bar withstood and compare it to their guess.

Discussion: For example, if the number of pennies recorded by 3 groups for the milk chocolate bar was 234, 358, and 279, have students calculate the class average using the following formula:

$$average = \frac{\text{sum of all measurements}}{\# \text{ of measurements}} = \frac{234 + 358 + 279}{3} = 290.33 = 290 \text{ pennies}$$

For each type of bar, determine which student guessed closest to the class average. Offer a prize, such as an additional chocolate bar, to the student that had the best guess for each type of chocolate bar.

3. For older students, also have them calculate the standard deviation of the class averages found in Question 8 and compare the bars in terms of standard deviations.

Discussion: For the same measurements of 234, 358, and 279, the standard deviation can be calculated as follows:

$$\text{standard deviation} = \sqrt{\frac{\sum_{i=1}^N (x_i - \text{average})^2}{N}}$$

where N is the number of measurements and x_i are the individual measurement values. The calculated standard deviation for this example is:

$$\text{st.dev.} = \sqrt{\frac{(234 - 290.33)^2 + (358 - 290.33)^2 + (279 - 290.33)^2}{3}} = 50.80$$

The higher the standard deviation, the greater the spread (or variability) in the data.

Have students compare the standard deviations of the chocolate bars that were tested. Alternatively, if computers are available, have the students plot the class data for each bar in an application such as Excel and add trend lines to examine the variability of the data. This provides a visual representation of the information provided by the standard deviation.

Bars that are heterogeneous, like the bar with almonds, will tend to have higher standard deviations. Since the almonds are scattered randomly throughout the bar, the number of pennies that the bar can hold will vary. Due to bonding issues between the almond and the chocolate, an almond near the location of the twine holding the cup or one of the supports will create a weak point quicker than if the almond is far away from the load contact points. Since the location of the almonds in each bar is different, the test result will be different as well.

STUDENT LAB HANDOUT

How Strong is Your Chocolate?

Introduction: Materials such as *metals* (aluminum, iron, copper, etc.), *ceramics* (porcelain, silicon carbide, etc.) and *polymers* (milk jugs made of polyethylene) are tested by scientists and engineers to reveal the material's mechanical properties. One type of mechanical testing is strength testing. Strength is a measurement of the maximum stress that a material can withstand. Many of the materials that we see every day are subjected to a variety of stresses and must be designed to provide a certain measure of strength.

The atomic structure of a material is a major factor that influences the strength of a material and involves the elements in the material – the way they are bonded to each other and the way the atoms are arranged to make different structures. However, two materials that share all of the same atomic traits can still have different strengths if their microstructure is altered due to processing. The chocolate bars in this lab are an excellent example of how microstructure can be altered due to processing. The chocolate in all of the bars has the same elemental make-up and atomic traits. However, the microstructures differ due to things that have been added to the chocolate, such as almonds or crisped rice.

Lab Description: In this lab, different types of chocolate bars will be tested to examine the influence of different microstructures on the strength of the chocolate bar. The flexural strength of the chocolate bars will be measured using a conventional 3-point bending test set-up (see Figure 1). For this test set-up, chocolate bars are placed on two supports (making two points of contact), and a force is applied to the center of the bar (making the 3rd point of contact in a 3-point bending test).

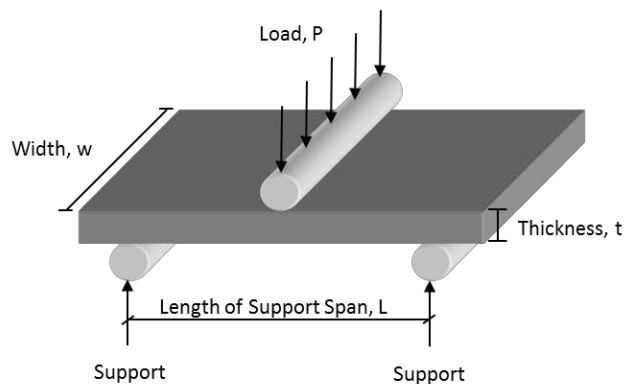


Figure 1. Test set-up for a 3-point bending test

Keywords: Mechanical properties, stress, 3-point bending test, microstructure

Materials List:

- protective mat (aluminum foil, saran wrap, etc.)
- tape or stapler
- plastic cup with twine attached
- mass balance
- pennies
- milk chocolate bar, milk chocolate bar with almonds, and milk chocolate bar with crisped rice

Safety Precautions: This lab does not require any safety apparel. However, standard lab rules and procedures (only using the equipment as indicated in the instructions) should be followed.

Instructions:

1. Measure and record on your data sheet the following information about the bar:
 - a. Type (milk chocolate, almond, crisped rice, etc.)
 - b. Width of the bar (mm), w
 - c. Thickness of the bar (mm), t
2. For each type of chocolate bar, make a prediction of how many pennies you think the chocolate bar can hold.
3. Position two desks so that the chocolate bar can span across the space between the desks. Approximately $\frac{1}{2}$ inch of the chocolate bar should be touching each desk.
4. Measure and record (in mm) on your data sheet the length of the chocolate bar that is not supported by the desks. This is called the length of the support span, L .
5. Place the twine with the cup attached across the middle of the chocolate bar so that the cup hangs freely below the chocolate bar as shown in Figure 2.

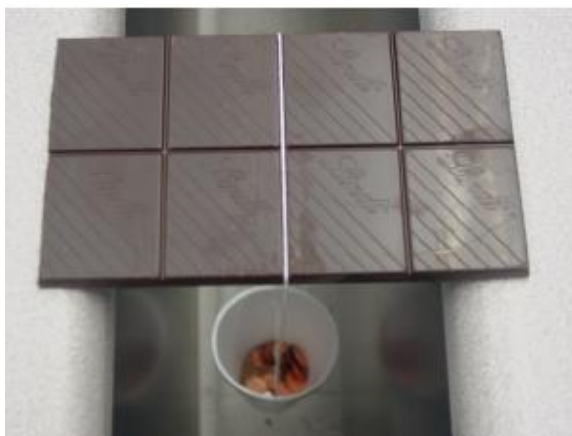


Figure 2. Chocolate bar subjected to a 3-point bending test

6. Place the protective mat on the floor to catch the chocolate when it falls.
7. Create a paper funnel by rolling a piece of paper and either stapling or taping it.
8. Using the funnel, start placing the pennies into the cup, one at a time. The pennies should be funneled in at a steady pace, ensuring that each penny lands in the cup before the next penny enters the cup (a pace of two to three pennies per second is good). Try funneling the pennies in a way that they do not fall a large distance when they enter the cup.
9. Continue placing pennies into the cup at a steady rate until the chocolate bar fractures. Be sure to note any deflections or bending of the chocolate bar during the loading process.
NOTE: If it is difficult to see the bar start to deflect, place the ruler across the desk just to the side of the chocolate bar to help indicate when the bar starts to deflect from a horizontal line.
10. Record the number of pennies in the cup at the time of fracture.
11. Look at the fracture surface and record any observations.
12. Find the mass (in grams) of the cup, string, and the pennies in the cup at fracture using a mass balance. The force, P , applied to the chocolate bar can then be calculated as follows:

$$P = (\text{weight of cup, twine, and pennies}) * (\text{acceleration due to gravity} = 9.81 \text{ m/s}^2)$$

If you do not have access to a mass balance, use the following weights to approximate the mass:

- a. Weight of one penny – 2.35 grams
- b. Weight of the cup and twine – 25 grams

The force, P , applied to the chocolate bar can then be calculated as follows:

$$P = ((\text{weight of penny}) * (\# \text{ of pennies}) + \text{weight of cup and twine}) * (\text{gravity} = 9.81 \text{ m/s}^2)$$

13. Use the force, P , found in step 12, to calculate the flexural strength of the chocolate bar. The formula for calculating flexural strength is:

$$\sigma = \frac{1.5PL}{wt^2}$$

where σ is the flexural strength (MPa), P is the applied force (N), L is the length of the support span (mm), w is the width of the bar (mm), and t is the thickness of the bar (mm).

14. Repeat steps 1 - 12 for each chocolate bar to be tested.
15. Complete the questions on the Student Question Handout.

Clean Up: Eat the chocolate! Clean any chocolate residue from the cup and twine with a wet paper towel and return the cup and twine to your teacher.

Data Sheet for a Chocolate Bar

Type of Bar	Penny Prediction	Width (w)	Thickness (t)	Length of Support Span (L)
Changes in the bar during the loading process:				
Number of pennies in the cup when the bar failed:				
Observations of the fracture surface:				
Weight of the cup/twine/pennies:				
Calculation of load, P:				
Calculation of the bar's flexural strength, σ:				

STUDENT QUESTION HANDOUT

How Strong is Your Chocolate?

1. Did you notice any changes in the chocolate bars during the loading process? Were these changes the same for all of the chocolate bars or different?
2. Which type of chocolate had the highest flexural strength? The lowest flexural strength?
3. Why do you think the bars had different strength values?
4. Which bar had the highest standard deviation for the number of pennies that it held? Which one had the lowest?
5. Why do you think that the standard deviations were different?