HARDNESS OF MATERIALS--INTRODUCTION

Mark Palmer and Thomas Stoebe**
**Professor Emeritus, University of Washington
National Resource Center for Materials Technology Education
Edmonds Community College, Lynnwood, WA 98036

Abstract
Hardness of materials varies depending on the type and properties of the materials in question. In this demo/lab, students observe these differences in a simple, straightforward manner: that is, the differences are seen based on the height that a standard ball bounces off the surface. This is called rebound hardness and differs from other measurements, but it does give a qualitative feel for the differences. Students also see differences in observed results depending on operator methods. The accompanying PowerPoint presentation assists in explaining the experiment.

Module Objective
This demonstration or lab provides an introduction to the differences in properties between different materials. It provides a means to differentiate properties within the same class of materials, such as metals or plastics, and quantify differences that the students may not be able to predict. It also provides a basis for the larger differences between the different classes of materials, metals vs. ceramics vs. plastics vs. composites. The experiment also provides a means to interject operator method as a variable (since the ball must be dropped perpendicular to the material for the most accurate results).

Student Learning Objectives
- Determine property differences between different types of materials
- Observe property differences between materials of the same class
- Measure, record and report results
- Observe differences in results due to operator error

MatEdU Core Competencies Covered
If a laboratory:
- 0.B Prepare tests and analyze data
- 0.D Demonstrate general technical competence
- 1.C Demonstrate Laboratory Skills

For either a demonstration or a laboratory:
- 7.A Illustrate the general nature of metals
- 7.F Explain the general nature and properties of other materials

8.A Demonstrate the planning and execution of materials experiments
8.E Perform appropriate tests of metallic materials

Key Words: Hardness, strength, rebound hardness, data analysis
Type of Module: lab or demonstration
Time required: 20 to 30 minutes with discussion
Pre-requisite knowledge: none
Target Grade Levels: High School, Introductory College Level

Table of Contents

Materials and supplies required

Pieces of materials about ¼" in thickness or more, such as
- Steel (any type OK)
- Aluminum (pure or an alloy is OK)
- Copper, brass or bronze
- Plastic (heavy plastic sheet, several kinds if available)
- Styrofoam (perhaps sheets used in package packing)
- Composite (anything non-metallic, not clearly a plastic)
- Wood (several types, several types of cuts,
  even particle board might be interesting)
  Note that wood is actually a composite

Some of these materials are available at a hardware store, or try the local surplus or recycling store or yard. Often for class use they will donate the materials if they have them.

Also needed, one each for each student team or one for the instructor if a demo:
- Hardened ball, such as a ball bearing
- Transparent tube in which to bounce the ball, plastic or glass. The inside diameter should be larger than the ball but not more than 50% larger than the diameter of the ball. The tube should be 2 – 3 ft long.
- Meter stick or other means of measuring the height of the bounce (marks may be made on the tube or the meter stick can be attached next to the tube for easy observation).
- Students also need means for recording their observations

Means for showing the short PowerPoint presentation.

Curriculum Overview and Notes for Instructor

Hardness of a material correlates to its elastic modulus and its tensile strength, although the relationship is not always direct and depends on the test involved. Hardness of metals is usually done using an indenter, with a "hardness number" being related to the depth of the indentation. Ceramics and other very hard materials are often measured using a scratch method. Plastics and other soft materials' hardness can be measured using rebound and other methods. More details on methods may be found in the bibliography.

Rebound hardness is a simple method that can be used to determine relative hardness. It is related more to elastic modulus than to tensile strength, and the relationships are different for different materials. However, relative "bounce" is a reasonable method for demonstrating the differences between different materials. Differences will be clear and the students will be able to predict some of the differences. Ceramics generally are harder than metals, while plastics and composites are softer than metals. The hardness of wood will depend on type as will hardness of plastics and composites. Students will generally predict the differences between different materials, but not necessarily the differences between different materials of the same type.

In carrying out this exercise, it should be noted that thickness of the material is a variable since the bounce from too thin a material may reflect either the hardness of the surface on which the material lies or the response from bending of the material. Thus it is recommended that a strong support surface be used (one without any bend to it) and that materials tested be at least ¼ inch thick. Thicker than ¼ inch will change the results only slightly. If dinner plates are used for the ceramic materials, be aware that the curve on the underside will provide bending and thus skew the results (because the ceramic will not be firmly supported underneath).

Surface preparation is also a variable. Initially, the surfaces should all be smooth and flat. A variant of the exercise is to use materials with different surface finishes.

In the experiment, the tube must be held perpendicular to the metal surface. If not, the ball will lose momentum by rolling along the tube. This is an important part of the experiment and should be either demonstrated (in the demo) or the students in the lab should see the differences themselves (and record the differences). This provides an understanding of the importance of the operator in a measurement or other process.

Many of the experimental concerns mentioned above are also concerns when performing a hardness test. In a hardness test an indenter is vertically displaced into the sample at a known speed until the resisting load reaches a certain magnitude. If the sample is not correctly supported then the displacement will be

incorrect and the reported hardness value will be in error. If the sample is too thin one runs the risk of penetrating through the sample or having the hardness of the material that makes up the support affecting the measurement. Finally, if the surface has flakes or oxides the displacement will be effected as well. Thus one can use this as an opportunity to discuss sample preparation.

This exercise may be used as a class demonstration, or may be carried out by student teams. For the demonstration, a larger size of ball and tube should be used for visibility. The setup, key concepts and data analysis are discussed in the accompanying PowerPoint presentation.

This exercise may be followed by measurements of hardness using other techniques if the equipment is available. Bounce ability of different balls (really an elastic property) may also be investigated using different types of balls with as hard a bouncing surface as possible (ceramic or glass may be best, should be well supported so as not to allow bending).

Module Procedure

1. Display each type of material on a hard surfaces table or lab bench to ensure strong support for each sample.
2. Ask the students to predict which materials will have the greatest bounce. Ask them not just about metals vs. ceramics vs. plastics, but also about different materials in each class.
3. Ask the students to predict any differences in surface preparation of the materials (if this is a variable).
4. Show the PowerPoint presentation and discuss each slide with the class:
    i. Slide 1 shows the experimental setup
    ii. Slide 2 lists key concepts
    iii. Slide 3 discusses experimental analysis
5. Proceed with the demo/lab:
    - If a demonstration, show the students the tube and measuring technique. Choose a student (or a student team) to observe and record the height of the bounce from each material.
    - If a lab, issue each team a tube, ball and measuring stick, and have them rotate among the materials to make their measurements and to record their observations. Each measurement should be taken 3 times.
5. Ask the students to identify the variables in their measurements. Why are the 3 observations different? Have them record differences in how the experiments are done and what could affect results
6. As appropriate for the class, have the students record and report their observations. Often a bar chart can provide the best visual recording of these results.
7. Conduct a class discussion on the exercise to determine what the students have learned that is new. Were their predictions correct?

Repeat the PowerPoint to bring out the concepts and experimental analysis questions. What variables cause differences in results? Why?

Additional optional activity
An extension of this concept could include the classic physics experiment known as Newton's Cradle, which is an interesting example of hardness, elasticity, momentum and conservation of energy. This apparatus can be constructed or purchased. See references below.

Bibliography
Bouncing steel ball off anvils made of different metals
http://www.anvilfire.com/FAQs/anvil-5.htm

Wikipedia—Provides discussion of different types of tests for hardness
https://en.wikipedia.org/wiki/Hardness

Scleroscope Hardness Test (rebound hardness) discussion
http://www.instron.us/wa/applications/test_types/hardness/sclero.aspx

Newton's Cradle
http://www.lockhaven.edu/~dsimanek/scenario/cradle.htm

Newton's Cradle availability
http://www.teachersource.com/Physics/LawsofPhysics/NewtonsCradle.aspx?Print=1

Acknowledgment
The authors wish to thank the reviewer for his useful input, especially concerning Newton's Cradle.

EVALUATION PACKET:
Student evaluation questions (discussion or quiz):

1. Are the hardness results of these various types of materials as you would have expected them to be?
2. Why is there a difference in hardness between steel, aluminum and copper?
3. Why are ceramics harder than plastics?
4. Why is it important for the tube to be perpendicular to the material surface?
5. How does the surface preparation of the material affect the results?
6. How could you use hardness as a criterion in choosing a material for a skateboard? For a bicycle frame?

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the lab/demonstration work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material on hardness of materials sufficient for your understanding? Sufficient for your discussion with the students? Comments?
5. Did the demonstration/lab generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the lab/demonstration clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?

This work is part of a larger project funded by the Advanced Technological Education Program of the National Science Foundation, DUE #1400619