**TEACHER DISCUSSION QUESTIONS**

**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. 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-35Wbridge 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, 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.

**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. For each type of bar, determine which student guessed closest to the class average.

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:* 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.