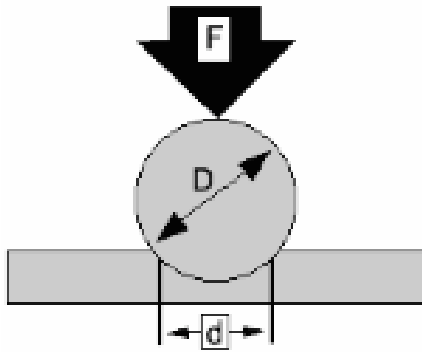


Name _____ Date _____ Period _____

Mechanical Properties of Chocolate- How Hard is Chocolate?

Background:

Hardness is probably a concept you are well familiar with. You already know that certain materials are harder than others; in fact, you demonstrate it everyday when you chew your food and your teeth don't brake (because your teeth are harder than the foods you chew). **Hardness** can be defined as a material's ability to resist a change in shape. In 1812, Friedrich Mohs came up with a way of ranking materials on a comparative scale- he simply took two different materials and observed which one scratched the other. Since then, a more quantitative measure of hardness has been developed. Modern hardness testers take a well-defined shape and press it into a material with a certain force and observing the indent left behind. Today, you will be performing hardness testing on different bars of chocolate.



While there are many types of indenter heads used in measuring hardness, a more common example is simply called a hard sphere. We will be able to mimic this indenter tip by using a marble.

You will be testing four types of chocolate bars:

- Hershey's Milk chocolate
- Hershey's Dark Chocolate
- Nestle's Crunch Bar
- Hershey's Mr. Goodbar

Equipment:

4 different Hershey's bars, for example:

- Regular milk chocolate (1.55 oz.)
- Dark chocolate (1.45 oz.)
- Hershey's Mr. Goodbar (1.75 oz.)
- Nestle's Crunch bar (1.55 oz.)

Roll of Pennies

Marbles (22 mm in diameter preferred)

Analytical Balance

Metric ruler

Tape

Blank sheet of standard paper

Hypothesis:

State a hypothesis ranking the candy bars from hardest to softest.

hardest- _____ -softest

Procedure:

Note: During the actual experiment procedures, be sure to record all observations (i.e. surface smoothness, any cracking in the chocolate after indent, etc.)

1. Measure the diameter of the marble and record it on the data sheet. You may wish to take several measurements and average them.
2. Tape the marble to the end of the roll of pennies. This will be referred to as your indenter.
3. Measure the mass of the indenter and record it on the data sheet.
4. Roll up a sheet of paper and tape it in place so it creates a hollow tube that would allow your indenter to fall through. This will serve to make sure the indenter will fall straight down onto the chocolate.
5. Unwrap one of the chocolate bars and set it on its wrapper face down (the flat end should be up while the letters/grooves are face down).



6. Measure the height of the rolled sheet of paper and record it on the data sheet. This height is important because it will be used to determine how fast the indenter falls, and thus how much force is being applied.
7. Place a sheet of paper vertically on top of the chocolate. Hold the indenter so that the marble just barely hovers over the opening of the paper. DROP THE INDENTER.
8. After it has fallen, and impacted the chocolate, carefully remove the indenter and paper.
9. Record any relevant observations (i.e. cracks, breaks, errors, etc.)
10. Record the diameter of the indent left behind. If the indent is not visible, try increasing the mass of the indenter by taping an additional stack of pennies to the indenter, or drop the indenter from a taller height. Be sure to record any of these modifications.
11. Repeat steps 7-10 and create two more indents on the same chocolate bar.



12. Repeat steps above for each chocolate bar to be tested.

DATA SHEET

| | |
|---------------------------|--|
| Diameter of Marble | |
| Mass of Indenter | |
| Height of Paper | |

| | Milk Choc | Diameter of Indent (mm) | Observations |
|----------|------------------|--------------------------------|---------------------|
| Trial #1 | | | |
| Trial #2 | | | |
| Trial #3 | | | |

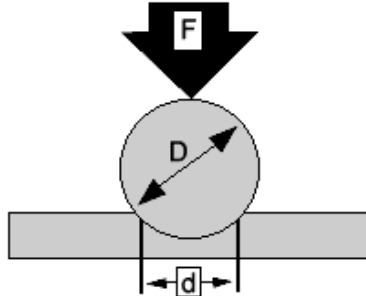
| | Dark Choc | Diameter of Indent (mm) | Observations |
|----------|------------------|--------------------------------|---------------------|
| Trial #1 | | | |
| Trial #2 | | | |
| Trial #3 | | | |

| | Mr. GB | Diameter of Indent (mm) | Observations |
|----------|---------------|--------------------------------|---------------------|
| Trial #1 | | | |
| Trial #2 | | | |
| Trial #3 | | | |

| | Crunch Bar | Diameter of Indent (mm) | Observations |
|----------|-------------------|--------------------------------|---------------------|
| Trial #1 | | | |
| Trial #2 | | | |
| Trial #3 | | | |

Formulas:

The size of the indent left behind, relative to the size of the indenter is a measure of the hardness of the indented material because it determines how much deformation it underwent.



Equation 1: Potential Energy

$$PE = m * g * h$$

Where PE is potential energy in Joules, m is the mass of the indenter in Kg, g is the acceleration of gravity known to be 9.81 m/s^2 , h is the height from which you dropped the indenter in meters.

Equation 2: Velocity

$$V = \sqrt{2 * g * h}$$

Where V is the velocity before impact in m/s, g is the acceleration of gravity known to be 9.81 m/s^2 , h is the height from which you dropped the indenter in meters.

Equation 3: Kinetic Energy

$$KE = \frac{1}{2} * m * v^2$$

Where KE is kinetic energy in Joules, m is the mass of the indenter in Kg, and v is the velocity before impact in m/s.

Equation 4: Hardness

$$\text{Hardness} = \frac{KE}{\left(\frac{d}{D}\right) * PE}$$

Where KE is the kinetic energy, PE is the potential energy, d is the diameter of the indent left in the chocolate, and D is the diameter of the marble.

Analysis Questions

1. Calculate:
 - a. The potential energy of the indenter right before it is dropped using equation 1. **SHOW YOUR WORK.**

 - b. The velocity of the indenter right before impact using equation 2. **SHOW YOUR WORK.**

 - c. The Kinetic Energy of the indenter using equation 3. **SHOW YOUR WORK.**

2. Using the values above, calculate the hardness for each chocolate bar. **SHOW YOUR WORK.**
 - a. Hershey's milk chocolate

 - b. Hershey's dark chocolate

 - c. Mr. Goodbar

 - d. Nestle's Crunch

3. Based on your results, rank the different chocolates in order of their relative strength.

_____ strongest

_____ weakest

4. How did your results compare to your hypothesis?

5. Explain why is it important that the indenter be harder than the material it is testing.

6. Why do different types of chocolate have differing hardness values?

7. How would the hardness values differ if the marble used was smaller? Explain your answer.

8. How would the hardness values differ if the indenter was dropped from a taller height?

9. How would the hardness values differ if the indenter had more pennies behind it?

10. How do you think the hardness would be affected if the chocolate was partially melted, or completely frozen?

11. Modern hardness testers do not actually drop the indent from a height, but instead, slowly and carefully press the indenter into the material, at either a certain force, or to a certain depth. Why do you suppose they do this?

12. If you have done lab I in this series (strength of chocolate), graph your results of strength on the X axis VS your results for hardness on the Y axis. Draw a best-fit curve on the graph.

13. Using the graph, what would the hardness be of a candy bar that has a strength of ___?
