Materials Science Classroom Kit
with Interactive Lessons and Labs

Designed for grades 7-12

The American Ceramic Society
www.ceramics.org

CERAMIC AND GLASS INDUSTRY FOUNDATION

We are pleased to present this introduction to 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.

The objective of the kit is to facilitate STEM education by making scientific concepts relevant, interesting, and fun for young adults, many of whom are deciding what to study in college. The hands-on demonstrations and labs are a proven way of getting students interested in subject matter that they will need to know as they prepare to enter the innovative, high-tech workforce of today.

The Ceramic and Glass Industry Foundation (CGIF) *was established by The American Ceramic Society in 2014 to attract, inspire, and train the next generation of ceramic and glass professionals. The Foundation's mission is to help industry attract and train the highest quality talent available to work with engineered systems and products that utilize ceramic and glass materials. The Ceramic and Glass Industry Foundation (CGIF) helps students discover glass and ceramic science and encourages them to pursue degrees in materials science.*

The American Ceramic Society (ACerS) *is a 501(c)(3) non-profit organization that serves the informational, educational, and professional needs of the international ceramic materials community with over 10,000 members, including engineers, scientists, researchers, manufacturers, plant personnel, educators, students, marketing and sales professionals, and others in related materials disciplines. ACerS serves members in 80 countries by providing access to the latest industry research through periodicals, books, meetings, and online technical information.*

The President's Council of Student Advisors (PCSA) *is the student-led committee of ACerS that is responsible for representing student interests to the Society. PCSA delegates represent their collegiate institution on the Council and represent ACerS at their Material Advantage Chapter, Keramos Chapter, and school's academic department. The mission of the PCSA is to engage students as active and long-term leaders in the ceramics community and increase participation in ACerS at the local, national, and international levels.*

If you have any questions or comments about the kit or lessons, please contact Belinda Raines, Outreach Manager, at braines@ceramics.org.

Materials Science Lessons and Demonstrations
with Interactive Lab Activities

- An Introduction to Materials Science
- Lessons Included
- Introductory Demonstration and Lab Information
- Lessons, Demonstrations, and Labs Overview
- Supplemental Information

Introduction to Materials Science

Materials science is the study of solid matter:

- investigating the relationship between the atomic or molecular structure of a material and its micro- and macroscopic properties
- examining and understanding what influences the properties of a material so that the right material can be selected for a particular application

A material will typically fall into one of four classes:

- ceramics

- metals

- polymers

- composites

Ceramics

- An inorganic and nonmetallic solid created through heating and then cooling.
- Classic properties include durability, strength and brittleness, high electrical and thermal resistance, and an ability to withstand the damaging effects of acids and oxygen.
- Ceramics can be divided into two classes: traditional ceramics and advanced ceramics.
- Some common ceramic materials include:

Alumina Tubing

CorningWare®

Body Armor

Biomedical Implant

Jet Turbine Blade

Metals

- Metals generally possess properties such as good electrical conductivity, high strength and hardness, and heat and corrosion resistance.
- They are usually more malleable and ductile, and have higher densities than non-metals.
- Metals tend to lose electrons in reactions.
- Common metal materials include:
  - ◊ Elements: iron, copper, gold, silver, tin, aluminum, titanium
  - ◊ Alloys: steel, nitinol, bronze, cast iron, brass

Iron Railways

Aluminum Die Casting

Nitinol Stent

Polymers

- Polymers are molecules that consist of a long, repeating chain of smaller units called monomers. Polymers are strong, flexible, non-reactive, and moldable.
- There are two types of polymers:
  - ◊ Synthetic polymers are engineered from artificial components; examples of synthetic polymers include nylon, polyethylene, polyester, Teflon, and epoxy.
  - ◊ Natural polymers occur in nature and are often water-based; examples include silk, wool, DNA, cellulose, and proteins.

Synthetic Polymer: Neoprene

Synthetic Polymer: Polyethylene

Natural Polymer: Cotton

Natural Polymer: DNA

Composites

- A composite is created from the combination of two or more different materials to create a superior and unique material.
- The constituent elements in a composite retain their identities (they do not dissolve or merge completely into each other) while acting in concert.
- The majority of composite materials use two constituents: a matrix and a reinforcement. The reinforcement is stronger and stiffer, forming a sort of backbone, while the matrix keeps the reinforcement in a set place.

Portland cement + water + sand + aggregate = concrete

Steel + concrete = reinforced concrete

Alternating layers of glass + layers of polycarbonate = bullet resistant glass

Lessons Included

An introduction to materials science through interactive teacher-led demonstrations:

- **Hot or Not**: a ceramics lesson which demonstrates that materials can be designed to withstand very high temperatures.
- **Candy Fiber Pull**: a ceramics lesson that demonstrates the unique properties of glass by examining the solid-liquid and liquid-solid transitions of a glass-like system.
- **Piezoelectric Materials**: a ceramics/polymer lesson that demonstrates the piezoelectric effect in several materials and explains why this property exists in certain materials.
- **Shape Memory Alloys**: a metals lesson that demonstrates how the motion of atoms under added heat can change a metal’s shape.
- **Thermal Shock**: a glass lesson that demonstrates the two most important properties that determine resistance to thermal shock in glass, thermal conductivity and coefficient of thermal expansion.

Lessons Included *(continued)*

An introduction to materials science through interactive student labs:

- **Glass Bead on a Wire**: a ceramics lab that demonstrates that glass can be a "phase of matter" rather than a particular material and examines the ability of glasses to absorb other ions during thermal treatments.
- **Engineered Concrete**: a composites lab that demonstrates the influence of preparation (design) on the final composite's properties.
- **Thermal Processing of Bobby Pins**: a metals lab that demonstrates the influence that thermal processing can have on the properties of a material.
- **How Strong is your Chocolate?**: a general lab that demonstrates how the properties of materials, such as microstructure, can influence the strength of a material.

Introductory Demo and Lab Information

- Although five lessons are teacher-led demonstrations, be sure to involve students in the steps of the demonstration to keep them engaged and interested. Ask for volunteers to help with different parts of the demo.
- Suggestions for how to incorporate student participation can be found in the Teacher's Manual of Instructions for the materials science lessons and demonstrations included in the kit (and found on the flash drive also included).
- If appropriate, have students bring in items needed for a demo or lab to help pique student interest.
- Some items are provided in the kit for each lab and demo, while other items will need to be purchased. Such items are commonly found in a grocery store and were not included due to shipping issues or the need to replace certain items after every demo or lab.
- The student interactive labs are designed to accommodate a class of 20 students. You may need to modify the instructions and materials if you have more than 20 students in your class.

Materials Included for Teacher Demos

1 refractory brick

2 piezoelectric polymer films

6” nitinol wire

9 glass rods

1 propane torch head

2 piezoelectric ceramic disks

6” steel wire

8 alligator clip sets

1 beaker and tongs

4 light-emitting diodes (LEDs)

Materials Included for Student Labs

5 C-clamps

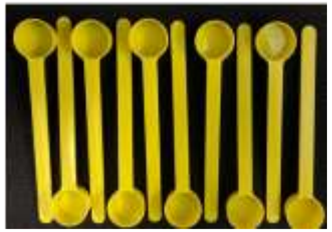
5 plastic cups

twine

1 package bobby pins

20’ copper wire

10 plastic measuring spoons



20’ nichrome wire

1 mass balance

1 hole punch

Hot or Not (Teacher-led Demo)

Objective: To demonstrate that materials can be designed to withstand very high temperatures.

Description: A torch will be used to heat one side of a refractory brick, demonstrating that the other side remains cool.

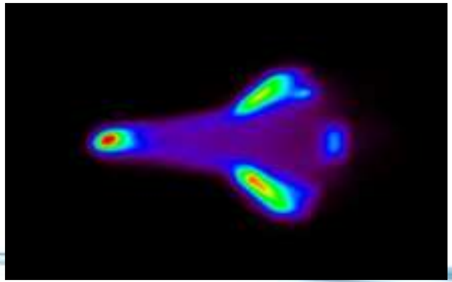
Keywords:

- **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.

Hot or Not *(continued)*

Background Information

- When heat is transferred, it must have physical matter to move through.
- Heat can transfer through conduction, which happens when heat vibrates the atoms in a material which then transfers energy to other atoms in a process called thermal conductance.
- Gases, such as air, contain very little matter in comparison with solids or liquids and, therefore, “insulate” heat from flowing.
- Refractory bricks are made from ceramic fibers that can withstand extreme temperatures without melting.
  - ◊ The bricks are very porous, meaning a large amount of air is trapped between the ceramic fibers, which slows the movement of heat through the material.
  - ◊ A similar material was used on the space shuttle to protect it and the crew from outside temperatures of >1200°C achieved upon re-entry of the shuttle into the Earth’s atmosphere.



Thermal image of shuttle re-entry

Hot or Not *(continued)*

Materials included:

1 refractory brick

1 propane torch head

Materials not included:

1 small propane tank

1 spark lighter or matches

1 thermometer

Hot or Not *(continued)*

Ways to encourage student participation:

- Allow students to read the temperature.
- Allow older students to hold the propane torch.

Real-world applications:

- The NASA space shuttles used special lightweight, porous refractory tiles to prevent the aluminum frame from melting due to the extreme temperatures during re-entry into the Earth's atmosphere.

- When melting a material, another material with a higher melting temperature is needed to hold it. Refractory bricks are used in foundries as molds for large metal pieces.

Hot or Not *(continued)*

Supplemental information:

- A variety of propane tanks are available, all of which are suitable for the torch head included in the kit. One of the less expensive options is the green 1-liter propane tank found in the camping aisle of stores like Walmart.
- In the same way, a number of different thermometers will work for this demonstration. Since the thermometer is placed on the cool side of the brick, high temperatures should not be an issue. Some thermometer sources include:

Amazon.com: https://www.amazon.com/Taylor-Precision-Products-Classic-Thermometer/dp/B00004XSC4

Sears: http://www.sears.com/search=instant%20read%20pocket%20thermometer

Walmart: http://www.walmart.com/ip/Taylor-Instant-Read-Thermometer/16543483

Meijer: http://www.meijer.com/catalog/search_command.cmd?keyword=thermometer&tierId=

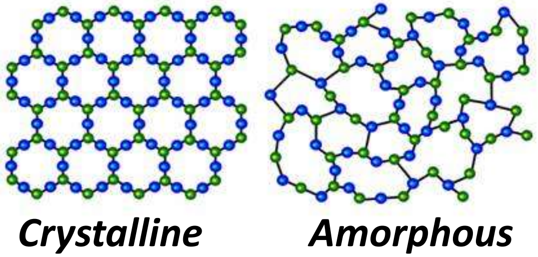
Candy Fiber Pull (Teacher-led Demo)

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

Description:

- Jolly Rancher candies will be heated in a beaker until reaching a molten state to demonstrate the glass-liquid transition.
- Using wooden skewers or popsicle sticks, candy fibers will be pulled from the molten candy to demonstrate the liquid-glass transition. The fiber will be almost instantly cooled once it is removed from the beaker due to the small diameter of the fiber and the temperature difference between the air and the molten candy.
- Students can then eat the cooled fibers to again demonstrate the glass-liquid transition.

Candy Fiber Pull *(continued)*



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.

Candy Fiber Pull *(continued)*

Background Information:

- Glass is an amorphous solid, meaning that its atomic arrangement has no long-range order.
- As glass is heated, its viscosity decreases until it flows like water (glass-liquid transition).
- As glass cools, its viscosity slowly increases (liquid-glass transition), which allows the glass to be molded into many different shapes.
- Glass-liquid transition typically occurs due to heating.
- Liquid-glass transition typically occurs due to cooling or compression.

Candy Fiber Pull *(continued)*

Background Information *(continued)*:

For example, cotton candy (and other candies) make use of the glass-liquid and liquid-glass transitions to form a desired shape.

- Sugar is heated until it reaches a molten (thick liquid) state.
- The molten sugar is then squeezed through small holes of a spinner into a large bowl.
- The thin sugar fibers solidify almost immediately in room temperature air, which creates the "cotton" candy.
- When the cotton candy is eaten, the heat from one's tongue causes the fibers of sugar to dissolve into a liquid form again.

Candy Fiber Pull *(continued)*

Materials Included:

1 Beaker

Beaker Tongs

Materials Not Included:

Hotplate

Jolly Rancher Candies

Popsicle sticks or wooden skewers

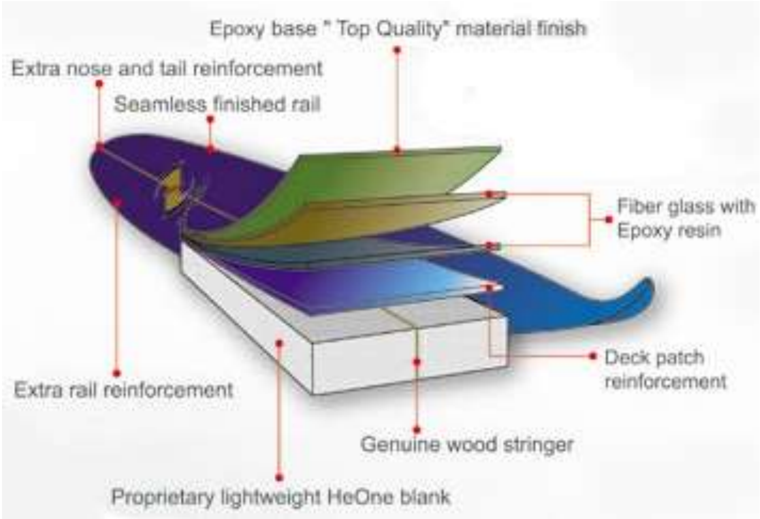
Candy Fiber Pull *(continued)*

Ways to encourage student participation:

- Ask students to help pull the fibers.
- Allow some competition to see who can pull the longest fiber.

Real-world applications:

- Fiber optic communications use pulled (drawn) glass or polymer fibers to guide pulses of light over long distances, which allows for information and communication at the speed of light.
- Glass fibers can be used to make a lightweight composite known as fiberglass. It is used in high-performance sports equipment, such as surfboards, which are made of alternating layers of fiberglass, epoxy, and resin.



Candy Fiber Pull *(continued)*

Supplemental Information:

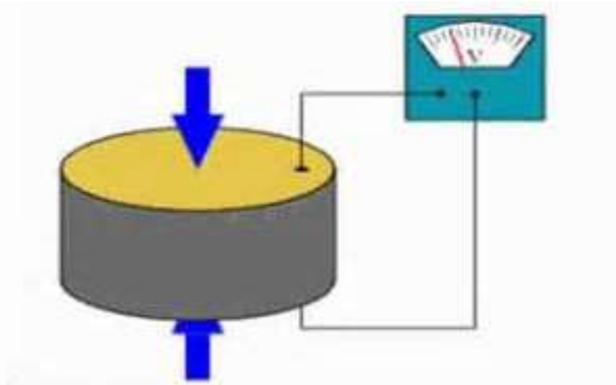
- This demonstration has the potential to get messy.
- The best way to clean the work area is with hot water which will dissolve the sugary fibers.
- If you have other beakers readily available in your classroom, use the beaker from the kit for this lesson only.
- Keep the beaker for this lesson for food use only so that students can eat the fibers without having to worry about contamination.
- If using the beaker for food use only, be sure to label it so that students do not accidentally use it for another experiment.
- The beaker should be thoroughly washed after every use to avoid contamination.

Piezoelectric Materials (Teacher-led Demo)

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

Description:

- The piezoelectric effect of a ceramic disk and a polymer film will be examined. LEDs will be used to demonstrate the piezoelectricity of these materials.
- The influence of applied voltage on the polymer film will be investigated.
- A musical greeting will be used to demonstrate real-world applications of piezoelectric materials.



Piezoelectric Materials *(continued)*

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.

Piezoelectric Materials *(continued)*

Background Information:

- Pressure generates charges on the surface of piezoelectric materials. This **direct piezoelectric effect** converts mechanical energy into electrical energy.
- Conversely, the **inverse piezoelectric effect** causes a change in length in this type of material when an electrical voltage is applied. This effect converts electrical energy into mechanical energy.
- Piezoelectric materials are everywhere and used every day:

sensors headphones ultrasonic transducers inkjet printers lighters

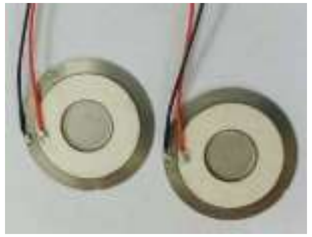




Piezoelectric Materials *(continued)*

Materials Included:

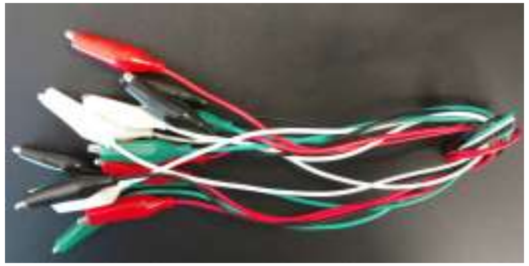
2 piezoelectric ceramic disks



2 piezoelectric polymer films

4 light emitting diodes (LEDs)

8 alligator clip sets



Materials Not Included:

Voltmeter
(optional)

Musical
greeting card

Piezoelectric Materials *(continued)*

Real-world applications:

A piezoelectric device in the heel of some shoes harvest enough energy from walking to power a cell phone.

A remote control with a signal that is powered from the push of buttons rather than being powered by batteries.

The Jaguar XKX's concept is built on brains: the body would be covered in a layer that houses microscopic ripples of piezoelectric cells that, when stimulated by airflow, could produce electricity to recharge the car's battery.

Shape-Memory Alloys (Teacher-led Demo)

Objective: to demonstrate how the motion of atoms under added heat can change the shape of metals

Description:

- During this demonstration, a nanoscale change is impacting the macroscale.
- Shape-memory alloys return to their original shape when heated, while other alloys do not.
- Nitinol wire, a shape-memory alloy, will be subjected to heat treatment.
- Steel wire will also be subjected to heat treatment.
- The behavior of the two wires will be compared and the mechanisms behind each behavior will be discussed.

Shape-Memory Alloys *(continued)*

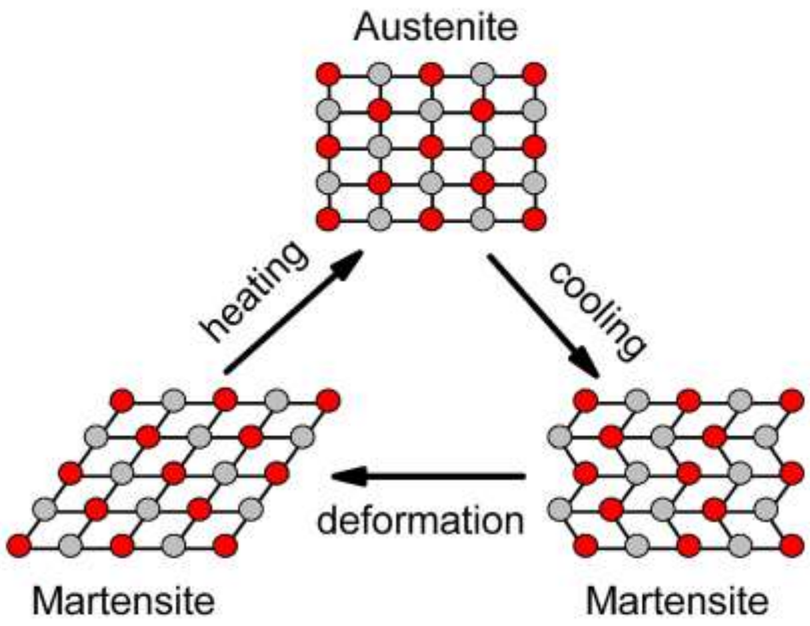
Keywords:

- **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.

Shape-Memory Alloys *(continued)*

Background information:

- Nitinol is a nickel titanium alloy (~ 50% Ni, ~ 50% Ti) that has two phases
  - ◊ high temperature phase: austenite
  - ◊ low temperature phase: martensite
- 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.



Shape-Memory Alloys *(continued)*

Materials Included:

6 inches nitinol wire

6 inches steel wire

Beaker

Materials Not Included:

Hotplate

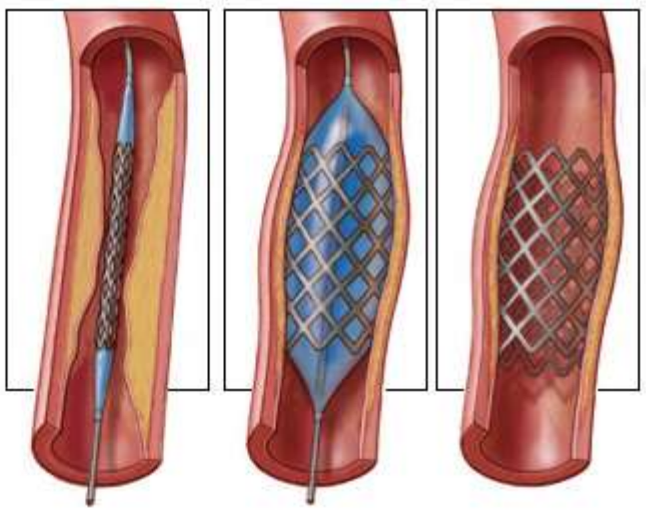
Needle nose pliers

Water

Shape-Memory Alloys *(continued)*

Ways to encourage student participation:

Allow students to bend the wire and put it in the hot water.



Real-world applications:

- Nitinol stents can be inserted into a blocked artery where the temperature of the blood is warm enough to trigger reversion to its original expanded shape, opening the artery enough for proper blood flow.
- NASA and several aircraft companies developed this jagged exhaust cone out of shape memory alloys, which change shape from the heat of the exhaust to reduce engine noise when running at full power.

Thermal Shock (Teacher-led Demo)

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

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.
- The two most important properties that determine resistance to thermal shock in glass are thermal conductivity and coefficient of thermal expansion.

Hot glass, cold water

Thermal Shock *(continued)*

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 of 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.

Thermal Shock *(continued)*

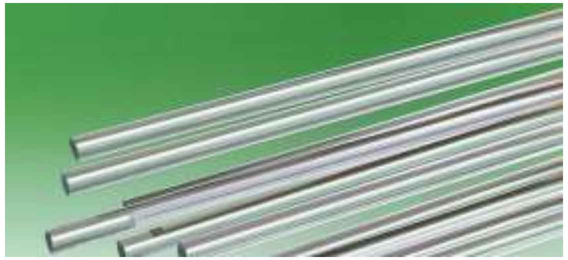
Background information:

- 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. When materials contract, tensile forces are created. When things expand, compressive forces are created.
- Thermal shock is the name given to cracking as a result of rapid temperature change. Glass and ceramic objects are particularly vulnerable to this form of failure, due to their low toughness and low thermal conductivity, as well as their high melting point (which often leads to their use in high-temperature applications).

Thermal Shock *(continued)*

Materials included:

Three soda-lime glass rods, three borosilicate glass rods, and three fused silica (quartz) glass rods



Beaker

Torch head

Materials not included:

Propane

Ice water

Strike lighter or matches

Thermal Shock *(continued)*

Real-world applications:

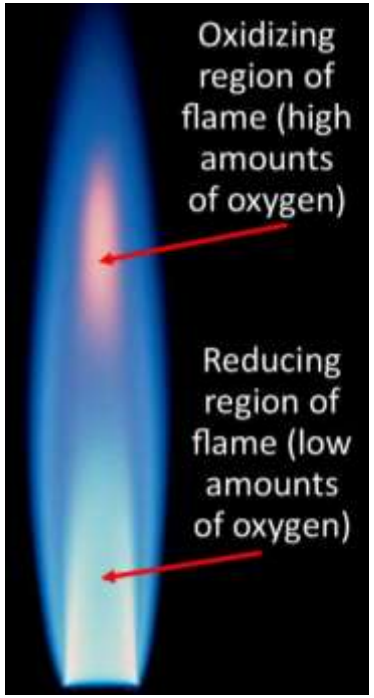
- **soda-lime glass** is generally used for flat glass (automotive and construction), bottles, jars, everyday drinking glasses, and storefronts.

- **borosilicate glass** is stronger and more durable than conventional glass and can handle both extreme heat and cold, making it very popular for some brands of cookware, laboratory glassware, other scientific instruments, and telescopes.

- **fused silica or quartz glass** has high working and melting temperatures, has superior optical and thermal properties to other types of glass, and is used in solar panels, semi-conductors, and microscope lenses.

Glass Bead on a Wire (Student Lab Activity)

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



Description:

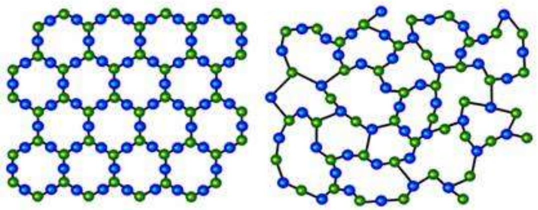
The borax bead test is a popular method for determining the presence of certain metals.

- A hot metal wire loop is dipped into powdered Borax and then reheated.
- Borax undergoes a crystalline to amorphous transition during the heating process to form a "bead" on the wire.
- The color of the bead is dependent upon the type of metal in the wire and the mount of oxygen incorporated into the borax during heating.
- The amount of oxygen added during heating can be controlled using different parts of a Bunsen flame.

Glass Bead on a Wire *(continued)*

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



Crystalline *Amorphous*

Borax bead test

Glass Bead on a Wire *(continued)*

Background information:

- Glasses are amorphous solids with no long-range order of atoms.
- Upon heating to a certain temperature, glasses have the ability to incorporate metal ions and additional oxygen ions into their atomic structure.
- The level of oxygen and the type of metal ion gives glass its “color.”
- For some materials, glass is a “phase of matter” rather than an actual material.
- Borax and quartz sand will transition from a crystalline structure to an amorphous structure (glass) when heated to a certain temperature.
- Quartz sand is the main raw material used in most of the types of glass we see every day (drinking glasses, windows, etc.)

Quartz sand

Glass Bead on a Wire *(continued)*

Materials included:

Nichrome wire

Copper wire

Materials not included:

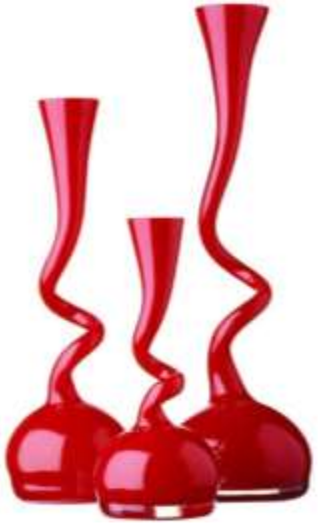
Borax

Bunsen burner

Pliers or tongs

Heat-resistant container

Glass Bead on a Wire *(continued)*



Real-world applications: Glass can be heated to a molten (liquid) state and then molded into many different shapes – everything from vases to sheets of colored glass for stained glass to jars and bottles to TVs and auto parts. The introduction of different ions during the heating process can yield glass in any desired color.

Glass Bead on a Wire *(continued)*

Supplementary information:

- This student lab was designed for groups of two students. Materials in the kit are enough for ten groups.

- There are websites that provide additional information about the borax bead test, including other metals that can be used:
  - ◊ http://en.Wikipedia.org/wiki/bead_test
  - ◊ http://www.webmineral.com/help/BoraxBead.shtml#.V5oXoFUrJMw

- Replacement copper and nichrome wire is available in our supplies replacement kit:
  - ◊ http://ceramics.org/replacement-supplies-for-the-materials-science-classroom-kit

Engineered Concrete (Student Lab Activity)

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

Description: This is an experiment with various water to cement (w/c) ratios to determine the amount of water that should be added to a set amount of Portland cement and reinforcement to create a workable cement paste.

- The students will evaluate the influence of the w/c ratio on the strength of their reinforced cement paste pucks.
- The students will create a new mix design based on the results of the first round of pucks.
  - ◊ How much water should be added?
  - ◊ How much reinforcement should be added?
- The students will evaluate the second mix design in terms of strength of their reinforced cement paste pucks.

Engineered Concrete *(continued)*

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).

Engineered Concrete *(continued)*

Background information:

- Composite materials exhibit characteristics different from the characteristics of the individual materials used to create the composite.
- Concrete is the most commonly used human-made composite (and one of the oldest).
- Concrete is composed of Portland cement, water, sand, and gravel. Its final material properties are dependent upon how much of each individual material is used.
- Portland cement is a ceramic material that, when combined with water, forms the building block of concrete.

Engineered Concrete *(continued)*

Background information *(continued)*:

- Concrete goes through a curing process.
  - ◊ When water is mixed with Portland cement, it forms a bond with the cement particles and hardens into an intertwining mix.
  - ◊ The sand (a fine aggregate) and gravel (a coarse aggregate) get trapped within this matrix and act as reinforcement to provide strength to the material.
- Concrete strength is dependent upon several factors.
  - ◊ water to cement (w/c) ration: the right amount of water is needed to react with the Portland cement.
  - ◊ type of reinforcement added: sand vs. gravel vs. fibers vs. combination of several types
  - ◊ amount of reinforcement added

Material	Mix proportions [kg/m^3]
Water (kg)	147
Cement (kg)	400
Gravel (kg)	1023
Sand (kg)	693
Total (kg)	2263
w/c	0.37

Engineered Concrete *(continued)*

Background information *(continued)*:

Influence of the w/c ratio on the thickness of the puck

Engineered Concrete *(continued)*

Background information *(continued)*:

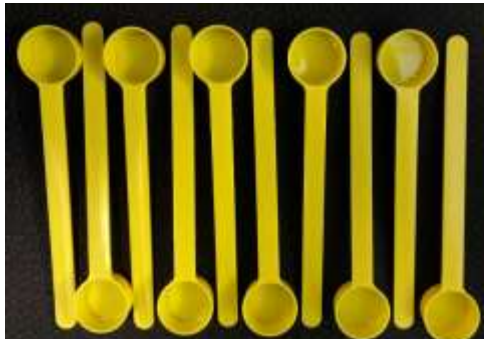
Pucks after dropping from a height of 15 feet; influence of w/c ratio: “average” ratio of 0.49 exhibits the best performance (majority of the puck is still intact).

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

Engineered Concrete *(continued)*

Materials included:

10 plastic measuring spoons



1 mass balance

Materials not included:

- Styrofoam bowls
- Portland cement
- Permanent marker
- Reinforcement materials
- Plastic wrap
- Plastic cups
- Latex/non-latex gloves *(optional)*
- Popsicle sticks/plastic spoons
- Ruler
- Sandwich bags *(optional)*

Engineered Concrete *(continued)*

Real-world applications:

To strengthen the concrete in large structures such as the foundation of a wind turbine (shown right), a lattice frame of reinforcing steel bars (rebar) are set in place. The concrete will be poured around it to form a composite.

steel fiber reinforced concrete

Engineered Concrete *(continued)*

Supplementary information:

- This student lab was designed for groups of three students.
- Portland cement (Type I or Type I/II) is available from a number of suppliers:
  - ◊ Lowe's:
    http://www.lowes.com/pl/Cement-mix-Concrete-cement-stucco-mix-Asphalt-concrete-masonry-Building-supplies/4294515401
  - ◊ Home Depot:
    http://www.homedepot.com/s/portland%2520cement?NCNI-5
  - ◊ Ace Hardware:
    http://www.acehardware.com/product/index.jsp?productId=2041962
  - ◊ Walmart:
    http://www.walmart.com/search/?cat_id=&query=Portland+cement

Thermal Processing of Bobby Pins (Student Lab Activity)

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

Description:

- The influence of thermal treatment on bobby pins will be examined.
  - ◊ A bobby pin will be annealed by heating it with a Bunsen burner and then slowly cooled.
  - ◊ A bobby pin will be quenched by heating with a Bunsen burner and then quickly cooled by plunging the pin in a cup of cold water.
- The control bobby pin, annealed bobby pin, and quenched bobby pin will be subjected to an end flexural loading.
  - ◊ This type of loading is also referred to as a cantilevered beam loading.
- The deflections of each pin will be compared to determine the influence of thermal treatment on the mechanical properties of the metal.

Thermal Processing of Bobby Pins *(continued)*

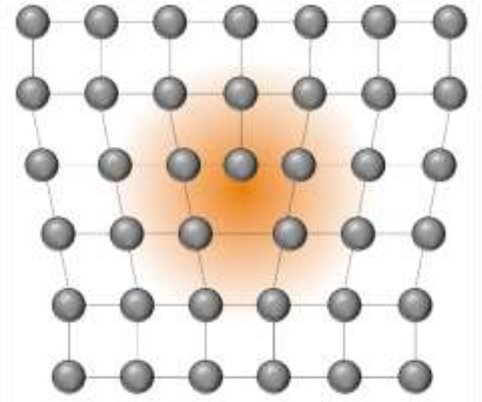
Keywords:

- **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.

Thermal Processing of Bobby Pins *(continued)*

Keywords *(continued)*:

- **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.



dislocation

Thermal Processing of Bobby Pins *(continued)*

Background information:

- Thermal processing is used to change the microstructure of a material, thus changing its physical properties.
- Annealing weakens metals, which makes them easier to form into desired shapes.
- The process of annealing involves heating a material to a critical temperature, maintaining that temperature, and then allowing the material to cool slowly.
- Quenching makes metals hard and brittle. The process is the same as annealing, except the material is rapidly cooled to room temperature.

Annealed stainless steel wire

Steel quench crack

Thermal Processing of Bobby Pins *(continued)*

Materials included:

5 plastic cups

Twine

Mass balance

5 C-clamps

1 package of bobby pins

Materials not included:

- Bunsen burner
- Pennies
- Ruler
- Cup of cold water
- Pliers or tongs

Note:
This student lab was designed for groups of three to four students.

Thermal Processing of Bobby Pins *(continued)*

Real-world applications:

Heat treatment is the most important factor in the processing of metal parts. High temperatures and slow cooling rates allow large grains to form in the metal, which deform more easily than small grains. When making a hardened metal for a hammer, drill, or gear, the metal must be quenched to keep the grains small. Quenching can also "freeze" a crystal structure that only otherwise exists at a high temperature.

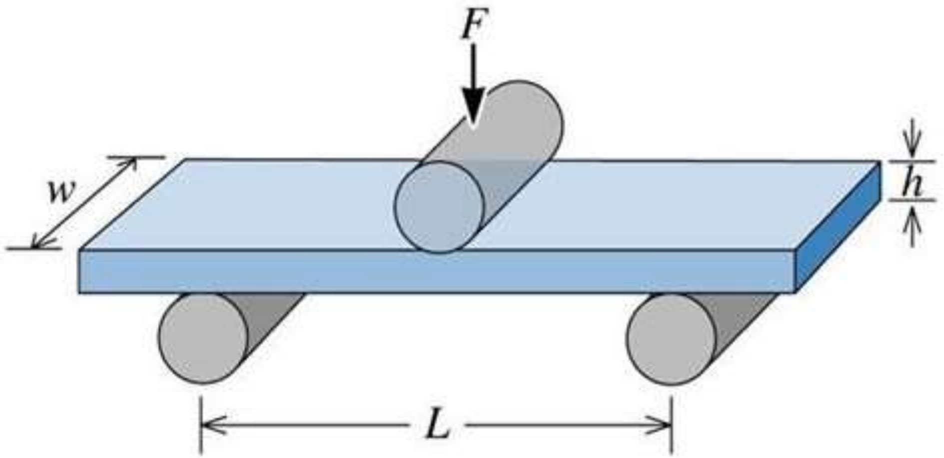
Aircraft landing gear glowing red-hot, about to be quenched in oil

How Strong is Your Chocolate? (Student Lab Activity)

Objective: To demonstrate how material properties, such as microstructure, can influence the strength of a material.

Description:

- Different types of chocolate bars will be tested to demonstrate the influence of different microstructures on the strength of the bar.
- A 3-point bending test set-up will be utilized.



How Strong is Your Chocolate? *(continued)*

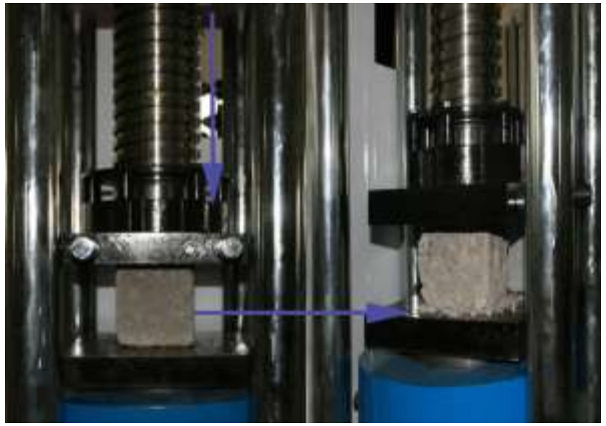
Background information:

- The materials we use every day are subjected to a variety of stresses and must be designed to provide a certain measure of strength.
- The microstructure of a material influences its strength under various loadings.
- Sometimes a microstructure can be altered due to processing.
  - ◊ For example, the microstructure of a chocolate bar can be altered by adding something to it such as almonds, crisped rice, or air voids.
- It is important to understand how microstructural changes can affect the final properties of a material.
  - ◊ Will the changes produce a stronger material? A weaker material? A more durable material (even if it is weaker)?

How Strong is Your Chocolate? *(continued)*

Background information *(continued)*:

- Engineers must understand how a material will respond to stresses in order to choose the right material for a particular application.
- Engineers use a variety of mechanical tests to evaluate the ability of a material to sustain stresses.



compressive testing

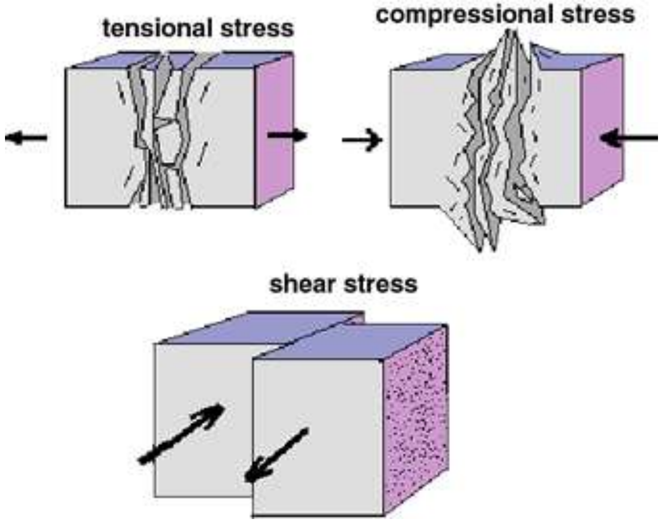
tensile testing

flexural testing

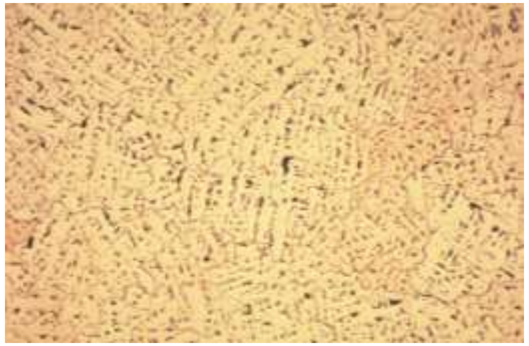
How Strong is Your Chocolate? *(continued)*

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.



stainless steel microstructure



copper microstructure

How Strong is Your Chocolate? *(continued)*

Materials included:

5 plastic cups

Twine

Mass balance

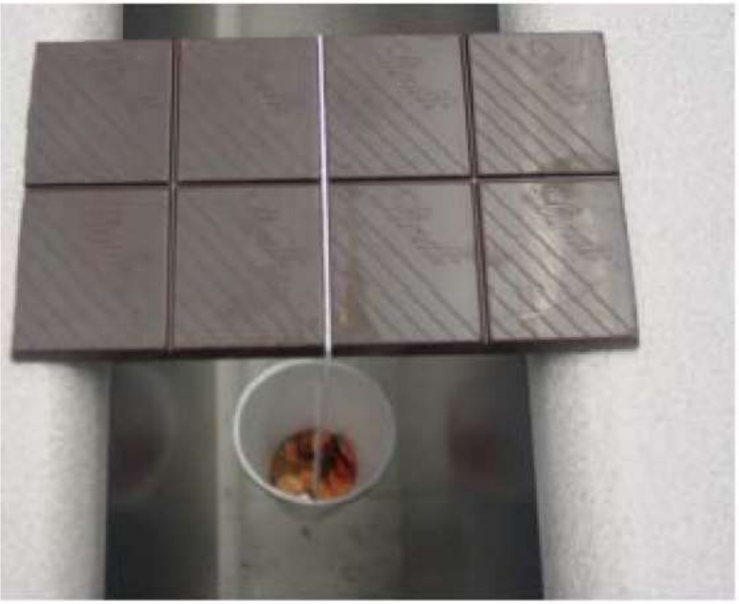
Materials not included:

- Pennies
- 5 rulers
- 5 protective mats
- 5 milk chocolate bars
- 5 milk chocolate bars with almonds
- 5 milk chocolate bars with crisped rice

How Strong is Your Chocolate? *(continued)*

Supplementary information:

- This student lab was designed for groups of three to four students.



3-point bending test for a chocolate bar

A chocolate bar fracture surface

How Strong is Your Chocolate? *(continued)*

Real-world applications:

· Impurities and other elements in a material can **strengthen** it (e.g., the engineered concrete lab) or can **weaken** it (e.g., the chocolate bar strength lab). In most modern materials, the processing is so well-controlled that impurities are not a problem and other materials are added on purpose to strengthen the material.

An excess of sulfur and phosphorus in the steel of the Titanic is widely believed to have made it more susceptible to cracking.

The metal blades of a jet engine are mostly nickel, but can have more than 10 other elements added to improve performance.

Additional Information

Additional information on the kit, lessons, and demos can be found on our website:

- Free download of the lessons and demos in the kit, plus three additional labs involving liquid nitrogen and three ceramics-specific lessons: ceramics.org/free-lesson-download

- Videos that demonstrate how to perform each demonstration and lab: https://www.youtube.com/playlist?list=PLraTz7kJQLvBv_2fzQo-JMklQwLnPnIJa

- Use our sponsor letter template to ask a local company to donate a kit to your classroom: http://ceramics.org/acers-community/presidents-council-of-student-advisors/download-materials-science-lessons-for-7th-through-12th-grade-classrooms

Additional Information *(continued)*

- Replacement supplies for most of the consumable items in the Materials Science Classroom Kit are available in one convenient package. Go to our website for more information: http://ceramics.org/replacement-supplies-for-the-materials-science-classroom-kit

- Download a Study Guide manual for *The Magic of Ceramics*: http://ceramics.org/wp-content/uploads/2017/06/MAGIC-OF-CERAMICS-STUDY-GUIDES-1.pdf

Additional Information *(continued)*

The American Ceramic Society (ACerS) and The Ceramic and Glass Industry Foundation gratefully acknowledge the work of the President's Council of Student Advisors – the ACerS group of engineering students who designed and produced the first version of our materials science kit for teachers and students.

Learn more about the ACerS President's Council of Student Advisors:
http://ceramics.org/acers-community/presidents-council-of-student-advisors

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JUNE 2017