**Candy Engineering**

This lesson was developed by the American Ceramic Society (www.ceramics.org)

**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 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 3rdpoint 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:



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

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. a ruler

five milk chocolate bars–one plain milk chocolate, one milk chocolate with almonds, one milk chocolate 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 ½ 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.



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*= (weight of cup, twine, and pennies)\*(acceleration due to gravity = 9.81m/s2).

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*= ((weight of penny)\*(# of pennies) + weight of cup and twine)\*(gravity = 9.81m/s2)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.