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.

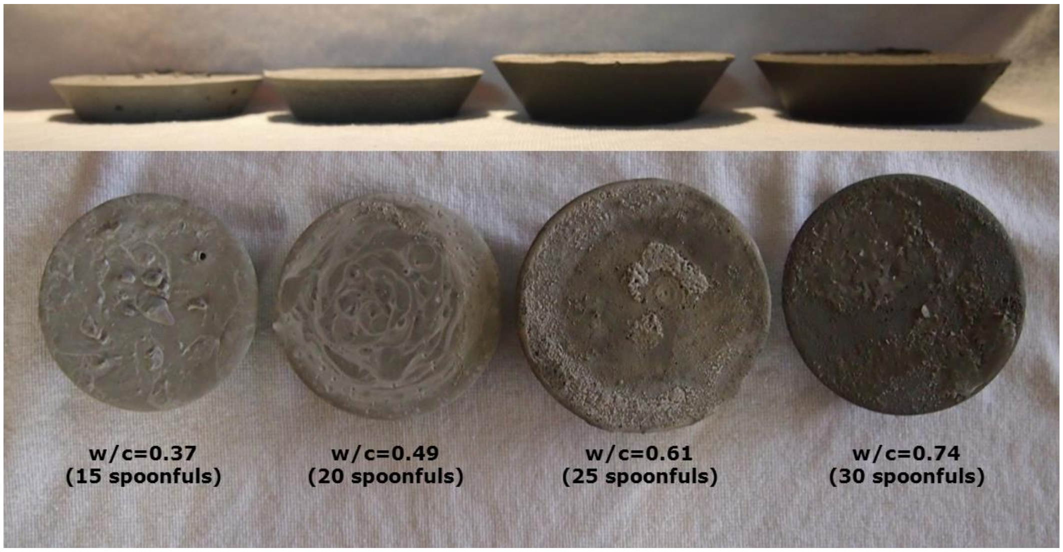

Figure 1. Influence of w/c ratio on the thickness and color of the cement puck

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 $4.93 cm^3$ and the density of water is $1 g/cm^3$. 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?