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CERAMIC AND GLASS INDUSTRY FOUNDATION

Teacher's Manual

for the

Materials Science Classroom Kit

with

Interactive Lessons and Labs

The American Ceramic Society and The Ceramic and Glass Industry Foundation are pleased to provide you with this Teacher's Manual of Instructions for the demos and labs in the Materials Science Classroom Kit.

The kit was originally designed by The American Ceramic Society's President's Council for Student Advisors — college students from the best engineering universities around the world — to assist teachers with instructing science in an interactive and engaging way.

Once you have tried one or more of the demonstrations, we would love to hear from you about your experiences. Please complete the evaluation form on page 97 and let us know how things worked for you, as well as any suggestions you may have for future kits.

All of the information in this manual, study guides for *The Magic of Ceramics*, and the introductory PowerPoint presentation can be found on the thumb drive included in the kit, as well as online at: http://ceramics.org/buyakit

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TEACHER INSTRUCTIONS

Hot or Not

Objective: To show how materials can be designed to withstand very high temperatures.

Background Information: There are four different mechanisms by which heat can transfer: conduction, convection, radiation, and advection. Conduction occurs when two things are in physical contact with each other. Heat causes the atoms in a material to vibrate which then transfers energy to other atoms in a process called thermal conduction. In the vacuum of space, there is no matter and therefore no conduction of heat. Gases, such as air, contain very little matter in comparison with solids or liquids. They "insulate" heat from flowing. This is why porous materials like foam insulation and ceramic tiles, which contain a lot of air, are used to keep our houses warm.

A refractory material is chemically and physically stable at high temperatures and has good resistance to thermal shock. Refractory bricks are made from ceramic materials that can withstand extreme temperatures without melting. In addition, they contain a great deal of trapped air since they are so porous. When the brick is heated on one side, the heat cannot travel to the other side since there is so much insulating air in between. Tiles, similar to the ceramic refractory brick used in this demo, were used on the outside of the space shuttle to protect the ship and crew from the >1200°C temperatures achieved on reentry into Earth's atmosphere (Figure 1).

Metals can also be refractory materials. These types of refractory materials are often used as tools to work other metals at high temperature, light bulb filaments, and in furnaces used to manufacture steel and glass (Figure 2).

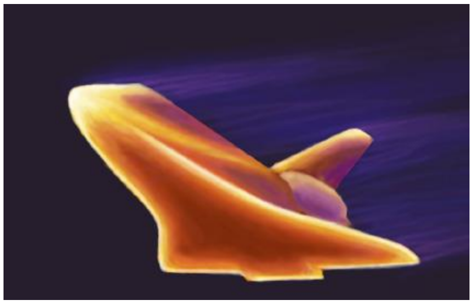


Figure 1. Computer simulation of the space shuttle upon re-entry. Because its surface reaches extremely high temperatures, it is covered in refractory ceramics.

Figure 2. Steelmaking – refractory materials are used in the crucible.

Demo Description: In this demo, a propane torch will be used to heat one side of a refractory brick. A thermometer will be used to monitor the other side of the brick, which should remain cool during heating.

Keywords:
· heat – the energy transferred from one body to another.
· temperature – the measurement of the amount of heat present in an object.
· insulator – a material that resists the flow of heat (e.g., ceramics or plastics).
· thermal conductor – a material that aids in the flow of heat (e.g., metals).
· refractory – a substance that is chemically and physically stable at high temperatures and is resistant to thermal shock.
· porous – an object having many small spaces (i.e., pores) that can hold a gas or liquid or allow a gas or liquid to pass through.

Materials List:
Items provided in the kit:
·1 refractory brick
·1 propane torch head

Items to be provided by the teacher/school:
· small propane tank (1 liter, generally found in the camping aisle at stores like Walmart®)
· thermometer (a variety of thermometers will work – the easiest to use is probably a meat thermometer since it is made to be "stuck" in a material)
· spark lighter or matches (also generally found in the camping aisle)

Safety Precautions: Be very careful not to touch the hot side of the refractory brick. Do not look directly at the flames of the torch.

Instructions:
1. Attach the propane torch head to the propane tank.
2. Show students the refractory brick.
3. Explain what refractory materials are and what they are used for.
4. Set up the refractory brick so that both sides can be seen and accessed. It is possible to hold the brick in your hand because the back side will remain cool.
5. Insert the thermometer on the side of the brick that will not be heated.
6. Heat the side of the brick without the thermometer.
7. Have a student read the temperature on the thermometer as the other side of the brick is heated.

Demo Delivery Hints:

1. If students are mature/responsible enough, allow several to take turns controlling the propane torch to keep them involved in the demo.
2. When the refractory brick is not in use for the demo, be sure to keep it in the included plastic baggie. If the plastic baggie becomes worn or dirty, replace it with a new one. (There is nothing special about the baggie included in the kit – feel free to replace it with a similar plastic bag). The refractory brick will slough off in small pieces if handled roughly and may also dent or crack into two pieces if hit against hard surfaces. If the brick cracks into two smaller pieces, the smaller pieces can generally still be used to run the demo as long as the piece is large enough to allow for heating on one side.

Troubleshooting: Do not put the thermometer on the side of the brick you are heating. It may melt! Be sure not to push the thermometer all the way through the brick as this will produce the same result as putting the thermometer on the heated side. When lighting the propane torch with a grill lighter, keep the flame turned down low or else the torch will blow itself out. Light it on low, and then turn the flame up as desired.

Cleanup/Replacement Parts: DO NOT TOUCH THE HOT SIDE OF THE BRICK! Place the brick in a safe place (out of the reach of students) and allow it to cool. Do NOT put the brick away until it has cooled completely. Use the thermometer to confirm that the temperature of the heated side has returned to room temperature. Tighten the knob on the propane tank and put everything back in the kit. Be gentle with the refractory brick.

Hot or Not

Discussion Questions to Ask Before the Demo

1. What is heat?

   Discussion: The energy (other than work) that is transferred from one body to another.

2. What causes things to heat up? How does heat transfer?

   Discussion: When heat travels, it must have physical matter to move through. It transfers by vibrating the atoms in a material which then transfers energy to other atoms in a process called thermal conductance. In the vacuum of space, there is no matter and therefore no heat.

3. What could prevent heat from transferring?

   Discussion: Gases, such as air, contain very little matter in comparison with solids or liquids. They "insulate" heat from flowing. This is why porous materials like foam insulation and ceramic tiles, which contain a lot of air, are used to keep our houses warm.

4. What uses would you have for materials that easily transfer heat? What uses would have for materials that prevent heat transfer?

   Discussion: Kitchen pots and pans are made out of metals, which generally have very high heat transfer coefficients. This is why we use them for tasks such as boiling water on a stovetop. Refractory materials are generally made out of ceramics and are highly porous, meaning they contain a lot of trapped air within the microstructure of the material. Refractory bricks similar to the one supplied for this demo were used on the NASA space shuttle to prevent overheating during atmospheric re-entry. Refrigerators and freezers are another example of items in a kitchen which have low heat transfer.

Discussion Questions to Ask During the Demo

1. Why is the heat not transferring through the material?

   Discussion: Gases, such as air, contain very little matter in comparison with solids or liquids. They "insulate" heat from flowing. This is why porous materials, like the refractory brick, do not transfer heat well. It contains so many pores full of trapped air that it significantly slows the transfer of heat to the other side of the brick.

2. What would happen if we exposed something else in the classroom to the heat of the propane torch (for example, the metal leg of a chair)?

   Discussion: The chair leg would begin to glow where exposed to the heat and slowly that glow would spread over a large area of the leg. If the torch is hot enough, it would likely cause the leg to melt and deform.

Discussion Questions to Ask After the Demo

1. What are different ways materials are made to stop heat from transferring?

   Discussion: The refractory brick in this demo uses pores, or empty areas filled with air, to prevent heat from transferring via conduction. Double pane windows have a similar concept, using an empty (gas-filled) area between the panes. Heat can be prevented from transferring via radiation by blocking the radiation, such as is done by a parasol to keep cool on a sunny day.

2. What would happen if this brick were dense (i.e., did not have pores)?

   Discussion: The refractory brick would allow the transfer of heat from one side to the other. However, due to the refractory nature of the material, no physical or chemical changes would occur. This means that the material would not melt, unlike most other materials exposed to the heat of a propane torch.

STUDENT QUESTION HANDOUT

Hot or Not

1. What is heat? How does it transfer from one object to another?

2. What is the difference between an insulator and a conductor?

3. What is special about the microstructure of the refractory brick?

4. How does that special microstructure impact the way the refractory brick responds to the heat of the propane torch?

5. Identify the mechanism of heat transfer (conduction, convection, radiation, or advection) in the following situations:
   a. Cooling your room using a fan
   b. A pan of vegetables on the stove
   c. Your driveway on a sunny summer day
   d. A chicken cooking in the oven

TEACHER INSTRUCTIONS

Candy Fiber Pull

Objective: To demonstrate the unique properties of glass by examining the solid-liquid and liquid-solid transitions of a glass-like system.

Background Information: Glass is an amorphous solid that is typically brittle and optically transparent. An amorphous solid is any material that has no long-range order of atoms. Crystalline materials (such as a metal) have an orderly arrangement of atoms, while amorphous materials do not (Figure 1). Glass is a unique material because its viscosity slowly decreases as heat is applied until it flows in a similar fashion to water. The temperature at which it transitions from solid to liquid is often referred to as the glass-liquid transition temperature. As the glass is cooled, the viscosity slowly increases. This property allows gaffers (people who "blow" glass) or machines to work with and shape the glass into products such as vases or bottles. If the glass is cooled too quickly, stresses will form in the glass causing it to crack. The glass-liquid reaction is typically reversible, meaning the solid can move to a liquid state and then back to a solid state. The glass-liquid transition of a solid to a liquid state typically occurs due to heating, and the reverse reaction of a liquid to a solid state typically occurs due to cooling or compression.

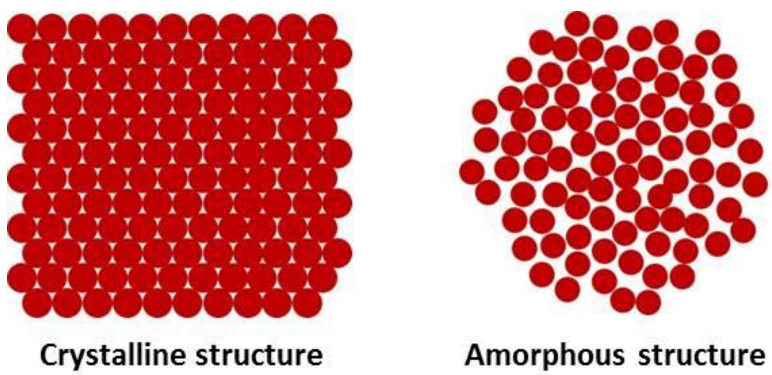


Figure 1. Crystalline vs. amorphous atomic structures

The term "glass" includes many different materials, some with which you are familiar. Soda-lime glass – composed primarily of silica (sand) – is used in the production of windows and drinking glasses. Sugar glass – composed of a brittle transparent form of sugar – is used in movies, photographs, and plays to simulate soda-lime glass. It breaks very easily and is less likely to cause injuries, but still has the look and breaking patterns of soda lime glass. Cotton candy and lollipops are two glasses that are made from cane sugar. Cotton candy is made by heating sugar until it reaches a molten state (liquid form) and squeezing it through small holes into a larger bowl that is spinning. The thin sugar fibers solidify almost immediately in the room temperature air and begin to collect on the outer edges of the bowl. When you eat the cotton candy, the heat from your tongue causes the fibers to dissolve into a liquid form again. Other candies, such as lollipops and Jolly Ranchers, follow a similar process. Insulation used to keep your house warm in the winter is fiberglass, which is made in a similar fashion to cotton candy. See the introductory PowerPoint presentation on the flash drive in the kit for additional examples of how glass and the glass-transition temperature are used in real-world applications.

Demo Description: During this demo, Jolly Ranchers® will be melted in a beaker using a hot plate. Once the Jolly Ranchers® have reached a molten state, candy fibers can be pulled from the beaker. When a fiber is pulled, it is almost instantly cooled because of the small diameter of the fiber and how cool the air is in relation to the molten Jolly Ranchers®. This simulates the production of glass-like fibers.

Keywords:

- amorphous – non-crystalline materials that lack a long-range atomic order.
- glass – an amorphous, brittle solid which exhibits a glass-liquid transition when heated.
- liquid – fundamental state of matter characterized as having a definite volume, but no shape.
- solid – fundamental state of matter characterized by structural rigidity.
- glass-liquid transition – reversible reaction in amorphous materials from a hard, brittle state to a semi-liquid, molten state.
- viscosity – an internal property of a fluid that offers resistance to flow.
- fiberglass – a material fabricated from extremely fine fibers of glass and is used in a variety of applications ranging from household insulation to a reinforcing agent in ladders and automotive body panels.

Materials List:

Items provided in the kit:

- 1 beaker
- beaker tongs

Items to be provided by the teacher/school:

- hotplate (can also use a microwave if no hotplate is available)
- Jolly Ranchers®
- wooden skewers or popsicle sticks (something to pull fibers with)

Safety Precautions: The hot plate and the beaker will get very hot. Caution should be used when handling the beaker during the demo. Allow the beaker and hot plate to cool before cleaning and returning to the kit. It may be helpful to clean some of the Jolly Ranchers® while it is still warm and fluid, but be sure that the beaker is not hot to the touch. If the Jolly Ranchers® cool and harden, they can always be removed with soap and warm water. Allow the Jolly Ranchers® to melt away in the warm water rather than trying to scrub it.

Instructions:

1. Be sure that the beaker is clean and dry.
2. Place four to six Jolly Ranchers® into the beaker.
3. Place the beaker on the hotplate and set the hotplate to a medium temperature setting.
4. Stir the Jolly Ranchers® while heating for approximately 10 to 15 minutes. The Jolly Ranchers® should begin to melt into a more fluid form.

   Note: The Jolly Ranchers® can burn! Pay close attention while melting the Jolly Ranchers® and be sure to stir them throughout the heating process. If they start to burn, reduce the heat (or remove the beaker from the heat) and continue to stir. If you have a microwave available in your classroom, it is easier to heat the Jolly Ranchers® in this fashion. You may have a shorter time period to pull the fibers before the Jolly Ranchers® harden again, but you are less likely to burn them.
5. Once the Jolly Ranchers® are in liquid form, use the wooden skewer/popsicle stick to pull one fiber from the beaker by dipping the skewer into the molten Jolly Ranchers® and removing it slowly.
6. Allow students to take turns pulling fibers.
7. Pick four or five students and have each one of them pull a fiber and quickly move away. Have the other students take rough measurements of how long the fiber gets before it breaks. See who can get the longest fiber.
8. Have students compare the flexibility and texture of a short, fat pulled fiber, a long skinny pulled fiber, and a solid Jolly Rancher®.

Demo Delivery Hints:

1. Turning the fiber pulling into a game to see who can get the longest fiber makes this demo fun. Most of the time, it helps to remove the beaker from the hotplate and tilt it so that the fiber doesn't contact the side of the beaker while the student is moving away. Do not touch the beaker with your bare hands; always use the beaker tongs or hot pads/gloves.
2. The Jolly Ranchers® do take a little time to heat up and turn to a liquid form. This portion of the demo can be started early, and the Jolly Ranchers® can continue to heat while you are explaining the background information and what is going to be done during the demo. Just make sure to stir the Jolly Ranchers® as they are heating.

3. If you have other beakers readily available in your classroom, it is recommended that you use the beaker included in the kit for ***this lesson only*** and designate it as a ***"food-only" beaker***. This will allow students to eat the fibers without having to worry about contamination from the beaker. Be sure to clearly label the beaker as "food-only" and thoroughly wash and dry the beaker each time before using it for this lesson.

Troubleshooting: It may take some time for the hot plate to heat up. Make sure to test the hot plate prior to the demo to ensure that the heating elements and temperature settings are working correctly (you can do this by placing some water in the beaker and checking to see that it boils after 10 to 15 minutes of heating on the hot plate). Alternatively, you can melt the Jolly Ranchers® in a microwave if one is available.

Cleanup/Replacement Parts: This demo can get very messy. The easiest way to clean the beaker is to run hot water over it until all of the sugar is dissolved. Fibers that end up sticking to the desk or floor can also be dissolved by scrubbing with a paper towel moistened with hot water or using a mop with hot water. The used wooden skewers/popsicle sticks should be replaced after every demo. A damp paper towel should also be used to clean the hotplate once it has cooled. Make sure that the beaker and hot plate are clean and dry before returning them to the kit.

TEACHER DISCUSSION QUESTIONS

Candy Fiber Pull

Discussion Question to Ask Before the Demo

Ask students what they know about the formation of glass, glass fibers, or glass-like fibers (such as cotton candy).

Discussion: Students most likely will not know much about how glass and glass fibers are made. Describe the process outlined in the Background Information section of the Teacher Instructions.

Discussion Questions to Ask During the Demo

1. Before pulling a fiber for the first time, ask students what they think will happen when you remove some of the Jolly Ranchers® from the heat and "pull" a fiber.

   Discussion: Emphasize the fact that the diameter of the fiber is very small compared to the amount of molten Jolly Ranchers® in the beaker. This facilitates an instant cooling of the Jolly Ranchers® fiber as it is removed from the heat and exposed to room temperature air, which causes it to take on a glass-like fiber quality.

2. Have students guess at how long of a fiber they think they can pull.

   Discussion: If this demo is done correctly, students should be able to pull a fiber that runs a good distance across the room. Most of them will not guess a number this high for the length. The key is to have them move very quickly away from the beaker so that the fiber continues to be pulled, otherwise it will start to sag. Once the fiber makes contact with any other surface (a desk, the floor, etc.), it will not be able to be pulled much longer.

3. Once several fibers have been pulled, ask students to compare the texture and flexibility of the fiber to the solid Jolly Rancher®. Are there any changes in the properties of the fibers as a function of length (i.e., do shorter fibers feel or look different than longer fibers)?

   Discussion: The fibers should be fairly flexible when they first start to cool, but may start to harden after being at room temperature for a while. In general, the thinner and longer the fiber, the greater the flexibility. The fibers may also have a different texture and color (transparency) compared to the original Jolly Rancher®.

4. Hold a short competition to see who can pull the longest fiber.

   Discussion: This is best done in groups of two to three students. First, have each student (or each group) make a guess at the longest fiber they think will be pulled. Record the guesses on the Student Question Handout. Have one student from each group pull the fiber, while the other students help measure the length of the fiber as it is being pulled. Use a meter stick, or have students walk alongside the fiber being pulled and count the number of steps taken along the length of the fiber. If you have enough space in your classroom, you can have each group take their fiber in a different direction (although this will make for some additional clean-up; a mop and warm water are suggested to help clean the floor if a lot of fibers end up on the floor). This allows all of the fibers to be pulled so that each student can evaluate the fibers of other groups to determine which is the longest. Give the student/group with the closest guess to the longest fiber pulled a reward, such as extra Jolly Ranchers® to take home.

Discussion Question to Ask After the Demo

Allow the students to eat the fibers that haven't been in contact with the floor. Ask them what is happening to the fibers as they are eaten.

Discussion: Emphasize that the heat from your tongue as well as the pressure of you sucking on the candy will cause the fiber to go from a solid form back to the liquid form. This is the reverse reaction of what happened when they pulled the molten Jolly Ranchers® from the beaker.

Student Question Handout

Candy Fiber Pull

1. What do you think will happen when you pull some of the molten Jolly Ranchers® out of the beaker?

2. What is the longest length of fiber that you *think* you can pull?

3. What was the length of the longest fiber pulled?

4. How does the Jolly Ranchers® fiber differ (in terms of texture, flexibility, shape, etc.) from the original solid Jolly Rancher®?

5. What happens when you eat the Jolly Ranchers® fibers?

TEACHER INSTRUCTIONS

Piezoelectric Materials

Objective: To demonstrate the piezoelectric effect in several materials and explain why this property exists in certain materials.

Background Information: Piezoelectric materials are everywhere. Piezoelectric materials are used in a wide variety of applications. Sensors, amplifiers, and ultrasonic transducers are just a few examples. They are a necessary component in all electronics and can be made very small (so your electronics can be compact as well).

The piezoelectric effect describes the relationship between a mechanical stress and an electric voltage in solids. Certain materials (e.g. quartz and barium titanate ($BaTiO_3$)) exhibit this effect. When a mechanical stress is applied to these materials, they generate a voltage. This is shown schematically in Figure 1. The effect is reversible as well. When a voltage is applied to the material, the shape of the material will change by a small amount (up to 4% in volume change).

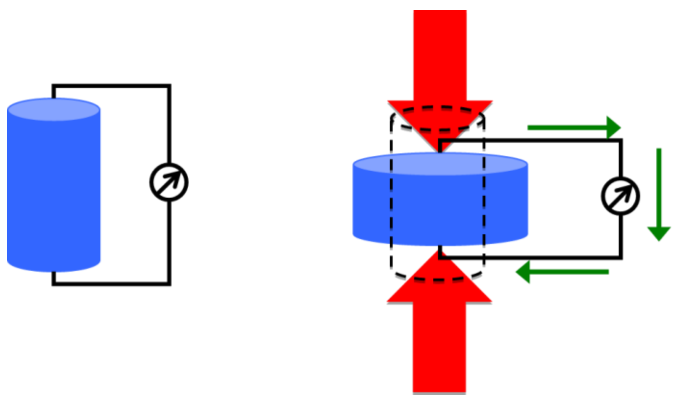


Figure 1. Schematic of the piezoelectric effect. When a force is added to the material (red arrows), it generates a voltage (green arrows). It also works in reverse.

This is how the speaker in a greeting card or the speaker in an mp3 player's headphones works. The material is electrically vibrated at certain frequencies that we then hear as sound. This sound can be amplified with the use of a diaphragm.

The piezoelectric effect is caused from the structure of the material. Sometimes atoms are arranged in such a way that they can be physically forced towards each other when the material experiences a compressive force. The change in the material's structure causes an electric dipole, or change in potential (voltage). The opposite is also true. When a potential is applied to the material, like a battery, then the atoms are driven apart and a force is created. See the introductory PowerPoint presentation on the flash drive in the kit for examples of how the piezoelectric effect is used in real-world applications.

Demo Description: In this demo, the piezoelectric effect of a ceramic disk and a polymer film will be demonstrated through the use of LEDs. Two of each piezoelectric material have been included in the kit so that you may keep one to demonstrate and pass one among the students.

Keywords:
· piezoelectric – the effect of generating electric charge from applied force; "piezo" comes from the Greek for "pressure."
· ceramic – classification of materials which are inorganic, non-metal solids.
· polymer – classification of materials which are characterized by long, chain-like molecules that typically have repeating sub-units.
· structure – the arrangement of atoms within a material.
· potential – difference in electric charges resulting in the capacity to do work.
· force – influence exerted on an object, such as pressure or tension.
· transducer – a device that converts small amounts of energy from one kind into another.

Materials List:
Items provided in the kit:
· two piezoelectric ceramic disks
· two piezoelectric polymer films
· four LEDs
· eight alligator clip sets

Items to be provided by the teacher/school:
· musical greeting card
· voltmeter

Safety Precautions: Too much force on either piezoelectric material can permanently damage them.

Instructions:

1. Test both piezoelectric materials prior to starting the demonstration to make sure neither is damaged or needs to be replaced.
2. Connect one LED to a piezoelectric polymer film so that the long wire of the LED is connected to one leg of the piezoelectric material, and the short wire on the LED is connected to the other leg of the piezoelectric film. Use the supplied alligator clips to make these connections (Figure 2).

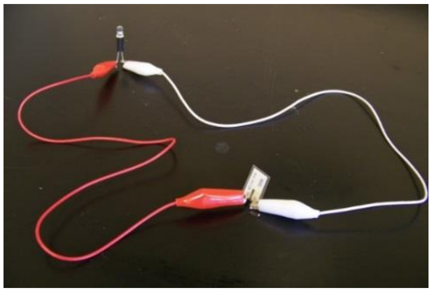


Figure 2. LED and piezoelectric polymer film connected by alligator clips

3. Connect 1 LED to a piezoelectric ceramic disc so that the long wire of the LED is connected to the red wire coming from the disk and the other wire of the LED is connected to the black wire of the disk.

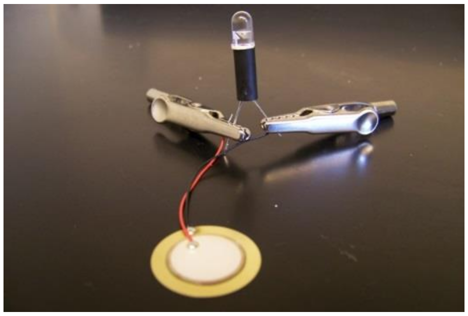


Figure 3. Piezoelectric disk ready to be tested

4. With a very light tap, slowly increase the force until the LED visibly flashes with each tap. Show effect to students. It is important to simply tap the disk and to not apply steady pressure. ***NOTE***: The room must be fairly dark to see the LED light.
5. Bend the polymer film back and forth slowly (Figure 4). Increase the speed at which you are bending the material until the LED lights up with each bending motion.

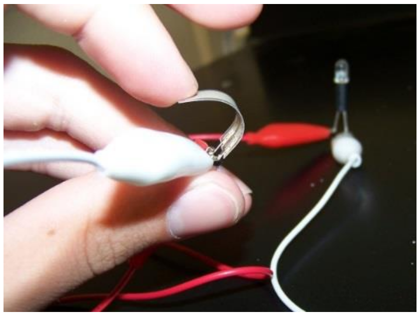


Figure 4. Bending the polymer film

6. Open the musical greeting card and explain the use of piezoelectric materials as a speaker. Take apart the card so that students can see the actual piezoelectric “buzzer.” Supply students with the background information on piezoelectric materials. A reproduction of Figure 1 should be created as a demonstration aid, linking it to the ceramic disk and polymer films used.

OPTIONAL ADDITIONS TO THE DEMO

7. Use a voltmeter in place of the LED to measure the voltage generated by the piezoelectric. This provides a better indication of the piezoelectric effect as the light generated by the LED is very minimal.
8. Connect the two piezoelectric materials in series and try to generate more voltage by simultaneously activating both materials.
9. Create a simple circuit by connecting the ceramic disk directly to the polymer film. Attempt to make the polymer film bend by striking the ceramic disk.

Demo Delivery Hints: Interest is key. This demonstration can be boring if you are not interested in it yourself. Try to be excited about the piezoelectric affect. The video “How a quartz watch works” can be used as an introduction:
http://www.youtube.com/watch?feature=player_embedded&v=1pM6uD8nePo

Troubleshooting: If either piezoelectric material is damaged or not working, then replacements should be purchased. If the demonstration isn’t functioning, then the piezoelectric materials are most likely the cause (the LEDs are nearly indestructible).

Clean-up/Replacement Parts: Disconnect the LEDs from the piezoelectric materials and return all materials to the kit. LEDs can be found at any electronics store for very little cost if they are lost or stolen. Piezoelectric ceramic disks can be purchased from online electric suppliers, including eBay. They are typically referred to as “transducers.” It is recommended to purchase the disks with wires already attached (for ease of use). Piezoelectric polymer films can also be purchased from online electronic suppliers. They are commonly referred to as “piezoelectric vibration sensors.” It is also recommended to purchase films with wires already attached (for ease of use).

TEACHER DISCUSSION QUESTIONS

Piezoelectric Materials

Discussion Questions to Ask Before the Demo

1. How do we, as a society, make electricity?

   Discussion: We typically use generators powered by water or steam pressure, wind, solar, coal, or nuclear power.

2. What objects or materials generate electricity?

   Discussion: Magnets (generator), batteries (chemical reaction)

Discussion Questions to Ask During the Demo

1. Why does the LED have to be polarized (red and black wires)?

   Discussion: The charge only moves in one direction when the material is compressed.

2. What do these piezoelectric materials have in common?

   Discussion: A similar structure that allows atoms to be forced together.

3. What is generating the charge observed as light from the LED?

   Discussion: The movement of atoms within the material causing an electric dipole to light the LED.

Discussion Questions to Ask After the Demo

1. What are potential applications this material could be used for?

   Discussion: Sensors, speakers, actuators, buzzers, switches, and power generation.

2. Is human hair a piezoelectric material?

   Discussion: It is . . . did you ever statically charge a balloon by rubbing it on your head?

STUDENT QUESTION HANDOUT

Piezoelectric Materials

1. What is the piezoelectric effect?

2. What causes the piezoelectric effect?

3. Name a type of material that can have the piezoelectric effect.

4. Name one current use of this material property.

5. What is a potential application of this material? Where could you use the piezoelectric effect?

TEACHER INSTRUCTIONS

Shape Memory Alloys

Objective: To learn how the motion of atoms under added heat can change the shape of metals.

Background Information: Nitinol is a nickel titanium alloy (~50% Ni, ~50% Ti) which has two phases or crystalline structures, a high temperature (austenite) and a low temperature (martensite), shown in Figure 1. The low temperature phase is weaker, allowing the material to be bent and pulled out of shape. When deformed at a low temperature and then heated, nitinol will return to the shape established when in the high temperature, stronger phase. By heating the material, the atoms are given enough energy to rearrange themselves back to their high temperature phase. The composition of the wire can be varied slightly to change the transformation temperature. This ability to remember and revert to the original shape gives this material the name “shape memory.”

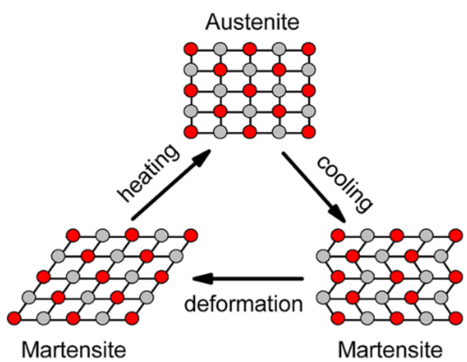


Figure 1. When deformed at a low temperature and then heated, nitinol will return to the shape established at the high temperature as the atoms rearrange themselves back to their high temperature positions.

In this demo, a nano-scale change is impacting the macro-scale. When heated, nitinol wire that has shape memory properties will return to its original shape due to changes that are happening on the nano-scale. See the Introductory Presentation for a top view of the atomic arrangements during this transition. In comparison, a piece of normal steel wire (whose composition is generally iron and carbon) will be unaffected by the addition of heat and maintain its deformed shape. Nitinol is an ordered intermetallic compound. This means that the atoms have very specific locations in the crystal structure. Nitinol is a popular choice for a variety of applications: as a material in temperature control systems, retractable antennas in cell phones, springs in orthodontic braces, and for eyeglass frames. See the introductory PowerPoint presentation on the flash drive in the kit for examples of real-world applications of shape memory alloys.

Demo Description: During this demo, students will see how a shape memory alloy can return to its original shape when heat is applied.

Keywords:
· phase – the region of a material that is chemically uniform, physically distinct, and usually mechanically separable.
· phase change – a change from one phase to another (often caused by a change in temperature).
· thermal shape memory – the ability of a material to return to its original, cold-forged shape when heated.
· alloy – a metal containing two or more elements.
· nanoscale – features smaller than 1/10 of a micrometer.
· macroscale – features measurable and observable with the naked eye.
· crystal structure – unique and orderly arrangement of atoms or molecules in a crystalline material.

Materials List:
Items provided in the kit:
· 6 inches of nitinol wire
· 6 inches of steel wire
· glass beaker

Items to be provided by the teacher/school:
· hotplate
· needle nose pliers
· water

Safety Precautions: Safety glasses should be worn in case of water splashing. The beaker and hot plate can get very hot. Use the beaker tongs to handle the beaker during the demo to avoid accidental burns. After the demo, be careful not to touch the wire, water, beaker or hot plate until they have completely cooled!

Instructions:
1. Fill the beaker with water.
2. Place the beaker on the hot plate and turn to the high temperature setting. The water should be heated to just below boiling.
3. Bend the nitinol wire to a desired shape.
4. Place the nitinol wire in the hot water.
5. The nitinol wire should immediately return to its original shape.
6. Remove the nitinol wire from the beaker using the pliers and show it to the students.

7. Repeat steps 3 - 6, trying different shapes and amounts of deformation.
8. Repeat steps 3 - 6 with the steel wire.

Demo Delivery Hints: Try coiling the wire into a tight spring and tossing it into the water. If done correctly, the nitinol wire will “jump” out of the beaker. Students can be asked to bend the wire or place it in the water for a more interactive demonstration.

Troubleshooting: Do not make sharp corners in the nitinol wire or tie it into knots. The wire is limited on how much deformation it can recover from.

Cleanup/Replacement Parts: Turn off the hot plate and allow it, the beaker, and the water to cool down. Pour out the water. Do not return the supplies to the kit until they are cool to the touch.

TEACHER DISCUSSION QUESTIONS

Shape Memory Alloy

Discussion Questions to Ask Before the Demo

1. Can nano-scale changes impact the macro-scale?

   Discussion: Yes, this demo shows how the movement of atoms just a very small distance can cause the macroscale shape of the metal to change.

2. What do you expect to happen when the nitinol wire is placed in the water?

   Discussion: Encourage the students to discuss what they think. Do they think the wire will stay the same, expand, or return to its original shape?

3. What is a phase?

   Discussion: A simple definition is a region of material that is physically distinct, and has its own state (solid, liquid or gas), own arrangement of atoms (crystal structure), and composition.

Discussion Questions to Ask During the Demo

1. Once the nitinol wire is placed in the water, what do you see?

   Discussion: The nitinol wire should start straightening out. Depending on what shape you bent the wire in (such as a spring-like shape), the wire may tend to “jump” or “pop” out of the water.

2. Why did the nitinol wire change?

   Discussion: The atoms are rearranging themselves back to the positions for the high temperature phase.

3. Does the same thing happen with the normal steel wire?

   Discussion: The steel wire should remain in the same shape as it was bent. No change or reactions occur, therefore the wire does not return to its original shape.

Discussion Questions to Ask After the Demo

1. Why does the nitinol wire change shape, but not the steel wire?

   Discussion: The nitinol wire has two distinct, ordered phases. The high temperature phase is called austenite and the low temperature phase, martensite. During this demo, the atoms in the nitinol wire are undergoing a phase transformation between the low temperature martensite and the high temperature austenite. The steel wire remains the same, regardless of temperature, as it does not undergo any phase transitions and is not an ordered intermetallic.

2. What uses can you think of for materials that have this special behavior?

   Discussion: Nitinol is a popular choice for a variety of applications: as a material in temperature control systems, retractable antennas in cell phones, springs in orthodontic braces, and for eyeglass frames! It was even used in the Mars Rover as part of a sensor used to close delicate ports and prevent damage.

Student Question Handout

Shape Memory Alloy

1. Define the following keywords:

   phase:

   phase change:

   thermal shape memory:

   alloy:

   nanoscale:

   macroscale:

   crystal structure:

2. What is happening to the atoms as the nitinol wire heats up?

3. What is the difference between the nitinol wire and the steel wire?

TEACHER INSTRUCTIONS

Thermal Shock

Objective: To illustrate thermal shock and the effects of differing amounts of modifier on the properties of glass.

Background Information: Thermal expansion is the tendency of matter to increase in length, area, or volume when heated. For liquids and solids, the amount of expansion will normally vary depending on the material's coefficient of thermal expansion. Tensile and compressive forces are created in different parts of an object as materials expand and contract due to temperature changes. Thermal shock is the name given to cracking as a result of rapid temperature change.

From the laboratory standpoint, there are three main types of glass used today: borosilicate, quartz, and soda lime or flint glass. Borosilicate and soda lime (flint) glass are the most commonly found in a home. Borosilicate glass is made to withstand thermal shock better than soda lime through a combination of reduced thermal expansion coefficient and greater strength, although fused quartz outperforms it in both respects. Some glass-ceramic materials include a controlled proportion of material with a negative expansion coefficient, so that the overall coefficient can be reduced to almost zero over a reasonably wide range of temperatures.

Improving the thermal shock resistance of glass and ceramics can be achieved by improving the strength of the materials or by reducing its coefficient of thermal expansion and tendency for uneven expansion and contraction. One example of success in this area is Pyrex, the brand name that is well known to most consumers as cookware, but which is also used to manufacture laboratory glassware. Pyrex traditionally is made with a borosilicate glass with the addition of boron, which reduces the risk of thermal shock by lowering the coefficient of thermal expansion.

Demo Description: Three different types of glass rods will be heated so that students can observe the amount of thermal shock that occurs. Different formulas of glass affect the mechanical, electrical, chemical, optical, and thermal properties of the glasses that are produced.

Keywords:

- sodium flare – a bright yellow flame caused by the reaction of an oxygen-rich flame with glass containing sodium.
- coefficient of thermal expansion – the amount of expansion (or contraction) per unit length of a material resulting from one degree change in temperature.
- thermal conductivity – the property of a material that describes its ability to conduct heat.
- thermal shock – the way in which some materials are prone to damage if they are exposed to a sudden change in temperature.

Materials List:

Items provided in the kit:

· three soda-lime (flint) glass rods
· three borosilicate glass rods
· three fused silica (quartz) glass rods
· glass beaker
· torch head

Items to be provided by the teacher/school:

· propane
· strike lighter or matches
· ice water

Safety Precautions: It is possible for small pieces of glass to become airborne during the quenching of the rod in ice water, so don't allow students to hover over the demo area.

Instructions:

Prior to starting the demonstration, discuss with the students the process of determining thermal shock by explaining that the two most important properties that determine resistance to thermal shock in glass are thermal conductivity and coefficient of thermal expansion.

Thermal conductivity, which refers to how well heat is conducted, is hard to measure and has a low variability in glass. The better the conductivity, the more rapidly and evenly heat is distributed. The better the conductivity, the less chance there is of thermal shock (inversely proportional). All three types of glass rods in the demonstration have about the same thermal conductivity.

The coefficient of thermal expansion refers to the amount of expansion per unit of length per °C. It is easy to measure and varies greatly in glass. The lower the coefficient, the less stress caused by a sudden temperature change. The lower the coefficient, the less chance of thermal shock (directly proportional).

The general guideline for determining thermal shock probability in glass is:

$$\frac{\text{coefficient of thermal expansion}}{\text{thermal conductivity}}$$

The larger the value of the ratio, the more likely damage will occur due to thermal shock. The value for thermal conductivity stays about the same for all glass. Thus, the coefficient of thermal expansion has the most effect (see chart below).

Material	Coefficient of Thermal Expansion (cm/cm x °C)
Fused silica glass	6×10^{-7}
Borosilicate glass	33×10^{-7}
Aluminosilicate glass	44×10^{-7}
Porcelain	60×10^{-7}
Soda-lime glass	85×10^{-7}
Mild steel	110×10^{-7}
Aluminum	250×10^{-7}

Glass is a poor conductor of heat. The outside will cool and contract much more rapidly when quenched. A lot of stress is put on the glass and it causes failure. The greater the coefficient of thermal expansion, the more likely the glass will break. Metals have a high coefficient of thermal expansion but since they are very good conductors of heat they typically do not show the effects of thermal shock.

A "modifier" is used to lower the melt temperature of the glass and increases the workability of the glass. Soda-lime has a high percentage of modifier. Fused silica glass has no modifier—it is pure silica. Borosilicate glass has an intermediate amount of modifier. The chart below shows the differences in glass depending upon the amount of modifier.

Lower	% of Silica in Glass	Higher
Soft	Type of glass	Hard
Lower	Melting temperature	Higher
Higher	Coefficient of expansion	Lower

1. Have the students record their observations during the demonstration.
2. Show students the difference in color of the three types of glass rods by looking at the ends. The soda-lime glass with have a definite green color (think Coke bottle green). The fused silica will be white if unpolished, and the borosilicate will be in-between (sort of a soft light gray). The higher the percentage of silica content, the less color the glass will have. The greenish tint is due to iron oxide impurities in the silica.
3. Attach the torch head to the propane and turn on.
4. Heat one end (about one inch) of the soda-lime glass rod in the flame. Try to hold the glass rod so that the same length of glass is in the flame throughout the heating. Point out the "sodium flare" that occurs as the glass heats up. Allow the glass to sag or slump to show softening.
5. Remove from the flame and quench in the ice water. Thermal shock will occur and pieces of glass will break off onto the bottom of the beaker. There will be many fractures throughout the portion that was heated.

6. Heat one end of the borosilicate glass rod in the flame keeping about one inch of the rod consistently in the flame. Have the students note that there is less sodium flare. Sagging or slumping should be harder to achieve but the end should fire polish (become smooth or "polished").
7. Remove from the flame and quench in the ice water. Some thermal shock will occur, but there should be fewer overall cracks than with the soda-lime glass. There should be one or two cracks at the interface between where the glass rod was in the flame and where it was not.
8. Heat one end of the fused silica glass rod in the flame in the same manner as the two previous rods. There should be no sodium flare, and no sagging, slumping, or fire polishing will occur. Remove from the flame and quench. The rod will not thermal shock and no cracks should occur.

An additional demonstration using the three different glass rods involves the index of refraction. Borosilicate glass has about the same index of refraction as vegetable oil or mineral oil. Immerse the three rods in a beaker or clear plastic cup containing an inch or two of vegetable oil. Only two rods should be visible in the oil. The third one, the borosilicate rod, "disappears."

Cleanup/Replacement Parts: Make sure propane torch is turned off and allow it, the beaker, and the water to cool down. Pour out the water. Using a paper towel, carefully wipe the broken glass pieces into a trash can or broken glass container. To reuse the soda lime and borosilicate rods, use a triangular file to score and break off the cracked end. (Use gloves and remove about one inch of rod.)

Sources of glass rods:
Pyrex and Quartz (borosilicate and fused silica)

- National Scientific Company - Quakertown, PA – www.quartz.com
- Phone: 215-536-2577
- 5 mm diameter Pyrex Rod x 8" long - saw cut ends - $.80 each
- GE 214 Quartz Rod 5mm x 8" long - saw cut ends - $2.16 each
- $50 minimum order required

Soda-lime (flint)

- Flinn Scientific – www.flinnsci.com
- stirring rods, soft glass, 5 mm x 24" - pkg/10 – item# GP9035 - $15.80

TEACHER DISCUSSION QUESTIONS

Thermal Shock

Discussion Questions to Ask Before the Demo

Before heating and quenching the first glass rod, ask students what they think will happen when you do that to the soda-lime glass rod.

> *Discussion:* Emphasize the fact that the soda-glass rod has a higher coefficient of thermal expansion ratio, which increases the risk of thermal shock.

Discussion Questions to Ask During the Demo

Following the soda-lime glass rod and prior to heating and quenching the borosilicate glass rod, ask the students if they think thermal shock will occur in this rod.

> *Discussion*: Refer to the charts and ask them to support their predictions of what will happen.

Discussion Questions to Ask After the Dem

Ask the students about any other observations they made about how the different glasses reacted to the heat.

> *Discussion*: Discuss the differences they should have noticed regarding sodium flare and any slagging or slumping that occurred.

STUDENT QUESTION HANDOUT

Thermal Shock

1. What is meant by the term “thermal conductivity”?

2. What is meant by the term “thermal expansion”?

3. What is the “coefficient of thermal expansion”?

4. Why does thermal shock occur?

5. Of the three types of glass used in the demonstration (soda-lime, borosilicate, and fused silica), which would be the best for the following uses:

   solar panels:

   everyday drinking glasses:

   cookware:

   bathroom mirrors:

   high temperature furnace windows:

TEACHER INSTRUCTIONS

Glass Bead on a Wire

Objective: To demonstrate that glass can be a "phase of matter" rather than a particular material and to examine the unique ability of glasses to absorb other ions during thermal treatments.

Background Information: Glasses are amorphous solids, meaning that they have no long-range order of their atoms. Crystalline materials have an orderly arrangement of atoms within their structure (Figure 1). Several materials that can be used to create a glass begin as a crystalline or semi-crystalline material. This indicates that glass can, at times, be a "phase of matter" rather than just a particular material.

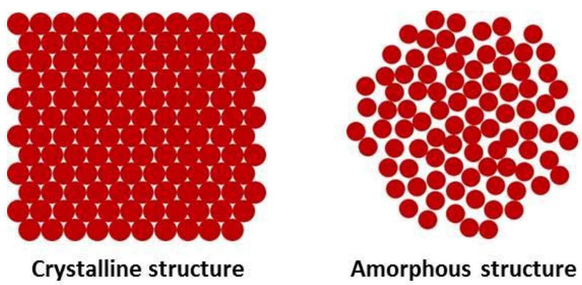


Figure 1. Crystalline and amorphous atomic arrangements

For example, borax crystals are typically found deep in the ground and are mined as large "chunks" (Figure 2a). Borax is actually sodium borate decahydrate ($Na_2B_4O_7 \cdot 10H_2O$). These chunks can be ground into a powder, which is sold in many grocery and convenience stores as a natural laundry booster that helps clean your clothes (Figure 2b). The powdered form of borax is also a crystalline material, although the crystals are much smaller than the borax that was originally mined.

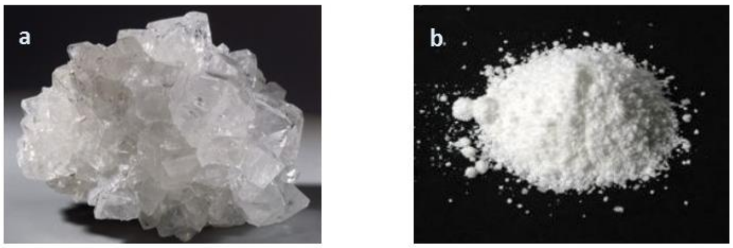


Figure 2. (a) Borax crystals as mined in California and (b) powdered borax crystals typically purchased as a household laundry booster.

The natural form of borax contains a large amount of water, which is held in the crystalline structure of the material. When borax is heated to temperatures high enough to start removing this water, the crystalline arrangement of the atoms in borax begins to change. The borax crystals will begin to swell as the water is being removed from the crystalline structure and then shrink as the water is being boiled off from the heat. This removal of water causes the crystalline structure of borax to lose its orderly arrangement of atoms, leaving a transparent, glassy solid behind.

Powdered borax crystals can be changed to a glassy form by heating with a Bunsen burner or a propane torch. Most Bunsen burners have the ability to control gas and air flow into the burner, which subsequently control the height and intensity of the flame produced. The oxidizing region of the Bunsen flame is produced with very high amounts of oxygen. This corresponds to the outer region of the Bunsen flame as this portion of the flame is in contact with high amounts of oxygen from the air. If the burner is turned up high, this flame is a purple color (Figure 3). The reducing region of the flame is produced with low amounts of oxygen. This corresponds to the inner region of the Bunsen flame.

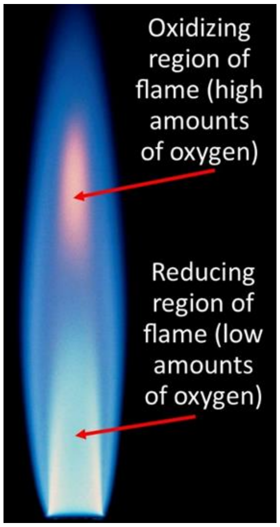


Figure 3. Bunsen burner flame with oxidizing and reducing regions

When heating powdered borax, the transition of its atomic arrangement from crystalline to amorphous as the water is being removed during heating allows for metal ions to be substituted into the borax atomic structure and form bonds with the oxygen atoms. The amount of oxygen available when this takes place (dependent on what part of the Bunsen flame you are using for heating) also affects how the metal ions will be incorporated in the structure and bond with oxygen atoms, which ultimately determines the color of glass that will be formed during this process. Borax glass is normally colorless, but different metal ions can be added to it during heating to produce different colors (Figure 4). See the introductory PowerPoint presentation on the flash drive in the kit for examples of how this phenomenon is used in real-world applications.

Figure 4. Borax beads formed with copper wire (blue bead) and nichrome wire (green bead)

Lab Description: In this lab, students will use copper and nichrome (nickel-chrome) wire to perform a borax bead test and determine what color beads are produced from each type of wire under different heating conditions. The bead test has traditionally been used to test for the presence of certain metals. The borax bead test is one of the oldest versions of the bead test and was developed by Jöns Jacob Berzelius in 1812! The borax bead test consists of making a small loop at the end of a wire and heating it in a Bunsen flame until red hot. The loop is then dipped in powdered borax and placed back in the Bunsen flame. The solid powder adheres to the hot wire and swells up as it loses its water of crystallization (the water found in the crystalline framework of a material – without this water, borax cannot maintain a crystal structure). It then shrinks, forming a transparent glass-like bead. The bead's color is dependent on the metal ions that were present in the wire.

Keywords:

· amorphous – non-crystalline solid that lacks a long-range order of atoms.
· oxidation – the addition of oxygen to a material.
· reduction – the removal of oxygen from a material.
· borax bead test – a heat-induced transition of borax from a crystalline state to an amorphous state which is typically used to test for the presence of certain metals.
· water of crystallization – water that is found in the crystalline structure of a material

Materials List:

Items provided in the kit

· 20 feet copper wire (18-gauge)
· 20 feet nichrome wire (20-gauge)

Items to be purchased/provided by the teacher
· powdered borax (available for purchase as a laundry booster from stores such as Walmart®)
· Bunsen burners (should have one burner for every student, but students can share if needed)
· needle nose pliers/tweezers/corks (to hold the wires while heating)
· watch glass or heat-resistant container, e.g. short water glasses or ceramic bowls (need one per table – several students can share one container)
· plastic sandwich baggies - OPTIONAL (if students want to take home their wires/beads)

Safety Precautions: Safety glasses should be worn during this lab. The wires will get very hot when placed in the Bunsen burner flame. Use pliers/tweezers/corks to hold the wires while heating. Borax is toxic to humans if ingested in large quantities, so students should avoid skin contact with the powder to reduce the risk of accidental ingestion. The glass beads can fall off the wire, so caution students not to "flick" the wire when they have a hot bead.

Instructions:
1. Cut two pieces of copper wire and two pieces of nichrome wire, each about 12 cm long.
2. Place a small amount of borax (about a teaspoon) in a watch glass or other heat-resistant container.
3. Use the pliers to form a small loop on the end of each wire. The loop should be slightly larger than the eraser on the end of a pencil (Figure 5).

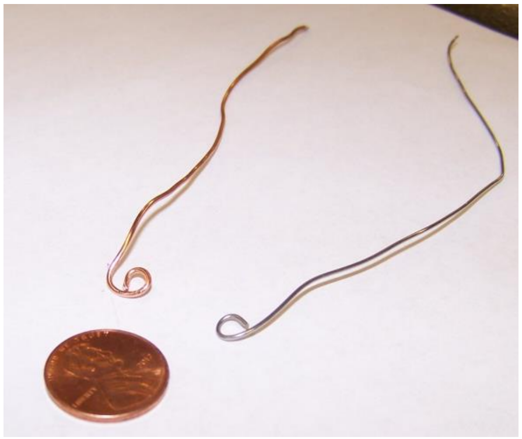


Figure 5. Wire with an appropriate size loop formed at one end

4. Using a Bunsen burner, heat the loop at the end of one of the copper wires until it gets red hot. Be sure to use the pliers to hold the wire while heating. Be sure that the Bunsen burner is turned up high – you should be able to clearly see the reducing region and oxidizing region of the flame.

5. Dip the hot end of the wire into the borax.
6. Carefully heat the borax on the wire until it is melted and the loop fills in by placing the loop in the purple-colored outer flame (also called the oxidizing region of the flame). When the bead has a transparent color with very few air bubbles, you may add more borax if you would like to make a larger bead. This process can be repeated to form a spherical bead if desired, but it is also ok to make a flat bead (this typically only takes one borax treatment). This bead should have a sky blue color.
7. Repeat steps 4 - 6 with the other copper wire, but during step 6, hold the borax-covered wire loop in the blue inner flame (also called the reducing region of the flame). Keep it red hot for 10 to 15 seconds, then cool it for 10 seconds by lowering it into the darker blue flame just above the Bunsen. The color of this bead should be red. ***NOTE:*** Be sure to let the bead cool for a few moments before inspecting the color. The color produced is temperature dependent.
8. Repeat steps 4 - 6 with one of the nichrome wires. The bead produced should be a shade of green. Nichrome wire is typically composed of nickel, chromium, and sometimes a small amount of iron. Nickel produces a bead that is red to violet in color when heated in the oxidizing portion of the flame. Chromium produces a yellowish-green bead, and iron a yellowish-orange bead. Depending on how much of each element is present in the wire, the color of the bead will vary.
9. Repeat steps 4, 5, and 7 with the other nichrome wire. The bead produced should be a shade of green as well. Nickel turns grey when heated using the reducing flame. Chromium turns green, and iron turns green as well. Depending on how much of each element is present in the wire, the shade of green will vary.
10. Once you are satisfied with the size and color of the bead, allow the bead/wire to cool completely before placing the bead/wire in a plastic bag to take home.
11. You can try to remove the beads from the wire by reheating the bead and then plunging the loop into cold water. This works best with spherical beads.

Demo Delivery Hints:

1. It can be difficult to create a bead that is actually spherical. Many times, it is just easier to try to fill in the loop with the glass. Students tend to use too much borax when trying to make a large bead and they don't take the time to get all of the gases (bubbles) out. This makes the bead look like a gray, foamy blob. Patience is required to successfully make a large, colorful bead. However, a spherical bead can be made if a student is patient and gradually adds more borax while heating thoroughly in-between each addition.

Figure 6. Beads that have a gray, milky color rather than a transparent, bright color due to the gas bubbles that remain trapped in the amorphous borax.

2. Borax is a deca-hydrate, which means there is a lot of water vapor to drive off as the borax melts. This process can take quite a bit of heating and patience to get all of the bubbles out of the glass. Students often get impatient and take the wire/bead out of the flame every few seconds to check it. It will take longer to get good results this way – the wire/bead needs to be left in the flame in order for the reaction to properly occur.
3. The borax glass beads are hygroscopic, meaning that they will absorb moisture from the air. As a result, the beads will become "cloudy" after several days or weeks. The bead can be reheated to drive off the moisture and return the color clarity to the bead.

Troubleshooting:

1. If the loop is too large, the melted borax can fall or drip from the loop. Be sure to keep the size of the loop just a little larger than the end of a pencil eraser.
2. It is possible to heat the wire for too long in the flame. In this case, the wire will melt. Care should be taken to monitor how long the wire glows red hot while it is in the flame.
3. At times, students may get impatient and not take the time to melt the borax crystals completely. This will affect the color of bead that they are able to obtain. Encourage them to be patient when forming their bead.

Cleanup/Replacement Parts: Turn off the Bunsen burners and allow them to cool completely before putting them away. Allow all the wires and beads to completely cool. Students should place the beads/wire in a plastic baggie to take home. Place any unused wire back in the kit. When it is time to replenish the wire supply, copper and nichrome wire can be ordered from a variety of suppliers, such as McMaster Carr (http://www.mcmaster.com). It is recommended that 18-gauge copper wire and 20-gauge nichrome wire be used for this lab. Dispose of any unused powdered borax that has been removed from the original container. The original container of borax can be stored for further use as long as it is kept dry. Powdered borax is commonly available at Walmart® under the name "20 Mule Team Borax."

TEACHER DISCUSSION QUESTIONS

Glass Bead on a Wire

Discussion Questions to Ask Before the Demo

1. What is an amorphous solid and what is a crystalline solid?

   Discussion: Crystalline solids have an orderly arrangement of atoms, while amorphous solids have no long-range order of atoms (see Figure 1 in the Teacher Instructions).

2. Can crystalline materials become amorphous? Why?

   Discussion: Ask this question to see what the students will say. Regardless of whether they answer yes or no, ask them why they think their answer is true. Try to facilitate as much discussion about this as possible. Essentially, this lab is transforming a crystalline material into an amorphous material using thermal treatment. Many students will not think this is possible because it seems that the crystalline structure should always be crystalline (and for many materials, it is). Most crystalline materials, such as metals, retain their crystalline atomic structure during heat treatment. Some movement (rearranging) of atoms or dislocations can occur, but the overall crystalline structure is still preserved. However, materials like Borax have the ability to move from a crystalline structure to an amorphous structure during heat treatment due to water removal from the atomic structure that rearranges the atoms. Quartz sand (i.e. silica) is a key ingredient in commercial glass production and undergoes a similar crystalline to amorphous transition during heat treatment.

3. What are the two parts of a Bunsen flame and why are they different?

   Discussion: Most Bunsen burners have the ability to control gas and air flow into the burner, which subsequently control the height and intensity of the flame produced. The oxidizing region of the Bunsen flame is produced with very high amounts of oxygen. This corresponds to the outer region of the Bunsen flame as this portion of the flame is in contact with high amounts of oxygen from the air. If the burner flame is turned to high, the flame is a purple color. The reducing region of the flame is produced with low amounts of oxygen. This corresponds to the inner region of the Bunsen flame. If the burner again is turned up to high, the flame is a blue color.

Discussion Questions to Ask During the Demo

1. Ask students to identify the oxidizing and reducing region of their Bunsen flame.

   Discussion: The oxidizing region (outer part of the flame) should be a purple color, and the reducing region (inner part of the flame) should be a blue color. By asking this question, you also ensure that the students have the appropriate amount of gas and air flow for their Bunsen flame. Having the gas/air flow too low will result in a flame that is yellow, and flow that is too high will result in a flame that is just blue and makes a loud roaring sound.

2. Before testing the first copper wire, ask students to make a prediction about what color bead they think they will get.

   Discussion: Students will most likely pick something close to the original color of the copper wire, or you will get a range of color guesses. This is to be expected, and part of what makes this lab fun is that the color of the bead does not correspond to the original color of the wire, but to the metal ion and amount of oxygen that transitions into the structure of the Borax during heating. This is next to impossible to guess, unless it is just a lucky guess. The point is to facilitate discussion about what the students have seen and what they think is going to happen.

3. Before testing the second copper wire, ask students to make a prediction about the color of bead they think they will get from this wire. Emphasize that they are going to be heating this bead in a different region of the Bunsen flame.

   Discussion: Students will most likely be stumped this time. After making the first bead, they will realize that the color of the bead doesn’t have anything to do with the original color of the wire. Some will probably guess the same color as the first bead, but some of them will try to figure out how heating the bead differently is going to impact the color. Encourage discussion, and the fact that there is not necessarily one right answer. No two students are going to heat the bead exactly the same which means that some of the beads may be varying shades of the same color or a different color altogether.

4. Before testing both of the nichrome wires, ask students to make a prediction about the color of bead that they think they will get.

   Discussion: By this point, they will have seen the influence of different heating methods on the color of bead, but now they are switching to a completely different kind of wire. Color guesses will most likely be all over the place. Students most likely will not guess the colors correctly. That's ok, the point is to facilitate discussion about what they have seen and what they think is going to happen.

Discussion Questions to Ask After the Demo

Ask the students what they learned about the borax bead test.

Discussion: Emphasize why the borax is able to incorporate metal ions into its atomic structure during heating (see explanation in the Background Information section about transition between crystalline and amorphous solids due to water loss during heating). Emphasize that the color of the bead is due to the type of metal ion and the amount of oxygen (aka the part of the Bunsen flame used for heating) that can be incorporated into the borax atomic structure. This is why the copper wires produced different color beads than the nichrome wires, and also why a single type of wire could produce two different colors of beads depending on how it was heated. There are many other metals that can be tested using this type of bead test. Each produces a different color of bead. Searching "borax bead test" on the internet will provide charts of the various metals and corresponding color of bead that is produced. Feel free to expand this lab to include other metals, especially if you have older students that can perform these heating steps more efficiently and quickly than younger students.

STUDENT LAB HANDOUT

Glass Bead on a Wire

Introduction: Glasses are amorphous solids, meaning that they have no long-range order of their atoms. Crystalline materials have an orderly arrangement of atoms within their structure. Several materials that can be used to create a glass begin as a crystalline or semi-crystalline material. This indicates that glass can, at times, be a "phase of matter" rather than just a particular material.

Lab Description: In this lab, you will use copper and nichrome wire to perform a borax bead test and determine what color beads are produced from each type of wire under different heating conditions. The bead test has traditionally been used to test for the presence of certain metals. The borax bead test is one of the oldest versions of a bead test and was developed by Jöns Jacob Berzelius in 1812! The borax bead test consists of making a small loop at the end of a wire and heating it in a Bunsen flame until red hot. The loop is then dipped in powdered Borax and placed back in the Bunsen flame. The solid powder adheres to the hot wire and swells up as it loses its water of crystallization (the water found in the crystalline framework of a material – without this water, the borax cannot maintain a crystal structure). It then shrinks as the water is burned off from the heat, forming a transparent glass-like bead. The bead's color is dependent on the metal ions that were present in the wire.

Keywords: amorphous, oxidation, reduction, borax bead test, water of crystallization

Materials List:
- Bunsen burner
- pliers/tongs (something to hold the wires while heating)
- copper wire
- nichrome wire
- watch glass containing powdered borax
- plastic baggie

Safety Precautions: Safety glasses should be worn during this lab. The wires will get very hot when placed in the Bunsen burner flame. Use pliers/tongs/corks to hold the wires while heating. The glass beads can fall off the wire, so do not "flick" the wire while the bead is still hot and in a molten state. Borax is toxic to humans if ingested in large quantities, so do not play with the borax powder.

Instructions:

1. Cut two pieces of copper wire and two pieces of nichrome wire, each about 12 cm long.
2. Use the pliers to form a small loop on the end of each wire. The loop should be slightly larger than the eraser on the end of a pencil.
3. Place a small amount of borax (about a teaspoon) in a watch glass or other heat-resistant container.
4. Using a Bunsen burner, heat the loop at the end of one of the copper wires until it gets red hot. Be sure to use the pliers to hold the wire while heating. Be sure that the Bunsen burner is turned up high – you should be able to clearly see the reducing region and oxidizing region of the flame.
5. Dip the hot end of the wire into the borax.
6. Carefully heat the borax on the wire until it is melted and the loop fills in by placing the loop in the purple-colored outer flame (also called the oxidizing region of the flame). When the bead has a transparent color with very few air bubbles, you may add more borax if you would like to make a larger bead. This process can be repeated to form a spherical bead if desired, but it is also ok to make a flat bead (this typically only takes one borax treatment). Be sure to let the bead cool for a few moments before inspecting the color. The color produced is temperature dependent.
7. Repeat steps 4 - 6 with the other copper wire, but during step 6, hold the borax-covered wire loop in the blue inner flame (also called the reducing region of the flame). Keep it red hot for 10 - 15 seconds, then cool it for 10 seconds by lowering it into the darker blue flame just above the Bunsen.
8. Repeat steps 4 - 6 with one of the nichrome wires.
9. Repeat steps 4, 5, and 7 with the other nichrome wire.
10. Once you are satisfied with the size and color of the beads, allow the beads/wire to cool completely before placing the beads/wire in a plastic bag to take home with you.
11. You can try to remove the beads from the wire by reheating the bead and then plunging the loop into cold water, but this usually only works with spherical beads.

Clean Up: Turn off the Bunsen burners and allow them to cool completely before putting them away. Allow all the wires and beads to completely cool before placing in a plastic baggie to take home with you. Dispose of any extra borax remaining in the watch glass, and rinse the watch glass with soap and warm water.

STUDENT QUESTION HANDOUT

Glass Bead on a Wire

1. Compare the nichrome and copper wires. What is different about them? What is the same?

2. Draw a picture of the Bunsen flame. Where is the oxidizing region of the flame? The reducing region? Why are these two regions different?

3. What happens to the borax when it is heated on the hot wire? Why?

4. What color bead did you make when heating the copper wire and borax in the oxidizing flame? The reducing flame? Why are these two different?

5. What color bead did you make when heating the nichrome wire and borax in the oxidizing flame? The reducing flame? Why are these two different?

6. Compare the bead colors obtained from the copper wire vs. the nichrome wire. Are they different? Why?

TEACHER INSTRUCTIONS

Engineered Concrete

Objective: To demonstrate how preparation (design) of a material can affect the final material properties and to provide an introduction to composites.

Background Information: Portland cement is a ceramic material that forms the main building block of concrete. When water is mixed with Portland cement, it forms a strong bond with the cement particles and starts to cure. Curing means that the water does not evaporate, but becomes part of the hardened cement; the water and cement particles become locked together in an intertwining matrix. This matrix will gradually harden over time to form a solid material which is typically called cement paste (due to the fact that only water and Portland cement were used to create it). The addition of other items such as sand, rock, or fibers to the cement paste while it is being mixed creates a composite material. The addition of sand, rock, or fibers provides reinforcement, and the cement paste provides a way of bonding the materials together. Cement paste containing sand is typically referred to as mortar. Cement paste containing sand (i.e., fine aggregate) and rock (i.e., coarse aggregate) is typically referred to as concrete.

Composite materials, such as mortar and concrete, exhibit characteristics different from the characteristics of the individual materials used to create the composite.

The final material properties of the composite are dependent on how much of each individual material is used in the composite (i.e., quantity of sand/rock vs. quantity of Portland cement vs. quantity of water). For concrete, adding too much reinforcement will cause the material to be very weak since there will not be enough cement paste to hold the composite together. Likewise, adding too much or too little water will also affect the concrete since there must be just the right amount of water in the composite to react with all of the Portland cement. Scientists and engineers must carefully plan how much of each material will go into a composite to make sure that the composite will have the final material properties needed for a given application.

When initially designing a composite, the appropriate amount of each material to be added is often unknown. Scientists and engineers often create the first mix design (which indicates the quantity of each component to add) based on how the individual components behave. As previously discussed, a composite has characteristics different from the characteristics of the individual materials used to create the composite, so the first mix design is really just a hypothesis, or educated guess, about what should go into the composite. The results of the first mix design are examined, and then the mix design is tweaked to create a second mix design (which hopefully performs better than the first). This second mix design is then tested, and the process is repeated until the desired material properties are achieved. When designing a new material, one rarely gets the mix design right the first time! It usually takes multiple iterations to achieve the desired properties for a specific application or material. This design process is an integral part of developing new composites to meet the challenges of our ever-changing world.

There are many examples of composites in our everyday lives. Wood is a natural composite composed of cellulose fibers in a matrix of lignin, a natural glue-like material. Wood is also sensitive to water. Wood has the ability to absorb water into its cells, which will make the material softer and more pliable (e.g., soggy wood that has been exposed to water has a different texture and strength than dry wood). Human-made composites include rubber tires, fiberglass, and concrete. Most car tires are composed of rubber reinforced with fibers. Rubber keeps the pressurized air in the tire, and the fibers provide the strength needed to sustain the stresses imposed on the tire by the road as the car is being driven. Fiberglass is also a very common composite that is used in a wide variety of materials such as boats, automobiles, bathtubs, and surfboards. Fiberglass is created by embedding fine glass fibers in a plastic matrix (e.g., epoxy or polyester). The most commonly used human-made composite is concrete. Concrete, like most composites, has the ability to be designed for different applications based on the type and quantity of reinforcement material that is added to the composite (e.g., steel rebar or fibers for tension reinforcement). See the introductory PowerPoint presentation on the flash drive in the kit for additional examples of real-world applications involving composites.

Lab Description: In this lab, students will design and make a reinforced Portland cement paste. There are numerous ways to run this lab. The main idea is for students to experience the composite design process. At least two mix designs (iterations) should be used to allow students to:

1. Hypothesize about the quantity of each component that should be added to the cement paste.
2. Test how well their first hypothesis worked.
3. Refine their design based on the results from step 2 to make a second mix design.
4. Test their second mix design and evaluate the results.

If time allows, you can have students perform more than two iterations of their mix design. Also, there are multiple ways to set-up the iterations that the students will perform. For example, you can have students experiment with different w/c ratios for the first iteration and different amounts of reinforcement for the second iteration. As an alternative, you could also have students add a set amount of reinforcement for the first iteration, and allow them to choose how much reinforcement to add for the second iteration. You will need to decide what is appropriate for your class. Generally, older students can handle changing multiple components (e.g., adjusting the w/c ratio in the first iteration and reinforcement in the second iteration), while younger students tend to do better with adjusting just one component (e.g., keeping the w/c ratio constant and adjusting the amount of reinforcement added for both iterations). For this set of instructions, the more complex example (changing multiple components) has been explained, but the instructions are written in such a way that it should be easy to update for different iterations. For both iterations, students will mix a reinforced cement paste and allow it to cure in a mold. The reinforced paste will be allowed to harden overnight and form cement "pucks." The pucks will be tested by dropping them from a height of at least 15 feet.

Keywords:

- Portland cement – a fine powder composed primarily of ground clinker (mostly ground limestone).
- concrete – a composite material composed of Portland cement, water, and aggregate.
- composite – a material that is composed of two or more materials and has different properties than the original materials.
- design – a plan for how to prepare a material or a method for combining the materials in a composite:
    - ◊ percentage of each material that should be added
    - ◊ how to combine the materials
    - ◊ curing conditions, etc.
- reinforcement – a material that is typically added to another material to give it increased mechanical properties (e.g., the addition of steel rebar or fibers to concrete).

Materials List:

Items provided in the kit

- 10 plastic measuring spoons
- one mass balance

Items to be provided by the teacher/school

- Portland cement – 200g of cement per puck is needed if using Styrofoam bowl molds
  Note: Portland cement can be purchased from a local hardware store in a variety of sizes, 20 lb. bag = 9000g cement = 45 pucks
- disposable plastic cups (Solo cups or a cheaper equivalent) – 8 to 10 cups are needed for each group
- polystyrene ("styrofoam") bowls (12 oz.) – two bowls per student are needed
- ruler
- popsicle sticks/plastic spoons or knives (something to stir the paste) – two per student are needed
- plastic wrap – 1 roll should be more than enough
- permanent marker (Sharpie® or cheaper equivalent)

· plastic sandwich bags – OPTIONAL (needed if you want to store the cracked pucks after testing)
· latex/non-latex gloves – OPTIONAL (for students to wear while mixing the cement if desired)

Items to be provided by the students
· Reinforcement items

Safety Precautions: Short-term skin exposure to Portland cement is not harmful, but students should avoid skin contact if possible. The Portland cement will be a very fine powder. Care should be taken when transferring the powder from the bag to the plastic cups to keep from generating a dust cloud. If a cloud occurs, allow the powder to settle and then wipe it up with a damp paper towel. Students should wash their hands immediately after handling the cement paste, before it has time to harden. If desired, have students where latex gloves (or non-latex if allergies are an issue) to prevent skin exposure.

Instructions:

1. A few days before the lab, split the students into groups of three and have them discuss what reinforcement item(s) they want to bring for their group.
2. On the day of the lab, have each student prepare a styrofoam bowl so that it is ready for the cement paste. They should use a ruler to measure ¾” from the bottom of the bowl on the slanted portion of the bowl and mark it with a pen. Measure this in several places and then use the marks to draw a line around the inside of the bowl. Students will pour cement paste into the bowl until reaching the line. This will create pucks that are approximately the same thickness. The thickness of a puck is influenced by the amount of each component added to the paste, and pucks of different thickness may perform differently due to geometry rather than the components added to the puck. Figure 1 shows pucks that were made with no regard to the thickness. It can clearly be seen that for the same amount of cement, adding different amounts of water can significantly influence the thickness of the puck. It is expected that the thicker pucks will perform better simply due to the added mass (i.e., a thicker object is usually harder to break than a thinner object of the same material). This is why it is important to specify the same thickness for all of the pucks.

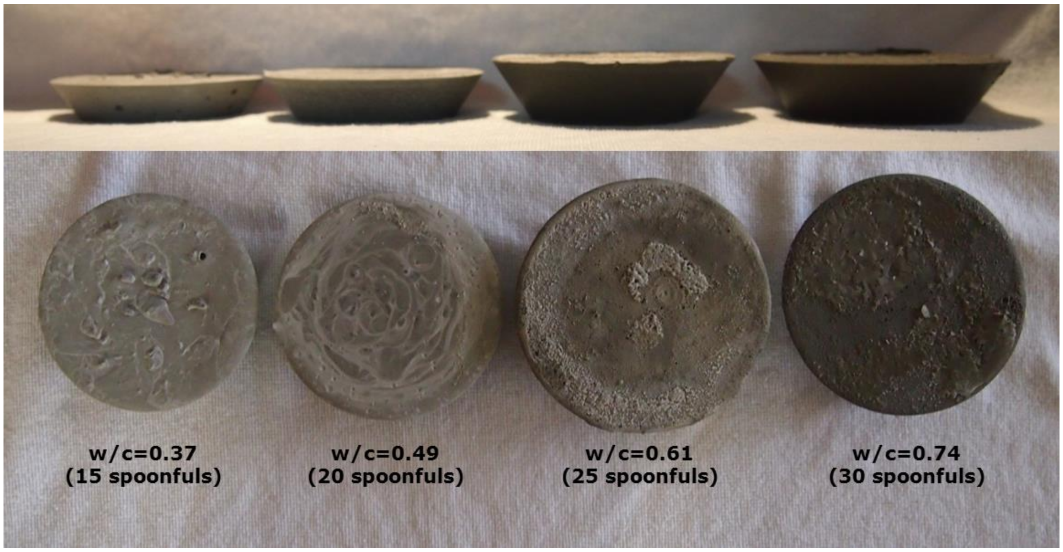


Figure 1. Influence of w/c ratio on the thickness and color of the cement puck

3. Have each student measure 200g of cement powder into a plastic disposable cup (you can also have this pre-measured for each student if access to a mass balance is limited).
4. For every group of three students, provide a plastic disposable cup full of water, three plastic measuring spoons, and three water to cement (w/c) ratios. Choose a low, average, and high w/c ratio so that students will be able to evaluate the effect of different amounts of water on their reinforced cement paste. For example, w/c ratios of 0.3, 0.5, and 0.8 work well for this part of the lab.
5. The w/c ratio can be calculated from the following equation:

$$w/c = \frac{mass\ of\ \ water}{mass\ of\ \ cement} = \frac{\#\ of\ \ spoonfuls \times 4.93cm^3 \times 1g/cm^3}{200g}$$

   The volume of the white measuring spoon is 4.93 cm^3 and the density of water is 1 g/cm^3. Give students the volume of the spoon and the density of water and ask them to figure out how many spoonsful of water should be added to their cement powder to get each of the three w/c ratios you specified in step 2. Encourage them to work with their group to do this, without your help.
6. Once the calculations for the amount of water to add have been completed (and checked by you for each group), decide on the amount of reinforcement to add to the pucks. For this first iteration, it is recommended that you set the amount of reinforcement in terms of a mass basis or a volume basis. For example, tell each group to add 5g of their reinforcement item (mass basis) or two spoonsful (volume basis – use the measuring spoons included in the kit to keep a consistent measurement for each group). You can let

the students discuss this and settle on the number as a class (the class should come to a consensus on **one** number, e.g., 2g), or you can just decide for them. Sometimes the mass vs. volume choice will depend on the reinforcement items that the students choose to bring in (this is why it is a good idea to have the students decide what to bring *before* the lab so that you have a chance to evaluate what they will be using). Items like rice are very easy to measure on both a mass and a volume basis, but items such as glass fibers are easy to measure by mass and difficult to measure by volume. Also keep in mind when using the mass basis that items can vary drastically: 5g of rice vs. 5g of glass fibers is going to be very different in terms of volume, and it could be difficult to incorporate that volume into a single cement puck.

7. Have each group measure the specified amount of reinforcement item decided in step 6. Each group should repeat the measurement two more times so that they have reinforcement items measured for three pucks. ***NOTE:*** Asking the students to pre-measure their reinforcement item before mixing gives you a chance to see what each group be adding to their puck in terms of mass/volume. You can check and see if this is a reasonable amount to add. If it's not, this is your chance to increase or decrease the amount the class is using (e.g., if you specified for them to add 5g of their item – say, feathers, for example – to the puck but then realize that this is a very large amount, you could decrease the amount to add to 2g). Try to be sure that the amount you ask the groups to add is reasonable for all reinforcement items that were brought in.
8. Have the groups start mixing their pucks. Each group should be making three pucks (one per student). Each puck should have the same amount of cement and reinforcement item and different amounts of water (the three w/c ratios specified in step 4).
9. Measure the appropriate amount of water for each puck into a plastic disposable cup.
10. Using the cup of pre-measured cement powder, slowly add some of the cement powder to the water. Caution students not to "dump" a large amount of cement powder into the cup as this usually creates a small dust cloud.
11. Stir the mixture with a popsicle stick or plastic spoon until well blended.
12. Continue adding cement powder and stirring until all of the powder has been added and the mixture is well blended.
13. Then have students decide how to add their reinforcement item. Depending on what item is being added, it may be easier to pour the item into the cup containing the cement paste and mix it with a popsicle stick. The item can also be placed in the mold and the paste poured over the top (this can also be done in layers – add some paste, add some reinforcement, add some paste, add some reinforcement, etc.). Encourage the groups to discuss which method they should use and why. ***NOTE:*** Some reinforcement items naturally lend themselves to one method or the other. This step is to get students to think about how they are actually making their puck in addition to what is included in it.

14. Record on the data sheet the method used for incorporating the reinforcement.
15. Once the students are satisfied with their method choice, have them add their reinforcement item and get their paste into a Styrofoam bowl with as little sloshing as possible. Be sure to remind them to fill only to the marked line and then discard any leftover paste.
16. Have students comment on any differences among their group's reinforced cement pastes, such as was one paste runnier than the other, did the reinforcement stick out of the top, etc.
17. Cover the top of the bowl with plastic wrap and allow it to cure overnight.
18. The following day, de-mold the cement paste pucks by gently pulling on the sides of the Styrofoam bowl to loosen the bond between the paste and bowl. Place your hand over the top of the bowl and turn it over. Most of the time, the puck will fall out of the bowl. If it does not, start tearing pieces of the bowl away in large chunks until the puck can be removed.
19. Label each puck with the student's name and w/c ratio using a permanent marker.
20. After all of the pucks are de-molded, have students comment on any differences that they notice about the color or texture of the pucks.
21. Drop the pucks from a height of at least 15 feet. The top of a set of bleachers works well as long as the puck can fall on a hard, solid surface. The second floor or roof of a school building or a tall play set will also work. The pucks should be dropped in an "upright" position (how they were poured in the bowl). Try to drop the pucks as evenly as possible, as if you were dropping a bowl full of oatmeal and want it to land in an upright position so that nothing spills. Have students stand in a semi-circle at least 15 feet away from the point of impact so that everyone can see what is happening. Figure 2 shows pucks with different w/c ratios after dropping from a height of at least 15 feet.

w/c=0.25 (10 spoonfuls) | **w/c=0.37 (15 spoonfuls)** | **w/c=0.49 (20 spoonfuls)** | **w/c=0.61 (25 spoonfuls)**

Figure 2. Pucks with different w/c ratios after dropping from a height of at least 15 feet.

22. After each puck is dropped, have the students record on their data sheet what happened to the puck (did it crack into lots of pieces, a few pieces, stay in one piece, etc.). Have the students describe what the fracture surfaces look like (is the reinforcement sticking out of the cross-section or sheared off, is the reinforcement spread throughout the cross-section or clumped up in one section, etc.). It can also be helpful to take a picture of the puck after it is dropped so that you can distinguish differences between how the pucks performed.
23. Have the student whose puck was dropped pick up the pieces so that the site is ready for the next puck to be dropped. You can also have the student place the pieces of their puck in a plastic baggy so that they can compare all of the pucks after the testing is finished.
24. Have each group compare the performance of their 3 pucks. Encourage them to discuss which w/c ratio worked best for their reinforcement item. Also have them discuss what they thought about the quantity of reinforcement added – was it too much? Too little?
25. Ask each group to share with the class which w/c ratio worked best and what they thought about the quantity of reinforcement used.
26. Next, as a class, discuss the performance of the different groups. ***NOTE:*** In step 24, the groups are evaluating the effect of w/c ratios; in this step, the class is discussing the influence of different reinforcement items as well as the w/c ratio.
27. For the second part of the lab, allow each group to decide their own mix design. Encourage them to evaluate the puck results from their group as well as the overall class results when deciding how much water and reinforcement to add to their second puck. Remind them that they must keep the amount of cement powder the same (to ensure that they make enough paste to fill the bowl appropriately). Since there are 3 students in each group, you can allow them to make 3 different pucks (i.e., they will have 3 attempts to adjust the water/reinforcement to make a better puck) or ask them to agree on one mix design and only make one puck per group. Do what works best for the time constraints in your classroom.
28. Repeat steps 9 - 23 and again discuss the results within the group and together as a class.

Demo Delivery Hints:

1. Cement paste is very easy to remove from desks and skin when it is still wet (it will wipe off with a damp paper towel), but more difficult to remove once it has dried. Providing each group with some damp and dry paper towels during the lab will help them keep their hands and the lab area clean. If students have a large amount of wet cement paste on their hands, have them wipe their hands on a paper towel before washing their hands in a sink. Large amounts of wet cement paste can harden in the pipes of a sink and will cause clogging (small amounts will generally wash down without any trouble).

2. During the first part of the lab, the lower w/c ratios may be more difficult to stir. Encourage students to stir for several seconds each time they add cement powder to make sure that they are allowing time for everything to mix well. The 0.3 w/c ratio can be especially difficult. This mix requires quite a bit of stirring, but will eventually take on the consistency of thick toothpaste. Encourage the students mixing this w/c ratio to be patient and to continue stirring.
3. Plastic cups are used for mixing the cement because it is more difficult to poke holes in this type of cup when stirring compared to a styrofoam or paper cup (styrofoam also tends to slough off in small amounts when gouged with a popsicle stick). However, a styrofoam bowl tends to provide a better mold since it is somewhat slick and does not have ridges to stick to the cement paste. It is also much easier to de-mold since styrofoam tends to easily break into pieces. Styrofoam cups generally do not work well as well as the bowls for molds since the cups tend to slough off in small pieces and are more difficult/messy to demold from the pucks. Feel free to experiment with other types of cups/bowls (e.g., paper cups that are waxed on the inside).
4. Before performing the drop test, it is often fun to have each student stand on their puck to see if it can hold their weight. Most pucks will be able to withstand this weight.
5. To help contain the pucks when they are dropped, open both ends of a large cardboard box and stand it upright in the “landing zone”. This will help contain the pieces of the puck when it hits the ground while still allowing the puck to hit a hard surface.
6. For younger students, it may be better to perform this lab by keeping the w/c ratio constant for all pucks and only changing the amount of reinforcement added. It is still recommended for you/the class to specify a single amount to be added by every student for the first iteration (e.g., 2g) and then allow each student the freedom to choose the amount for the second iteration. This allows them multiple iterations to adjust one component of the composite and look at the corresponding results, which is a simpler exercise than adjusting two components and analyzing the results.

Troubleshooting: In some cases, the styrofoam bowl may stick to the cement puck, especially if a lot of cement paste was sloshed up on the sides of the bowl. Using a butter knife to pry the Styrofoam bowl away from the cement puck can help break the bond between the bowl and cement.

Cleanup/Replacement Parts: Dispose of the plastic cups, popsicle sticks, styrofoam bowls, and crushed cement paste pucks in the trash. The plastic measuring spoons should be washed with soap and warm water, dried, and returned to the kit for later use. The balance should also be wiped down with a damp paper towel and returned to the kit. The Portland cement, plastic cups, styrofoam bowls, and popsicle sticks will need to be replaced before the lab is run again. All of these items can be purchased at local grocery and hardware stores. If you have Portland cement left over, this can be stored in a sealed container for further use. If the Portland cement begins to get clumpy, then new Portland cement should be purchased.

TEACHER DISCUSSION QUESTIONS

Engineered Concrete

Discussion Question to Ask Before the Demo

Why do you think it is important for scientists and engineers to be able to control the design of a material?

Discussion: See the information in the Background Information section of the Teacher Instructions.

Discussion Questions to Ask During the Demo

1. When students are adding water during the first part of the lab, have them discuss the differences that they see in the cement paste mixture of their group.

   Discussion: The low w/c ratio mixture will be very thick and difficult to stir. It should have a darker gray color compared to the higher w/c ratios. The high w/c ratio mixture will be very runny, almost like water. It should be a light gray color. The average w/c ratio will be somewhere between these two, both in color and texture. It is important for students to make these observations as they will be completely on their own in designing the second mix design. The first part of this lab provides the opportunity for them to make some conclusions on how water affects the texture of the paste and how this translates to performance.

2. During the first part of the lab, have students discuss how each puck performed after it was dropped.

   Discussion: Ask them general questions about how it broke. Did it shatter into lots of little pieces? Break into several large pieces? Did it break at all? Ask them why they think the pucks performed differently from each other? Assuming that each puck is dropped in a similar fashion, the main difference in the pucks is going to be w/c ratio and the reinforcement item used. For pucks with very low w/c ratios, strength will be lower due to the increased number of air voids in the paste. It is usually difficult to distribute reinforcement evenly in this type of paste which may also cause defects in the paste. For pucks with high w/c ratios, the strength will also be lower. The ratio of water to cement in this type of puck is so high that when the cement starts to mix with the water, there is not enough cement available to make a strong hydration product. This is similar to adding too much water to a Kool-aid mix. If you start with a set amount of Kool-aid powder and add the amount of water called for on the container, your Kool-aid will taste just right. If you add double the amount of water, your Kool-aid will taste very weak because there is not enough Kool-aid powder available to mix with that amount of water. This type of cement also generally has a hard time bonding to the reinforcement item because it is already weak. The average w/c ratio puck tends to work the best. However, if students bring in a reinforcement item that can absorb water, this will affect how the pucks perform. Encourage the students to think about why the puck performed the way it did. Have them examine the fracture surfaces for clues on how the reinforcement helped or hindered the puck.

3. After all the pucks have been tested, have students discuss which puck was the best.

   Discussion: Encourage students to discuss why this puck worked well – was it the reinforcement item itself, or the quantity of reinforcement added vs. the amount of water and cement in the puck?

4. Have students discuss what they plan to try for their second mix design based on the discussion from Questions 2 and 3.

   Discussion: Encourage students to discuss what they want to try and why. Have them discuss this within their group first, then as a class. Ask them how they decided on the quantity of water and reinforcement item to add. Have them record their reasoning on the Student Question Handout.

5. During the second part of the lab, have students discuss how each puck performed after it was dropped.

   Discussion: This is a similar discussion to Question 2, but emphasize whether what they changed from the first mix design was successful in improving the puck. Also encourage them to justify why their puck improved. If their puck did not improve, ask them what they would do differently the next time to try to get better results.

Discussion Questions to Ask After the Demo

1. What was the influence of the w/c ratio on the strength of the puck?

   Discussion: Pucks with very low or very high w/c ratios will perform worse than pucks with average w/c ratios (see reasoning in Question 2).

2. What was the influence of the reinforcement items on the strength of the puck?

   Discussion: This will vary depending on what items students bring in. Choose the items that performed the best and the worst and discuss with the students why they think this happened. Was too much of the item added? Were the item and cement able to bond together? Was the size of the reinforcement item too large compared to the size of the puck? Fibers or fiber-like reinforcement tends to perform the best. In real-world applications, fibers are added to concrete because they can be randomly distributed throughout the cement matrix. This means that the fibers are found in all different orientations throughout the matrix. When loading the concrete, the fibers are able to absorb many different kinds of loadings because of the different orientations. Steel rebar is another type of reinforcement that is traditionally used in concrete. Rebar typically runs only in one or two orientations in the matrix. It is too big and too thick to be randomly distributed throughout the matrix. As a result, the rebar only helps reinforce the concrete when loads are applied in a certain direction. In addition, the rebar is quite large and not very flexible compared to fibers. Therefore, de-bonding sometimes occurs between the concrete and the rebar during loading. This leads to cracking of the concrete and allows water to penetrate into the matrix, which starts corroding the steel rebar. Fibers can be made from a variety of materials (most of which are non-corrosive) and tend to be much smaller and flexible, so de-bonding is more difficult.

3. How important is it for scientists and engineers to be able to control the design of the material?

   Discussion: Based on the results of the lab, stress that it is important for scientists and engineers to be able to control the design of a material. This lab demonstrated that the amount of water and the amount of reinforcement added can affect the strength of a cement puck. It sometimes takes multiple iterations of tweaking the amount of materials included in order to optimize the ideal composite. Scientists and engineers routinely do this to develop materials for new applications. It is important to choose the materials that go in a composite with an understanding of the influence of each individual material on the final composite material properties. Many times, scientists and engineers can use different mix designs (same materials, but added in different amounts) for different applications. For example, cement can be designed to minimize the influence of a specific chemical attack on the final composite by decreasing the amount of certain compounds that are used to make the cement powder. However, what works for one type of chemical attack may be very detrimental for a different type of chemical attack. This is why cement mix designs are often tweaked based on the intended use of the finished concrete (outside vs. inside; chemically aggressive environments vs. normal environments, etc.).

STUDENT LAB HANDOUT

Engineered Concrete

Introduction: Portland cement is a ceramic material that forms the main building block of concrete. When water is mixed with Portland cement, it forms a strong bond with the cement particles and starts to cure. Curing means that the water does not evaporate, but becomes part of the hardened cement – the water and cement particles become locked together in an intertwining matrix. This matrix will gradually harden over time to form a solid material which is typically called cement paste. Addition of other items such as sand, rock, or fibers, to the cement paste while it is being mixed creates a composite material. When sand is added to cement paste, it forms a composite material called mortar. When sand and rock are added to cement paste, it forms a composite material called concrete.

Composite materials, such as concrete, exhibit characteristics different from the characteristics of the individual materials used to create the composite.

In concrete, the addition of sand, rock, or fibers provides reinforcement, and the cement paste provides a way of bonding the materials together. The final material properties of the composite are dependent on how much of each individual material is used in the composite. Scientists and engineers must carefully plan how much of each material will go into a composite to make sure that the composite will have the final material properties needed for a given application.
When initially designing a composite, the appropriate amount of each material to add is often unknown. Scientists and engineers often create the first mix design (indicates the quantity of each component to add) based on how the individual components behave. As previously discussed, a composite has characteristics different from the characteristics of the individual materials used to create the composite, so this first mix design is really just a hypothesis, or educated guess, about what should go into the composite. The results of the first mix design are examined, and then the mix design is tweaked to create a second mix design (which hopefully performs better than the first). This second mix design is then tested, and the process is repeated until the desired material properties are achieved. When designing a new material, one rarely gets the mix design right the first time! It usually takes multiple iterations to achieve the desired properties for a specific application or material. This design process is an integral part of developing new composites to meet the challenges of our ever-changing world.

Lab Description: In this lab, you will design and make a reinforced cement paste. For the first part of this lab, you and your class members will discuss with your teacher what goes into your cement paste. You will then pour your reinforced paste into a mold and allow it to harden overnight. Your hardened cement "puck" will then be tested by dropping the puck from a height of at least 15 feet. For the second part of the lab, you will use the results from the first part of the lab to make a second mix design. This time, you will decide how much water and reinforcement to add to your cement paste! You will again make a cement puck and test it to see if your mix design improved the performance of the puck.

Keywords: Portland cement, concrete, design, composite, reinforcement

Materials List (this list is for a group of three)**:**
- three plastic measuring spoons
- one balance (shared among everyone in the class)
- 1200g Portland cement (200g per student for each part of the lab)
- six plastic cups (three for each part of the lab)
- six styrofoam bowls (three for each part of the lab)
- six popsicle sticks (three for each part of the lab)
- ruler
- plastic wrap
- reinforcement items that you bring from home

Safety Precautions: The Portland cement will be a very fine powder. Care should be taken when transferring the powder from the bag to the plastic cups to keep from generating a dust cloud. If a cloud occurs, allow the powder to settle and then wipe it up with a damp paper towel. Short-term skin exposure to Portland cement is not harmful, but you should avoid skin contact if possible. If you get some of the wet or dry cement mixture on your hands, wipe your hands off with a damp paper towel immediately, before the cement has time to dry. If needed, ask your teacher for gloves to help protect you from skin exposure to the cement.

Instructions:
1. Get a styrofoam bowl and use a ruler to measure ¾" from the bottom of the bowl on the slanted portion and mark it with a pen. Measure this in several places and then use the marks to draw a line around the inside of the bowl.
2. Measure 200g of cement powder into a plastic cup. Each student in your group should do this.
3. Fill another plastic cup with water for your group to share.
4. Using the 3 water to cement (w/c) ratios provided by your teacher, calculate the number of spoonsful of water that should be added to the cement powder to obtain a paste that has each w/c ratio. The volume of the white measuring spoon is 4.93cm^3 and the density of water is 1g/cm^3. Remember, you are starting with 200g of cement powder.
5. Show your teacher your calculations for all three w/c ratios.

6. Discuss with your teacher and the rest of the class what amount of reinforcement should be added (for example, 2g of your reinforcement item, one spoonful of your item, etc.). The class should come to a consensus on the amount to add – all groups will use this number for their reinforcement item.
7. You are now ready to make your cement puck. Divide the w/c ratios among the members of your group so that each member is making a puck with a different w/c ratio. Each group should be making three pucks (one per student). Each puck should have the same amount of cement and reinforcement item and different amounts of water.
8. Measure the amount of water that you need for your particular w/c ratio into an empty plastic cup (each student in your group should do this).
9. Using the cup of pre-measured cement powder, slowly add some of the cement powder to the water. Do not "dump" a large amount of cement powder into the cup as this usually creates a small dust cloud.
10. Stir the mixture with a popsicle stick or plastic spoon until well blended.
11. Continue adding cement powder and stirring until all of the powder has been added and the mixture is well blended.
12. Once each mix is well blended, think about how you want to add your reinforcement item to the paste (all at once, a little at a time, as you are putting it in the mold, etc.)
13. Record on your Data Sheet the method used for incorporating the reinforcement.
14. Once you are satisfied with your method choice, add your reinforcement and get your paste into a Styrofoam bowl with as little sloshing as possible. If using the bowl, be sure to fill only to the marked line and then discard any leftover paste.
15. Record any differences among your group's reinforced cement pastes on your Data Sheet – was one paste runnier than the other, did the reinforcement stick out of the top, etc.
16. Cover the top of the bowl/ pipe mold with plastic wrap and allow it to cure overnight.
17. The following day, de-mold the cement paste pucks by gently pulling on the sides of the Styrofoam bowl to loosen the bond between the paste and bowl. Place your hand over the top of the bowl and turn it over. Most of the time, the puck will fall out of the bowl. If it does not, start tearing pieces of the bowl away in large chunks until the puck can be removed.
18. Label your puck with your name and w/c ratio using a permanent marker.
19. After all of the pucks are de-molded, comment on any differences you notice about the color or texture of each group's pucks.
20. Drop the pucks from a height of at least 15 feet. Try to drop the puck in an "upright" position (how they were poured in the bowl/pipe mold). Try to drop the pucks as evenly as possible – as if you were dropping a bowl full of oatmeal and want it to land in an upright position so that nothing spills.

21. After each puck is dropped, record on your Data Sheet what happened to the puck (did it crack into lots of pieces, a few pieces, stay in one piece, etc.). Describe what the fracture surfaces look like (is the reinforcement sticking out of the cross-section or sheared off, is the reinforcement spread throughout the cross-section or clumped up in one section, etc.).
22. If your puck was the one dropped, pick up the pieces so that the site is ready for the next puck to be dropped.
23. Once the pucks have all been tested, compare the performance of your group's 3 pucks. Discuss which one was best and why – was it the w/c ratio, the quantity of reinforcement added, the type of reinforcement added, etc.
24. Record your observations on the Student Question Handout and share your observations with the class.
25. Next, as a class, discuss the performance of the different groups. Consider the influence of different types of reinforcement items.
26. Record your observations about the other groups' pucks on the Student Question Handout.
27. For the second part of the lab, you will create your own mix design. Evaluate the results of the first part of the lab and decide how much water and reinforcement item you think should be added to your cement paste. Each member of your group can come up with a different mix design, but you must agree as a group on the 3 designs you want to try.
28. Repeat steps 7 - 21 and again discuss the results within the group and together as a class.
29. Record your observations on the Student Questions Handout.

Clean Up: Dispose of the plastic cups, popsicle sticks, Styrofoam bowls, and crushed cement paste pucks in the trash. The plastic measuring spoons should be washed with soap and warm water, dried, and returned to the kit for later use. The balance should also be wiped down with a damp paper towel and returned to the kit.

Data Sheet for Pucks

Mass of Portland cement: W/C ratio of your puck: Type and amount of reinforcement added:
Number of spoonsful of water added to your puck:
Method for adding reinforcement:
Differences in your group's reinforced cement pastes:
Performance
Puck 1:
Puck 2:
Puck 3:
Puck 4:
Puck 5:
Puck 6:
Puck 7:
Puck 8:
Puck 9:
Puck 10:
Puck 11:
Puck 12:

Student Question Handout

Engineered Concrete

1. What type of reinforcement did you bring from home to strengthen your puck? Why?

2. For the first part of the lab, which of your group's three pucks performed the best? Why?

3. How well did your puck perform compared to the rest of the class? Why?

4. Which puck performed the best out of the entire class? Why?

5. What did you choose to change for the second round of testing? Why?

6. Did this improve your puck's performance?

7. Which puck performed the best during the second round of testing? Why?

TEACHER INSTRUCTIONS

Thermal Processing of Bobby Pins

Objective: To show the difference that processing, especially thermal processing, can have on the properties of a material.

Background Information: A material can possess a variety of different mechanical properties such as strength, stiffness, plasticity, elasticity, and deflection. Deflection is the amount of displacement experienced by a material when placed under a load. This property is of great importance in building construction, and building codes often specify a maximum allowable deflection, generally as a fraction of the length of the beam. A material's mechanical properties are dependent on the material's microstructure, including the phases present, the number and arrangement of dislocations, and the grain size and shape.

Thermal processing is used to change the crystal structure, defect structure (dislocations), and/or grain structure of a material. Annealing is a process used to weaken metals, such as steel, to make them easier to form into desired shapes. To anneal metal, it must be heated above a critical temperature, maintained at that temperature, and then allowed to cool. For steel, that critical temperature is the transformation temperature to austenite or austenite/cementite. If a metal is annealed for too long it is considered to be "over-aged," and in this state, it has very few dislocations and is very ductile. Heating the metal to a red-hot temperature causes the atoms to move faster and more freely. By slowly cooling from this high temperature, the atoms are able to adopt more ordered arrangements and create a more perfect crystal. The more perfect the crystal of the metal, the easier atoms can "slide" past one another, and thus, the more easily the metal can bend. The material also tends to have large grains after annealing and slow cooling (see Figure 1), and this leads to a more malleable material. In contrast, to make a metal hard and brittle through thermal processing, it must be rapidly quenched from high temperature to room temperature. This quick cooling of the metal from red-hot temperatures freezes the atoms into a disordered phase with many defects. Due to the large number of defects, the atoms cannot move easily, and the metal is considered hard to bend and brittle. Quenching a metal such as steel will also cause it to change phases (or atomic arrangements) and sometimes form a phase called martensite (see Figure 2), which is very hard and brittle. See the introductory PowerPoint presentation on the flash drive in the kit for examples of real-world applications where thermal processing is used to modify materials.

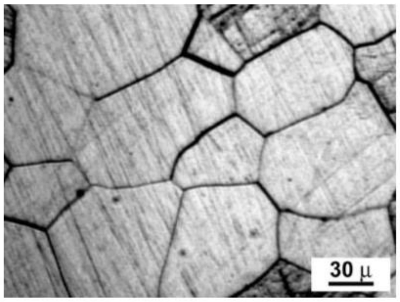


Figure 1. Grain structure of polycrystalline metal

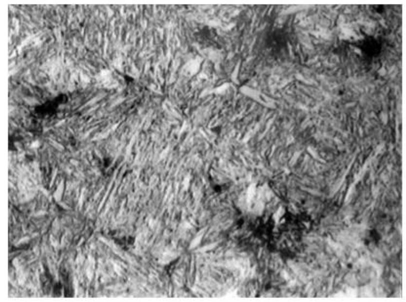


Figure 2. Martensitic grain structure of quenched steel

Lab Description: In this lab, students will see how thermal treatment of a normal steel bobby pin can influence its mechanical properties, especially strength, ductility, and deflection. This will be done using a control sample, an annealed sample, and a quenched sample.

Keywords:

· thermal processing – using temperature changes to impact material properties.
· annealing – heating a material and allowing it to cool slowly.
· quenching – heating a material and forcing it to cool quickly.
· strength – the ability of a material to withstand applied stress without failure.
· stiffness – the ability of a material to withstand deformation (bending).
· elasticity – the ability of a material to deform non-permanently without breaking.
· plasticity – the ability of a material to deform permanently without breaking.
· ductility – the ability of a material to deform under tensile stress.
· malleability – the ability of a material to deform under compressive stress.
· over-aging – having been annealed for too long, which decreases the desired properties of the material.
· deflection – the amount of displacement experienced by a structural element (e.g., beam) under a load.
· elastic modulus – the tendency of a material to deform elastically (i.e., not permanently).
· microstructure – the structure of a material observed through microscopic examination.
· grain – an individual crystal in a polycrystal.
· dislocation – a defect or irregularity in the ordered arrangement of atoms in a material.

Materials List:

Items provided in the kit

· one package of bobby pins
· five plastic cups with twine
· one hole punch
· five C-clamps
· one mass balance

Items to be provided by the teacher/school

· Bunsen burners (one per group)
· pliers or tongs (something for the students to hold the bobby pins with during heating)
· pennies (300 per group)
· ruler
· cup filled with cold water (styrofoam/paper/plastic disposable cups – cheapest you can find works)

Safety Precautions: Proper care and procedures should be used when handling the Bunsen burners, including wearing safety glasses. Remove the plastic tips from bobby pins if present. The bobby pins will get very hot during heating. Do not touch the bobby pins until they have cooled.

Instructions:

1. Set aside one pin to be used as the "control." The control sample will not receive any heat treatment and will be tested "as received."
2. Heat a second pin using the Bunsen burner. The entire pin should be heated until the bobby pin glows red-hot. (***Note:*** *When heating a pin, it is best to use pliers to grip the "open end" of the pin so that it separates the two sides of the pin. This allows the pin to heat much faster*.) Keep the bobby pin in the flame for 20 to 25 seconds after it starts glowing red.
3. After the bobby pin has been removed from the flame and returns to a gray color, set the bobby pin on a paper towel and allow it to continue to cool. This bobby pin has been "annealed."
4. While the second bobby pin is cooling, heat another bobby pin on the Bunsen burner. Place the looped end in the flame, heating the loop and about 1/3 of the pin. The pin should again be kept in the flame until glowing hot for 20 to 25 seconds.
5. Remove the pin from the flame and immediately plunge it into the cup of cold water.
6. Set the bobby pin on a paper towel and allow it to dry completely. This bobby pin has been "quenched."
7. Measure and record the width (mm) and height (mm) of the "smooth" side of the control bobby pin.
8. Punch a hole on each side of the cup and attach the twine as shown in Figure 3. Set up the control bobby pin as shown and be sure that the cup and string are hanging from the end of the bobby pin.

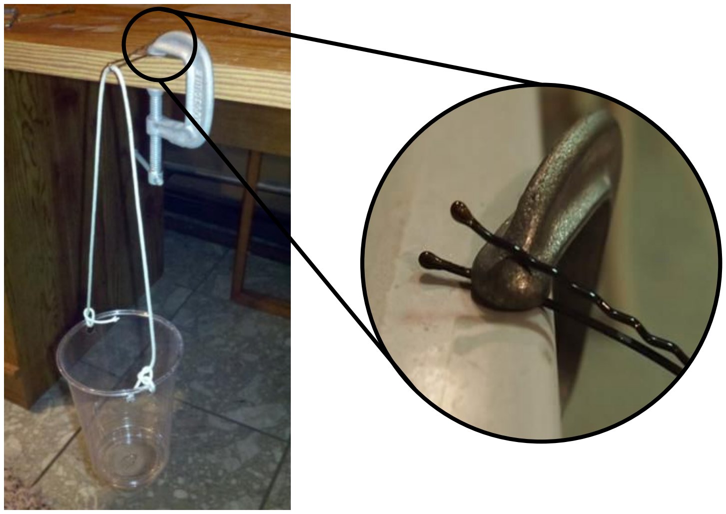


Figure 3. Test set-up

9. Record the length (mm), L, of the control bobby pin that is not supported by the table.
10. Measure and record any deflection that occurred due to the weight of the cup and twine (this will usually be very small, if it is measurable at all). The deflection is how far below the level of the table the far end of the bobby pin has been moved.
11. Create a paper funnel by rolling a piece of paper and either stapling or taping it.
12. Using the funnel, start placing 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 or 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.
13. Add a total of 300 pennies to the cup.
14. Measure and record the deflection of the control bobby pin using a ruler. The typical deflection of a control bobby pin subjected to a load of 300 pennies is 20 to 30mm.
15. Unload the control bobby pin. Measure and record any permanent deflection. The control bobby pin typically has only a slight permanent deflection (usually less than 10mm).
16. Bend the control bobby pin back to its original position to remove the permanent deflection. The control bobby pin should return to its original position.
17. Unclamp the control bobby pin and pull the two sides apart until the control bobby pin forms a straight line. Bend the bobby pin back to its original position. Observe and record any changes that occur during the bending and straightening process. Repeat several more times.
18. Calculate the force applied to the control bobby pin during the penny loading. Find the mass of the cup, string, and the pennies in the cup using the mass balance. The force, *P*, applied to the bobby pin can then be calculated as follows:

$$P = (\text{mass of cup/twine/pennies})*(\text{gravity} = 9.8\text{m/s}^2)$$

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

a. Mass of one penny = 2.4 grams
b. Mass of the cup and twine = 25 grams

The force, *P*, applied to the bobby pin can then be calculated as follows:

$$P = ((\text{mass of penny})*(\text{\# of pennies}) + \text{mass of cup/twine})*(\text{gravity} = 9.8\text{m/s}^2)$$

19. Calculate the area moment of inertia for the bobby pin:

$$I = \frac{1}{12}bh^3 = \frac{1}{12}*1mm*(0.5mm)^3 = 0.0104mm^4 \text{ (for provided pins)}$$

where *b* is the width of the bobby pin and *h* is the height.

20. Calculate the deflection using the cantilevered beam deflection equation:

$$deflection = \frac{PL^3}{3EI}$$

where *P* = force applied at the end of the bobby pin, *L* = unsupported length of the bobby pin, *E* = modulus of elasticity, and *I* = area moment of inertia. The modulus of elasticity for a steel bobby pin without additional thermal processing is 200,000 N/mm^2.

21. Compare the measured deflection to the calculated deflection.
22. Set up the annealed bobby pin as shown in Figure 3.
23. Add the pennies to the annealed bobby pin in the same fashion as the control bobby pin. Measure and record the deflection of the pin using a ruler. The typical deflection of an annealed bobby pin subjected to a load of 300 pennies is 25 - 30mm (usually slightly higher than the control bobby pin).
24. Unload the pennies from the bobby pin. Measure and record any permanent deflection. The annealed bobby pin typically has a permanent deflection of 20-30mm (much higher than the control bobby pin).
25. Bend the annealed bobby pin back to its original position. The annealed bobby pin may break when you try to do this.
26. If the annealed bobby pin does not break by moving it back to the original position, unclamp the annealed bobby pin and pull the two sides apart until the bobby pin forms a straight line. Bend the bobby pin back to its original shape. Observe and record any changes in the annealed bobby pin during the bending and straightening process. Unlike the control bobby pin, this pin should break after being bent/straightened the first time.
27. Using the cantilevered beam deflection equation given in step 20 and the deflection measured during testing, find the elastic modulus of an annealed bobby pin.

28. Compare the elastic modulus of the annealed bobby pin to the control bobby pin. The elastic moduli of these two pins should be very similar. Annealing does not have an influence on the elasticity of the pin, but on the microstructure.
29. Set up the quenched bobby pin as shown in Figure 3.
30. Load the pennies into the cup being held by the quenched bobby pin in the same fashion as the control bobby pin.
31. If properly quenched, this bobby pin will break before reaching the maximum load of 300 pennies (usually at a loading of ~70 pennies). Carefully monitor the deflection during the loading process. Calculate the deflection using the cantilevered beam equation. The force, P, applied to the pin will be based on the number of pennies in the cup at the time of failure of the pin. Assume that the elastic modulus, E, of a quenched steel bobby pin is 3000 N/mm^2.
32. Compare the measured deflection at failure to the calculated deflection for a quenched bobby pin.

Demo Delivery Hints: If the calculations become too difficult for younger students, simply compare the deflections (both measured during testing and deflection recovery after testing) and the number of pennies in the cup at failure load. The control, annealed, and quenched pins will behave differently with respect to these properties. For math intensive courses, ask the students to turn in their deflection calculations along with the lab.

Troubleshooting: The pins must remain in the heat long enough to anneal (20 - 25 seconds should be sufficient.) The quenched pin will be very brittle and will likely break after only a light loading (aka small deflection). If the entire pin is heated and then quenched, it will be too brittle to clamp. Therefore, be sure to heat only the 1/3 of the pin towards the looped end (the end that will be loaded) for the quenched bobby pin.

Cleanup/Replacement Parts: Allow the Bunsen burners to completely cool before storing. Dispose of the bent and broken bobby pins. Return the cups with twine, pennies, hole punch, and C-clamps to the kit.

TEACHER DISCUSSION QUESTIONS

Thermal Processing of Bobby Pins

Discussion Questions to Ask Before the Demo

1. What are strength and stiffness?

   Discussion: Strength is the ability of a material to withstand applied stress (or strain) without failure. Stiffness is the ability to withstand deformation (bending).

2. What makes a material strong or stiff?

   Discussion: This actually depends on the microstructure of the material: how the grains are arranged, if there are precipitates or defects in the material, etc.

3. What is plasticity (ductility, malleability)?
   Discussion: Plasticity is a material's ability to plastically deform without breaking. Ductility is specifically in response to tensile stress and malleability to compressive stress.

4. Why are all of these properties important to engineers and architects?

   Discussion: For engineers and architects, all of these properties must be considered when choosing the right material for any structure. Sometimes, a material must be strong enough to withstand the load upon it, for example the weight of cars on a bridge. Other times, a material must be stiff enough not to bend under the applied load. For example, to an engineer designing a new tool or an artist interested in metal jewelry, ductility and malleability are very important (as opposed to just strength), as the material needs these properties to withstand forming processes such as hammering and rolling.

5. How does adding heat affect a material?

   Discussion: The atoms rearrange themselves inside of the material. The heat provides enough energy to allow the motion of the atoms into arrangements of lower energy, which is more energetically favorable.

6. Predict which bobby pin you expect to deflect the most.

   Discussion: Ask this question of students to get them thinking about the differences between the three pins that will be examined. Encourage discussion. There is no right or wrong answer to this question as the students have not yet performed the lab and most likely do not understand the influence of thermal processing on deflection.

Discussion Questions to Ask During the Demo

1. What do you think is happening when the bobby pin is held in the hot flame?

   Discussion: The crystal structure (arrangement of atoms) in the bobby pin is changing, as is the grain structure. The new structure leads to a soft, ductile nature.

2. Will the annealed bobby pin be stronger or weaker than the control bobby pin?

   Discussion: Ask students to make a prediction before testing and explain why they chose this prediction. Encourage them to consider what the processing has done to the bobby pin and how they think that will influence the bobby pin.

3. What is happening when the bobby pin is placed into the cold water after annealing, instead of cooling on the paper towel?

   Discussion: The atoms are being frozen into their hot temperature positions, which is a more disordered crystal.

4. Will the quenched bobby pin be stronger or weaker than the control bobby pin?

   Discussion: Ask students to make a prediction before testing and explain why they chose this prediction. Encourage them to consider what the processing has done to the bobby pin and how they think that will influence the bobby pin.

Discussion Questions to Ask After the Demo

1. Did your prediction of which bobby pin should deflect the most match your experimental results?

   Discussion: The annealed pin should deflect the most. The quenched pin should break under even small loadings. Encourage students to discuss their predictions and why they were either the same or different than the experimental results.

2. Why did the annealed bobby pin deflect with much less load then the control pin?

   Discussion: To anneal the pin, heat is used. This heat provides enough energy for the atoms of the material to rearrange themselves. This allows the grains to grow larger and for dislocations in the material to be destroyed. Less dislocations allow materials to bend more easily.

3. Why is the quenched bobby pin brittle?

   Discussion: The microstructure of the pin has been changed. It is now martensite, a very strained crystal structure with a large number of dislocations and many carbon precipitates. Martensite also has a very needle-like microstructure which results in brittle behavior.

STUDENT LAB HANDOUT

Thermal Processing of Bobby Pins

Introduction: A material can possess a variety of different mechanical properties such as strength, stiffness, plasticity, elasticity, and deflection. Deflection is the amount of displacement experienced by a material when placed under a load. This property is of great importance in building construction, and building codes often specify a maximum allowable deflection, generally as a fraction of the length of the beam. A material's mechanical properties are dependent on the material's microstructure, including the phases present, the number and arrangement of dislocations, and the grain size and shape.

Thermal processing uses heat to change the crystal structure, defect structure (dislocations), and/or grain structure of a material. Heating a metal to red-hot and then allowing it to cool slowly is called annealing. By heating the metal, the atoms are given enough energy to move faster and more freely. Slow cooling allows the atoms to arrange themselves in low energy positions, specifically to create highly ordered crystal structures. When a metal's crystal structure is highly ordered, the atoms can slide past one another more easily, making the metal easy to bend. If a metal is annealed for too long it is considered to be "over-aged," and in this state, it has very few dislocations and is very ductile. To make a metal hard and brittle through thermal processing, it must be rapidly quenched from high temperature to room temperature. This quick cooling of the metal from red-hot temperatures freezes the atoms into a disordered phase with many defects. Due to the large number of defects, the atoms cannot move easily, and the metal is considered hard to bend and brittle.

Lab Description: In this lab, you will see how thermal treatment of a normal steel bobby pin can influence its mechanical properties, especially strength and ductility. This will be done using a control sample, an annealed sample, and a quenched sample.

Keywords: Thermal processing, annealing, strength, stiffness, elasticity, plasticity, ductility, malleability, over-aging, deflection, elastic modulus, microstructure, grain, dislocation

Materials List:

- three bobby pins
- one cup with twine
- one C-clamp
- ruler
- one Bunsen burner

·one pair of pliers or tongs (something to hold the bobby pins during heating)
· ~300 pennies
· one cup filled with cold water

Safety Precautions: Proper care and procedures should be used when handling the Bunsen burners, including wearing safety glasses. The bobby pins will get very hot during heating. Do not touch the bobby pins until they have cooled!

Instructions:

1. Set aside one pin to be used as the "control." The control sample will not receive any heat treatment, and will be tested "as received."
2. Heat a second pin using the Bunsen burner. The entire pin should be heated until the bobby pin glows red-hot. (When heating a pin, it is best to use pliers to grip the "open end" of the pin so that it separates the two sides of the pin. This allows the pin to heat much faster.) Keep the bobby pin in the flame for 20 - 25 seconds after it starts glowing red.
3. After the bobby pin has been removed from the flame and returns to a gray color, set the bobby pin on a paper towel and allow it to continue to cool for several minutes. This bobby pin has been "annealed."
4. While the second bobby pin is cooling, heat another bobby pin using the Bunsen burner. Place the looped end in the flame, heating the loop and about 1/3 of the pin. The pin should again be kept in the flame until glowing hot for 20 - 25 seconds.
5. Remove the pin from the flame and immediately plunge it into the cup of cold water.
6. Set the bobby pin on a paper towel and allow it to dry completely. This bobby pin has been "quenched."
7. Measure and record the width (mm) and height (mm) of the "smooth" side of the control bobby pin.
8. Punch a hole in each side of the cup and attach the twine as shown in Figure 1. Set up the control bobby pin as shown and be sure that the cup and string are hanging from the end of the bobby pin.

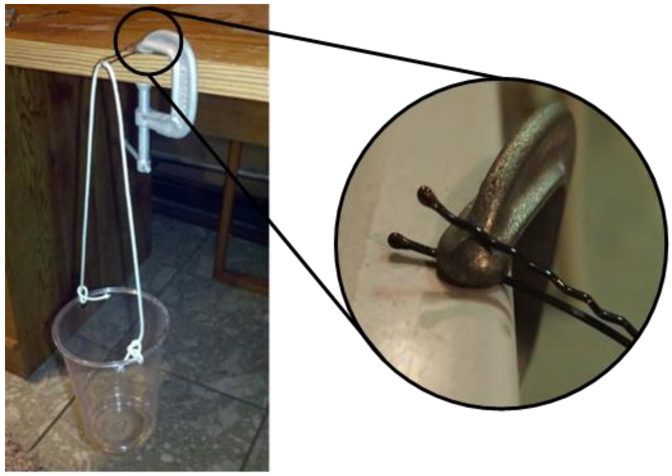


Figure 1 – Test set up

9. Record the length (mm), *L*, of the control bobby pin that is not supported by the table.
10. Measure and record any deflection that occurred due to the weight of the cup and twine (this will usually be very small, if it is measurable at all). The deflection is how far below the level of the table the far end of the bobby pin has been moved.
11. Create a paper funnel by rolling a piece of paper and either stapling or taping it closed. Using the funnel, start placing 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.
12. Add a total of 300 pennies to the cup. Measure and record the deflection of the control bobby pin using a ruler.
13. Unload the pennies from the control bobby pin. Measure and record any permanent deflection.
14. Bend the control bobby pin back to its original position to remove the permanent deflection.
15. Unclamp the control bobby pin and pull the two sides apart until the bobby pin forms a straight line. Bend the control bobby pin back to its original position. Observe and record any changes that occur during the bending and straightening process. Repeat several more times.
16. Calculate the force applied to the control bobby pin during the penny loading. Find the mass of the cup, string, and the pennies in the cup using a mass balance. The force, *P*, applied to the bobby pin can then be calculated as follows:

$$P = \text{(mass of cup/twine/pennies)*(gravity} = 9.8\text{m/s}^2)$$

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

a. Mass of one penny = 2.4 grams
b. Mass of the cup and twine = 25 grams

The force, *P*, applied to the bobby pin can then be calculated as follows:

$$P = \text{((mass of penny)*(\# of pennies) + weight of cup/twine)*(gravity} = 9.8\text{m/s}^2)$$

17. Calculate the area moment of inertia, *I*, for the bobby pin:

$$I = \frac{1}{12}bh^3 = \frac{1}{12} * 1mm * (0.5mm)^3 = 0.0104mm^4 \text{ (for provided pins)}$$

where *b* is the width of the bobby pin and *h* is the height.

18. Calculate the deflection using the cantilevered beam deflection equation:

$$deflection = \frac{PL^3}{3EI}$$

where *P* = force applied at the end of the bobby pin, *L* = unsupported length of the bobby pin, *E* = modulus of elasticity, and *I* = area moment of inertia. The modulus of elasticity for a steel bobby pin is 200,000 N/mm^2.

19. Compare the measured deflection to the calculated deflection.
20. Set up the annealed bobby pin as shown in Figure 1. Load the pennies into the cup being held by the annealed bobby pin in the same fashion as the control bobby pin. Measure and record the deflection of the annealed bobby pin using a ruler.
21. Unload the pennies from the annealed bobby pin. Measure and record any permanent deflection.
22. Bend the annealed bobby pin back to its original position. The bobby pin may break when you try to do this. If the annealed bobby pin does not break by moving it back to the original position, unclamp the bobby pin and pull the two sides apart until the annealed bobby pin forms a straight line. Bend the annealed bobby pin back to its original shape. Observe and record any changes in the bobby pin during the bending and straightening process.
23. Using the cantilevered beam deflection equation given in step 17 and the deflection measured during testing, find the elastic modulus of an annealed bobby pin.

24. Compare the elastic modulus of the annealed bobby pin to the control bobby pin.
25. Set up the quenched bobby pin as shown in Figure 1. Load the pennies into the cup being held by the quenched bobby pin in the same fashion as the control bobby pin.
26. Carefully monitor the deflection during the loading process. Calculate the deflection using the cantilevered beam equation. The force, *P*, applied to the pin will be based on the number of pennies in the cup at the time of failure of the pin. Assume that the elastic modulus, *E*, of a quenched steel bobby pin is 3000 N/mm^2.
27. Compare the measured deflection at failure to the calculated deflection for a quenched bobby pin.

Cleanup/Replacement Parts: Allow the Bunsen burners to completely cool before storing. Dispose of the bent and broken bobby pins. Return the cups with twine, pennies, and C-clamps to your teacher.

STUDENT QUESTION HANDOUT

Thermal Processing of Bobby Pins

Processing History	Total Pennies Added	Maximum Load Applied	Maximum Deflection Measured	Maximum Deflection Calculated
As Received				
Annealed				
Quenched				

1. What makes a material strong or stiff?

2. How is the microstructure of the bobby pin changing when it is heated up?

3. Why would one want to be able to soften a metal?

4. What is happening differently in the quenched bobby pin than the annealed bobby pin? Why does this change the material behavior?

5. Are your measured deflections and calculated deflections similar? If not, what could explain the difference?

6. Compare the deflection and elastic modulus of the control, annealed, and quenched bobby pins.

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.

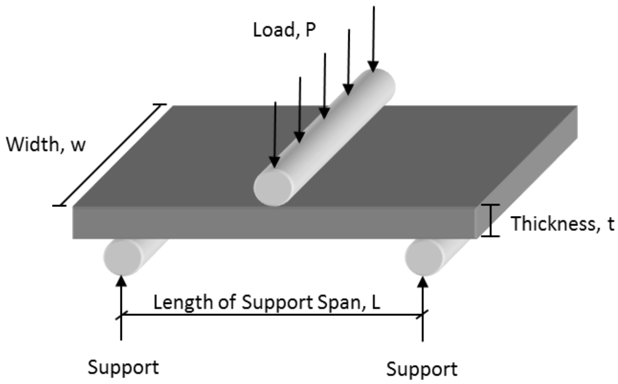


Figure 1. Test set-up for a 3-point bending test

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 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.

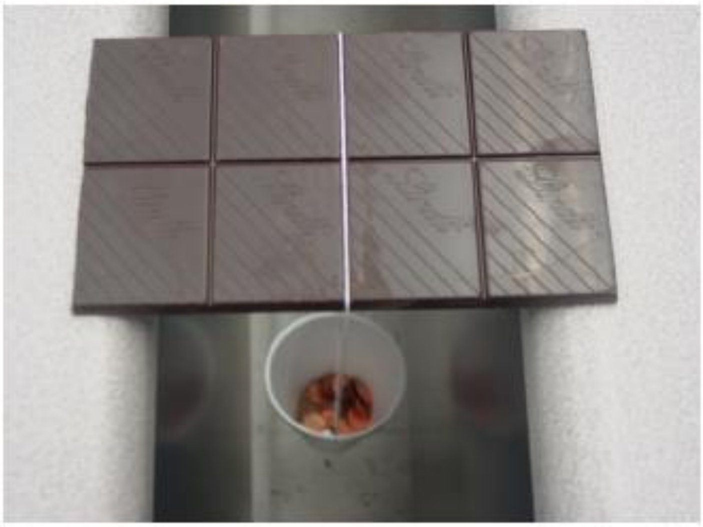


Figure 2. Chocolate bar subjected to a 3-point bending test

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 = (weight of cup, twine, and pennies)*(acceleration due to gravity = 9.81m/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 = ((weight of penny)*(# of pennies) + weight of cup and twine)*(gravity = 9.81m/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.

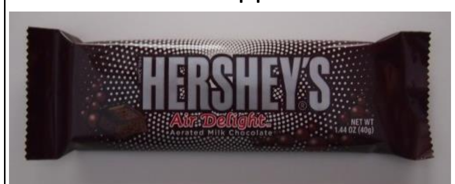
   Discussion: Students should be able to see the chocolate start to sag, or deflect, before it breaks. Have them place the ruler across the desks just to the side of the chocolate bar to help them check whether the chocolate bar has deflected.

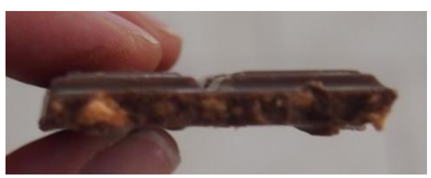
2. After each bar is tested, ask students what they think about the performance of that particular bar. Were there any differences between the bar they just tested and the previous bars they have tested? If yes, what do they think is the cause of this difference?

   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.

Table 1. Chocolate Bar Testing Table

Type of Bar	Type of Processing	Bar Pictorial Description	Testing Dimensions* (mm) L** x W x T	Failure load in pennies (flexural strength in parentheses)
Hershey's® Milk Chocolate	None	Wrapper  Front  Cross-section  Back 	95 x 50 x 9	297 (25.4 MPa)
Hershey's® with Almonds	Almonds added	Wrapper  Front  Cross-section  Back 	95 x 50 x 10	186 (13.2 MPa)

Crunch® Bar	Crisped rice added	Wrapper  Front  Cross-section  Back 	95 x 42 x 8	296 (38.2 MPa)
Hershey's® Air Delight	Air bubbles added	Wrapper  Front  Cross-section  Back 	95 x 39 x 10	256 (22.9 MPa)

Mr. Goodbar®	Peanuts added	Wrapper  Front  Cross-section  Back 	95 x 43 x 8	103 (13.8 MPa)
Butterfinger® Bar	Butterfinger pieces added	Wrapper  Front  Cross-section  Back 	72 x 42 x 7	51 (7.6 MPa)

*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

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:

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

   where N is the number of measurements and $\mathrm{x_i}$ 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).

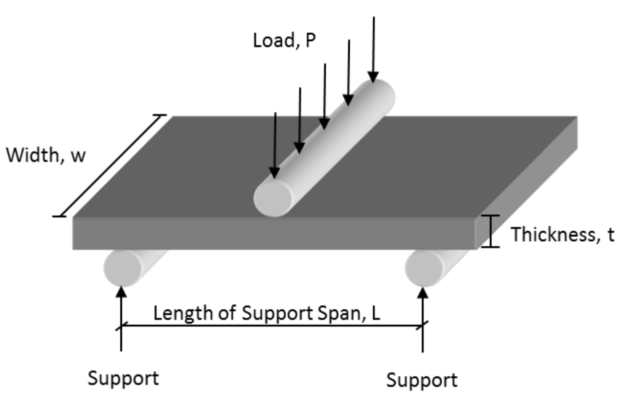


Figure 1. Test set-up for a 3-point bending test

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 ½ 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.

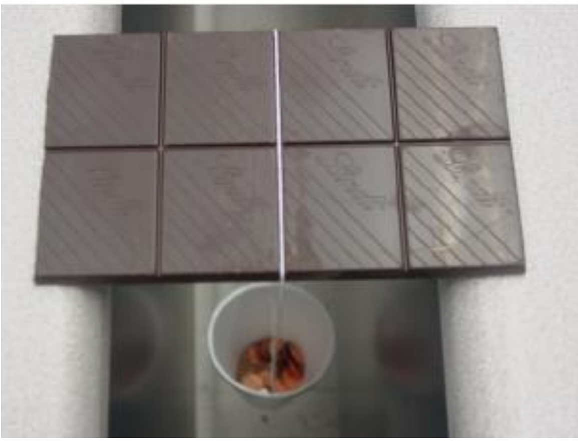


Figure 2. Chocolate bar subjected to a 3-point bending test

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 = (weight of cup, twine, and pennies)*(acceleration due to gravity = 9.81m/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 = ((weight of penny)*(# of pennies) + weight of cup and twine)*(gravity = 9.81m/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.

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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?

Materials Science Classroom Kit
with Interactive Lessons and Labs

Evaluation Form

Please take a moment to provide feedback so that we can make any needed improvements to the kits and lessons.

Name ____ Email ______________________________

1. Did the materials science kit provide you with sufficient materials to achieve the specified lesson objectives? ☐ Yes ☐ No
2. Did the lesson documents provide you with enough information to achieve the learning objectives? ☐ Yes ☐ No
3. In what type of class did you use the lessons/demonstrations?

   ☐ Chemistry ☐ Physics ☐ General Science ☐ Other____________________________

4. For what grade or age group did you use the lessons/demonstrations? ________________________
5. School Name and Location ____
6. Were there any additional materials that you felt should have been included in the kit? *(If yes, see #9 below)* ☐ Yes ☐ No
7. If you downloaded lessons from the ACerS website, which ones did you use?

   ☐ Candy Fiber Pull
   ☐ Engineered Concrete
   ☐ Glass Bead on a Wire
   ☐ Hot or Not
   ☐ How Strong is Your Chocolate?
   ☐ Piezoelectric Materials
   ☐ Shape Memory Alloy
   ☐ Thermal Processing of Bobby Pins
   ☐ Thermal Shock Demonstration
   ☐ Liquid Nitrogen Demonstrations
   ☐ Ceramic Concepts Demonstrations

8. Did you find the book *The Magic of Ceramics* to be helpful? ☐ Yes ☐ No
9. Please share any comments or suggestions you may have about the lessons checked above or about the kit in general.

____
____
____

Thank you so much for providing feedback!

Please submit your evaluation to: Belinda Raines, Outreach Manager, braines@ceramics.org or fax to: 614-794-5888

The American Ceramic Society Materials Science Kits
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CALIFORNIA RESIDENTS
California Residents: I understand that I am waiving rights with respect to claims that are at this time unknown or unsuspected, and in accordance with such waiver, I acknowledge that I have read and understand, and I hereby expressly waive, the benefits of section 1542 of the civil code of California, and any similar law of any state, country or territory, which provides as follows: "A general release does not extend to claims which the creditor does not know or suspect to exist in his or her favor at the time of executing the release, which if known by him or her must have materially affected his or her settlement with the debtor."

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THIS MATERIAL SAFETY DATA SHEET . . .

. . . IS AN IMPORTANT SOURCE OF PRODUCT INFORMATION AND WORK PRACTICES ACCORDING TO THE OSHA HAZARD COMMUNICATION STANDARD, ALL WORKERS AND EMPLOYEES MUST HAVE ACCESS TO THE MSDS AND IF YOU DISTRIBUTE OR RESELL THESE PRODUCTS YOU MUST PROVIDE COPIES OF THE MSDS TO ALL YOUR CUSTOMERS WHO PURCHASE THESE PRODUCTS.

SAFETY DATASHEET

(Following Regulations (EC) No 1907/2006 & (EC) No 1272/2008)

SDS Number: 151-1 Date of first issue: 28 March 1995 Date of last revision: 22 October 2014

1-Identification of product: Product Group: IFB 23 lile, Insalcor, JM-20, JM-23, JM-26, JM-28, JM-30, JM-32, K-20, K-23, K-24, K-25, K-26 , K-28, K-30, SR-90, SR-99, SR-99-LS, TC-23, TC-26, TJM-26, TJM-28,

INSULATING REFRACTORY BRICK

Chemical Name: ALUMINOSILICATE PRODUCT

Intended Use: High Temperature Thermal Insulation

Trade Names: Carboxite 8202, Firebrick 80, Insalcor JM-20, JM-23, JM-26, JM-28, JM-30, JM-32, K-20, K-23, K-24, K-25, K-26, K-28, K-30, K-3000, Kaomul 85 SR-90, SR-99, SR-99 LS Company

For Product Stewardship and Emergency Information: Hotline - 1-800-722-5681, Fax - 706-560-4054

For additional SDSs and to confirm this is the most current SDS for the product, visit our web page www.morgantherrnalceramics.com or send a request to MT.NorthAmerica@morganplc.com

2-Hazard Identification Emergency Overview

Respirable dust from these products may contain crystalline silica, which is known to cause respiratory disease. (See Section 11 for more information)

Chronic Effects: Prolonged/repeated inhalation of respirable crystalline silica may cause delayed lung injury (e.g. Silicosis, lung cancer).

Possible Health Effects: Target Organs: Eyes, skin, nose and/or throat Primary Entry Route: Inhalation

Acute effects: May cause temporary, mild mechanical irritation to the eyes, skin, nose and/or throat. Pre-existing skin and respiratory conditions may be aggravated by exposure.

Hazard Classification Info: Dust samples from these products have not been tested for their specific toxicity, but may contain more than 0.1% crystalline silica, for which the following apply: The International Agency for Research on Cancer (IARC) has classified crystalline silica inhaled in the form of quartz or cristobalite from occupational sources as carcinogenic to humans (Group 1).

The Ninth Annual Report on Carcinogens (2000), prepared by the National Toxicology Program (NTP), classified silica, crystalline (respirable size), as a substance known to be a human carcinogen. The American Conference of Governmental Industrial Hygienists (ACGIH} has classified crystalline silica (quartz) as "A2-Suspected Human Carcinogen." The State of California, pursuant to Proposition 65, The Safe Drinking Water and Toxic Enforcement Act of 1986, has listed "silica, crystalline (airborne particles of respirable size)" as a chemical known to the State of California to cause cancer.

The Canadian Workplace Hazardous Materials Information System (WHMIS) - Crystalline silica [quartz and cristobalite] is classified as Class D2A - Materials Causing Other Toxic Effects.

The Hazardous Materials Identification System (HMIS) -

Health: O* Flammability: O Reactivity: 0 Personal Protection Index: X (Employer determined) (* denotes potential for chronic effects)

3-Composition/Information on Ingredients

COMPONENTS	CAS NUMBER	% BY WEIGHT
Ceramic Matrics (consist of glass, mullite and anorthite)	none	95-99%
Crystalline Silica	14808-60-7 or 14464-46-1	Up to 5

(See Section 8 "Exposure Controls I Personal Protection" for exposure guidelines)

4-First-aid Measures

4.1-Eyes: Flush with large amounts of water for at least 15 minutes. Do not rub eyes.

4.2-Skin: Wash affected area gently with soap and water. Skin cream or lotion after washing may be helpful.

4.3-Respiratory Tract: Remove affected person to dust free location. See Section 8 for additional measures to reduce or eliminate exposure.

4.4-Gastrointestinal: Unlikely route of exposure. If symptoms persist, seek medical attention.

5-Fire-fighting Measures
5.1-NFPA Codes: Flammability: 0 Health: 1 Reactivity: 0 Special: 0
5.2-NFPA Unusual Hazards: None
5.3-Flanmable Properties: None
5.4-Flash Point: None
5.5-Hazardous decomposition products: None
5.6-Unusual Fire and explosion hazard: None
5.7-Extingushing media: Use extinguishing media suitable for type of surrounding fire

6-Accidental Release Measures: Avoid creating airborne dust. Follow routine housekeeping-procedures. Vacuum only with HEPA filtered equipment. If sweeping is necessary, use a dust suppressant and place material in closed containers. Do not use compressed air for clean-up. Personnel should wear gloves, goggles and approved respirator.

7-Handling and Storage
7.1-Handling: Limit the use of power tools unless in conjunction with local exhaust. Use hand tools whenever possible. Frequently clean the work area with HEPA filtered vacuum or wet sweeping to minimize the accumulation of debris. Do not use compressed air for clean-up.
7.2-Storage: Store in original container in a dry area. Keep container closed when not in use. Product packaging may contain residue. Do not reuse.

8·**Risk Management Measures/Exposures Controls/Personal Protection**

EXPOSURE GUIDELINES			
MAJOR COMPONENT	*OSHA PEL*	*ACGIH TLV*	*MANUFACTURER'S REG*
Crystalline Silica	See below(1)	0.025 mg/m^3 (respirable dust)	NONE
(1) Depending on the percentage and type(s) of silica in the mineral, the OSHA Permissible Exposure Limit (PEL) for respirable dust containing crystalline silica (8 HR TWA) is based on the formula listed in 29 CFR 1910.1000, "Air Contaminants" under Table Z-3, "Mineral Dust". For quartz containing mineral dust, the PEL = 10 mg/m³ / (% of silica + 2); for cristobalite or tridymite, the PEL = 5 mg/m³/ (% of silica + 2); for mixtures, the PEL = 10 mg/m³ / (% of quartz + 2 (% of cristobalite) + 2 (% of tridymite) + 2).			
OTHER OCCUPATIONAL EXPOSURE LEVELS (OEL) Industrial hygiene standards and occupational exposure limits vary between countries and local jurisdictions. Check which exposure levels apply to your facility and comply with local regulations. If no regulatory dust or other standards apply, a qualified industrial hygienist can assist with a specific workplace evaluation including recommendations for respiratory protection.			

Engineering Controls: Use engineering controls, such as ventilation and dust collection devices, to reduce airborne particulate concentrations to the lowest attainable level.
PPE· Skin: Wear full body clothing, gloves, hat, and eye protection as necessary to prevent skin irritation. Washable or disposable clothing may be used. If possible, do not take unwashed work clothing home. If soiled work clothing must be taken home, employers should ensure employees are trained on the best practices to minimize or avoid non-work dust exposure (e.g., vacuum clothes before leaving the work area, wash work clothing separately, rinse washer before washing other household clothes, etc.).
PPE ·Eye: Wear safety glasses with side shields or other forms of eye protection in compliance with appropriate OSHA standards to prevent eye irritation. The use of contact lenses is not recommended, unless used in conjunction with appropriate eye protection. Do not touch eyes with soiled body parts or materials. If possible, have eye-washing facilities readily available where eye irritation can occur.
PPE - Respiratory (general text): When it is not possible or feasible to reduce airborne crystalline silica or particulate levels below the PEL through engineering controls, or until they are installed, employees are encouraged to use good work practices together with respiratory protection. Before providing respirators to employees (especially negative pressure type), employers should 1) monitor for airborne crystalline silica and/or dust concentrations using appropriate NIOSH analytical methods and select respiratory protection based upon the results of that monitoring , 2) have the workers evaluated by a physician to determine the workers' ability to wear respirators, and 3) implement respiratory protection training programs. Use NIOSH-certified particulate respirators (42 CFR 84), in compliance with OSHA Respiratory Protection Standard 29 CFR 1910.134 and 29 CFR 1926.103, for the particular hazard or airborne concentrations to be encountered in the work environment. For the most current information on respirator selection, contact your supplier.

9-Physical and Chemical Properties
ODOR & APPEARANCE: Solid Brick or Block
CHEMICAL FAMILY: Insulating Refractory Brick
BOILING POINT: Not Applicable
WATER SOLUBILITY (%): Not soluble in water
MELTING POINT: 2750 °F to 3660°F (refer to specific product data sheets)
SPECIFIC GRAVITY: Not applicable
VAPOR PRESSURE: Not applicable
pH: Not applicable
VAPOR DENSITY (Air = 1): Not applicable
% VOLATILE: Not applicable
MOLECULAR FORMULA: Not applicable

10-Stability and Reactivity Incompatibilities
Powerful oxidizers; fluorine, manganese trioxide, oxygen disulfide
Conditions to avoid: None
Hazardous decomposition products: None
Hazardous polymerization: Will not occur

11-Toxicological information
Dust samples from these products have not been tested. They may contain respirable crystalline silica.
Epidemiology: No studies have been undertaken on humans exposed to these products in occupational environments.
Crystalline silica: Exposure to crystalline silica can cause silicosis, and exacerbate pulmonary tuberculosis and bronchitis. IARC (Monograph vol. 68, 1997) concluded that "crystalline silica from occupational sources inhaled in the form of quartz or cristobalite is carcinogenic to humans (Group 1)", and noted that "carcinogenicity in humans was not detected in all industrial circumstances studied" and "may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity".
Toxicology: Crystalline silica -- Some samples of crystalline silica administered to rats by inhalation and intratracheal instillation have caused fibrosis and lung cancer. Mice and hamsters, similarly exposed, develop inflammatory disease including fibrosis but no lung cancer.

12-Ecological Information
Adverse effects of this material on the environment are not anticipated.

13-Disposal Considerations
13.1-Waste Management: To prevent waste materials from becoming airborne during waste storage, transportation and disposal, a covered container or plastic bagging is recommended.
13.2-Disposal: If discarded in its purchased form, this product would not be a hazardous waste under Federal regulations (40 CFR 261) Any processing, use, alteration or chemical additions to the product, as purchased, may alter the disposal requirements. Under Federal regulations, it is the waste generator's responsibility to properly characterize a waste material, to determine if it is a hazardous waste. Check local, regional, state or provincial regulations to identify all applicable disposal requirements.

14-Transport Information: Hazard Class: Not Regulated United Nations (UN} Number: Not Applicable Labels: Not Applicable North America (NA} Number: Not Applicable Placards: Not Applicable Bill of Lading: Product Name INTERNATIONAL--Canadian TOG Hazard Class & PIN: Not regulated
Not classified as dangerous goods under ADR (road}, RID (train}, IATA (air} or IMDG (ship}.

15-Regulatory Information

UNITED STATES REGULATIONS
SARA Title III: This product does not contain any substances reportable under Sections 302, 304, 313 (40 CFR 372). Sections 311 and 312 apply.
OSHA: Comply with Hazard Communication Standards 29 CFR 1910.1200 and 29 CFR 1926.59 and Respiratory Protection Standards 29 CFR 1910.134 and 29 CFR 1926.103.
TSCA: All substances contained in this product are listed in the TSCA Chemical Inventory
California: "Silica, crystalline (airbome particles of respirable size)" is listed in Proposition 65, The Safe Drinking Water and Toxic Enforcement Act of 1986 as a chemical known to the State of California to cause cancer.
Other States: Crystalline silica products are not known to be regulated by states other than California; however, state and local OSHA and EPA regulations may apply to these products. Contact your local agency if in doubt.

INTERNATIONAL REGULATIONS
Canadian WHMIS: Class D-2A Materials Causing Other Toxic Effects
Canadian EPA: All substances in this product are listed, as required, on the Domestic Substance List (DSL).

16-Other Information
SARATITLE Ill HAZARD CATEGORIES
Acute Health: No Pressure Hazard: No Chronic Health: Yes Reactivity Hazard: No Fire Hazard: No

TECHNICAL. DATASHEETS
114-3, 114-2
Revision Summary
Section 16: Disclaimer Updated
SOS Prepared By: MORGAN THERMAL CERAMICS ENVIRONMENTAL, HEALTH & SAFETY DEPARTMENT

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