Teaching Aids and Laboratory Experiments to Enhance Materials Learning

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Abstract
Most civil engineering programs across the country require one course in materials and materials testing. Many times these courses are structured to provide students the basic understanding of the production, properties, and behavior of common structural materials. Emphasis is often placed on concrete, steel, and wood. This paper presents teaching aids and laboratory experiments that can be used as an effective and interesting method of introducing material properties and behavior to students. The authors have identified several analogies, in-class demonstrations, visual aids, and laboratory experiments that enhance the learning of structural materials. The Hamburger Helper analogy is used to describe aggregate's function as economical filler in concrete. Noodles (aggregates) are considerably cheaper than hamburger meat (cement) and can be used to produce a larger meal (concrete mixture) at a reduced cost. Cement hydration is often a difficult topic for students to understand. The reaction between water and cement can be demonstrated using the candy, atomic fireball. The heat liberation curve for cement hydration resembles the heat given off by an atomic fireball. The stress-strain curve for steel can be described as "Traffic Gridlock on an Interstate." The initial portion of the curve resembles slow moving traffic that produces large amounts of stress for drivers. This is followed by a point on the curve or location on the interstate when traffic speed increases resulting in decreased stress and much greater strain. This comparison continues through strain hardening until failure or the drivers reach their destination. Straws are an effective method of illustrating the structure of wood. Wood is composed of hollow tube-like cells that resemble a group of drinking straws. Laboratory experiments that examine the effects of water-to-cement ratio and curing environment on concrete compressive strength reinforce topics discussed in class lectures. Teaching aids and laboratory experiments are an effective method of demonstrating important concepts and can be used to enhance the learning of structural materials.

Introduction
Many civil engineering curriculums require at least one course in materials and materials testing. These classes provide students the basic knowledge and understanding of the production, properties, testing, and behavior of common structural materials. A large emphasis is placed on concrete, steel, and wood due to their wide use and availability in the design and construction of structures. This paper presents teaching aids and laboratory experiments that have been used by the authors in their respective classes. These teaching resources have been found to be an effective and interesting method of introducing material properties and behavior to students. The

resources identified in this paper include analogies, in-class demonstrations, visual aids, and laboratory experiments. Such resources discussed in this paper are used to explain the effects of aggregate shape on the properties of concrete, the use of aggregate in concrete, cement hydration, stress-strain behavior of steel, and the cellular structure of wood. The authors have received positive comments regarding the use of these teaching aids and experiments in class. Students often mention how these teaching resources reinforce the concepts discussed in class as well as creating more interest in course topics.

Teaching Aids

Dice and Marble Analogy

The shape of aggregate particles directly impacts how the material will pack into a dense configuration [1]. In addition particle shape also affects the materials mobility. Generally, there are five classifications of particle shape: angular, rounded, flaky, elongated, and flaky – elongated. Aggregates account for approximately 60 to 80% of concrete's volume and is typically an angular crushed stone or rounded gravel. Because aggregate shape affects the properties of concrete, the author uses the dice and marble analogy. This analogy compares the shape of dice and marbles to aggregates. Aggregate shape has a direct effect on the strength and workability of concrete. If the aggregate shape is round, typically the concrete will be more workable and easier to place. This is observed by using several marbles and rolling them on a table. If you rolled a pair of die on the same table, they do not move as easily resulting in less workability. Aggregate shape can affect the concrete compressive strength. Aggregates with an angular shape (dice) result in higher stability than aggregates with rounded shapes (marble).

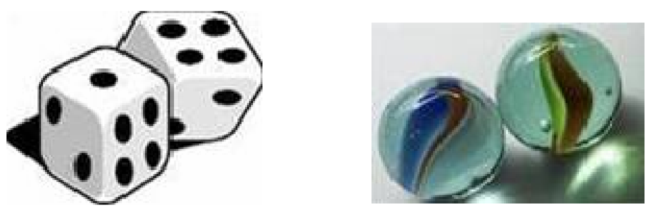


Figure 1. Comparison between Dice and Marbles [2,3]

Hamburger Helper Analogy

In the introduction to concrete lecture, the author discusses the five major constituents of concrete (cement, water, rock, sand, and air). The amount of volume in a concrete mixture that each constituent typically occupies is illustrated in Figure 2. Students often ask why aggregates are included in concrete since the cement paste contributes to the strength of concrete. The Hamburger Helper Analogy aids in this discussion. One pound of hamburger meat for a family of four does not go very far; however, if hamburger helper is used with the hamburger meat, a much large meal can be produced. Similarly, in concrete production aggregates are added to the cement paste as an economical filler producing a larger product at a lower cost. If aggregates were not added to concrete, the price for a standard concrete mixture would at least double based on the two mixtures having the same volume.

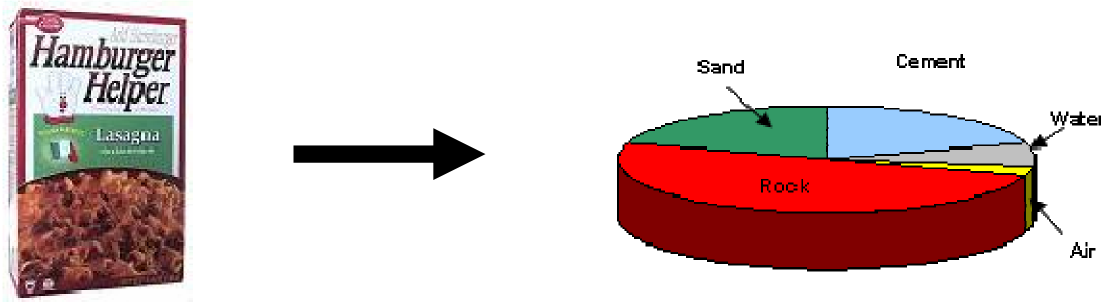


Figure 2. Aggregates Added as Economical Filler [4]

<u>Atomic Fireball Candy Experiment</u>

Cement hydration is often a difficult topic for students to understand. Cement hydration is defined as "the chemical reaction between the compounds of cement and water" [5]. This reaction is exothermic resulting in a certain amount of heat being produced during this reaction. Cement hydration will continue as long as moisture and heat are present. This reaction between water and cement can be demonstrated using the candy, atomic fireball. See Figure 3.

Figure 3. Atomic Fireball Candy [6]

Three comparisons can be made between the atomic fireball and cement hydration:

- Hydration reactions begin immediately once water touches the cement *(the reaction of the atomic fireball begins immediately once it enters your mouth).*
- Cement grains become smaller as hydration continues *(the atomic fireball candy becomes smaller the longer it stays in your mouth).*
- Hydration can continue as long as moisture and heat are present *(the reaction of the atomic fireball continues as long as it stays in your mouth and until it dissolves).*

The heat liberation curve for cement hydration resembles the heat given off by an atomic fireball. Figure 4 illustrates the heat given off during cement hydration. Cement hydration consists of 5 stages, Figure 4. Stage 1, initial hydrolysis, begins immediately when cement becomes in contact with water. This stage experiences a rapid evolution of heat as seen when the atomic fireball is first placed in the mouth. After a period of time, Stage 2 (induction) begins and is observed by a low amount of heat that is released and the concrete remaining in the plastic state. The atomic fireball experiences this "leveling off" of heat once the outer surface of the candy is dissolved. The rate of heat evolution begins to accelerate during Stage 3. Similarly, the atomic fireball resumes giving off heat as a new layer within the fireball is reached. The increased rate of heat evolution of cement hydration peaks and decelerates during Stage 4. Lastly, a steady state is reached in Stage 5 with low evolution of heat.

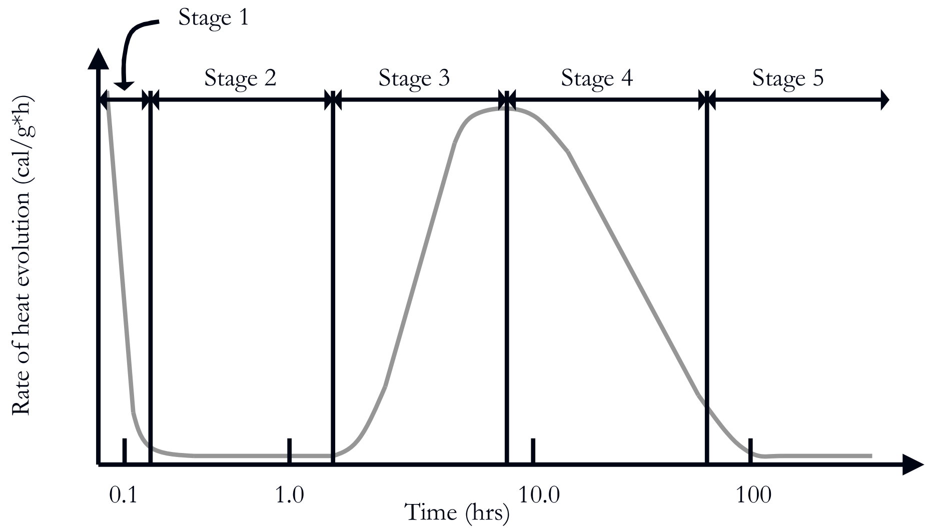


Figure 4. Heat Evolution During Cement Hydration

Traffic Gridlock Analogy

The stress-strain curve for steel can be described as "Traffic Gridlock on an Interstate." This analogy compares driving into a big city on the interstate with the stress vs. strain diagram of steel, Figure 5. The initial portion [1] of the curve resembles slow moving traffic that produces large amounts of stress for drivers. This portion of the stress-strain curve is normally referred to as the linear-elastic region of the curve. In this region the modulus of elasticity can be calculated. This is followed by a point on the curve or location on the interstate when traffic speed increases resulting in decreased stress and much greater strain or distance driving on the interstate [2]. This area of the curve produces a yield plateau, from where the yield strength of the steel is determined. Area [3] of the curve demonstrates strain hardening where mechanical strength is increased due to plastic deformation. This would resemble the slowing down of traffic as you approach a major interchange into a big city. This area will see an increased rate of stress and decreased strain. Finally, the steel specimen fails or the driver reaches their destination [4]. This analogy is meant to provide students with a way of understanding the changes in stress and strain of steel when subjected to load.

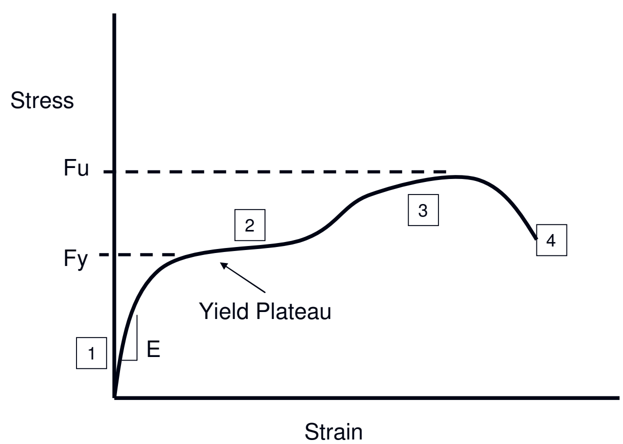


Figure 5. Typical Stress vs. Strain Diagram for Steel

Straw Demonstration
Straws are an effective method of illustrating the structure of wood. Wood is composed of hollow tube-like cells that resemble a group of drinking straws, Figure 6.

Figure 6. Comparison of Drinking Straws to Wood Structure [7]

This demonstration becomes valuable when discussing the behavior of wood to loads in different directions. Typically, wood testing can be performed with applying load parallel or perpendicular to the grain. See Figure 7.

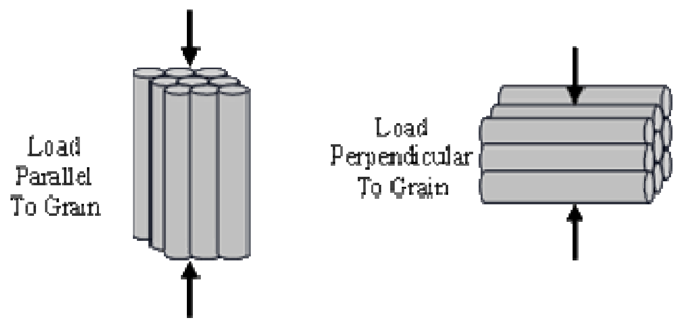


Figure 7. Testing Wood Parallel and Perpendicular to the Grain

The group of straws act as a visual demonstration of how wood is notably stronger when subjected to loads parallel to the grain than perpendicular. In addition, the manner in which the wood cells (straws) fail is also comparable. This comparison is listed in Table 1.

Water-to-Cement Ratio Experiment
A laboratory experiment can be conducted to evaluate the effect of changing the water-to-cement ratio (w/c) on concrete properties. The most notable affect w/c has on concrete properties is compressive strength. Typically, as the w/c increases (0.40 → 0.70), the concrete compressive strength decreases. This is observed by having five laboratory groups create five mixtures each with a different w/c. The mixture proportions used by the first author are shown in Table 2. Each group batches their mixture and observes workability of the mixture. In addition, 4”x8” cylinders are cast to test the compressive strength at 2 and 7 days of age. The students then gather the data and produce a compressive strength versus w/c curve. See Figure 8. This laboratory experiment provides the students with an opportunity to observe and test concrete at varying water contents.

Table 1. Straw Demonstration for Loading Wood in Different Directions

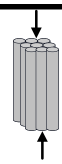
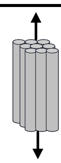
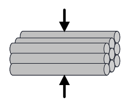
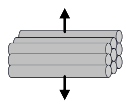
Type of Test	Demonstration	Wood Failure Type	Straw Failure Type
Compression		Failure caused by local buckling and crushing of cells. Large deformations at failure.	Straws will begin to bend at middle and separate from one another.
Tension		Failure occurs by breaking bonds with fibers. Small deformations occur prior to failure.	Straws are strongest when demonstrated in this manner.
Compression		Failure occurs from collapsing of cells. Extremely large deformations at failure.	Straws will totally collapse leaving no voids.
Tension		Failure by breaking bonds between cells. Large deformations at failure.	Straws will pull apart from one another.

Table 2. Mixture Proportions for W/C Experiment

w/c	Cement (lb)	Rock (lb)	Sand (lb)	Water (lb)
0.40	7.0	20.4	13.4	2.5
0.45	7.0	20.4	12.5	2.8
0.50	7.0	20.4	11.6	3.5
0.60	7.0	20.4	9.8	4.2
0.70	7.0	20.4	8.0	4.9

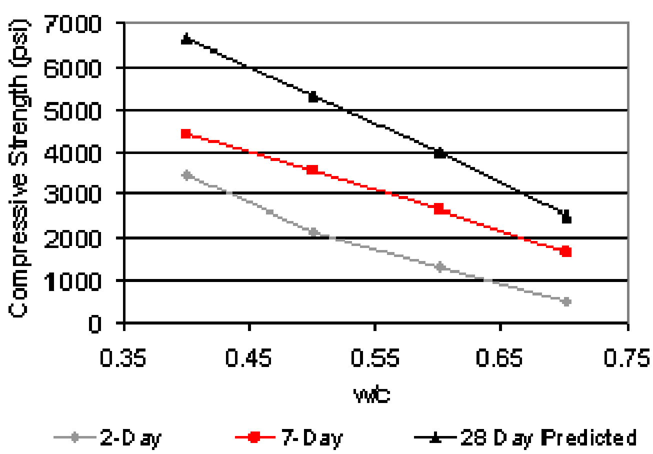


Figure 8. Compressive Strength vs. W/C

Student will often comment on how the addition of water increases the fluidity of the concrete mixtures. This is shown in Figure 9. Students typically report in their laboratory reports how the lower w/c concrete mixtures are more difficult to compact in the cylinder molds than higher w/c mixtures.

(a) (b)

Figure 9. Comparison Between (a) 0.45 and (b) 0.60 W/C Mixtures

This experiment also has a "real world" portion. Students are asked to provide cases where 0.40, 0.50, and 0.60 w/c concrete mixtures would be used in engineering practice. This provides an opportunity for students to research engineering projects and determine what w/c is frequently used for certain structures (bridge beams, highway pavements, sidewalks, etc…).

Concrete Curing Experiment

The concrete curing experiment is a laboratory exercise in which four different curing treatments for concrete are analyzed. The curing regiments used for this experiment include:

- Moisture curing in a water filled tank,
- Dry curing in the laboratory,
- Ambient curing outside the laboratory, and
- Box curing with insulation.

Students cast thirty-six – 4"x8" concrete cylinders to be used to determine the compressive strength. Each curing regiment consists of nine cylinders, of which three cylinders are tested and averaged at 1, 14, and 28 days of age. A typical graph of the different curing treatments is shown in Figure 10. The overall objective of this laboratory experiment is to demonstrate the significance of moisture curing. Moist curing promotes continued hydration of the cement, thereby producing higher strength than air cured concrete. In addition, when cylinders are cured at elevated temperatures, the early age strengths are typically higher than other curing methods. This is demonstrated by curing cylinders in an insulated box which traps the heat given off by the cylinders.

The trends that are typically recognized by the students during this experiment are:

- The box cured concrete cylinders produce almost double the strength when compared to cylinders of the other three methods.
- The moist cured concrete cylinders experience the highest compressive strength at 28 days of age.
- The ambient and dry cured cylinders are similar in strength at 1, 14, and 28 days of age.

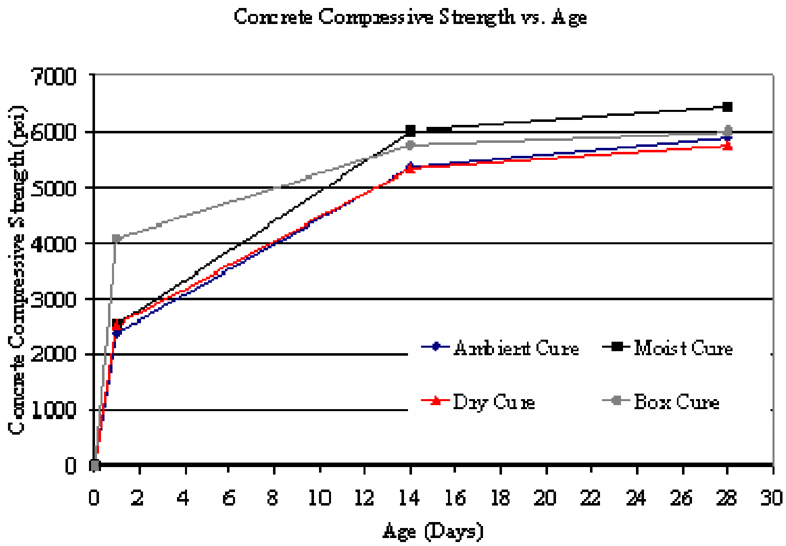


Figure 10. Compressive Strength using Different Curing Techniques

Student Feedback and Comments
The analogies and experiments discussed in this paper have proved to be successful in relating familiar items to engineering materials and concepts. Students have commented on how these teaching aids have helped them learn and retain knowledge regarding difficult topics in the civil engineering materials class. A few comments from former students are found below:

> *"The teaching techniques used in the materials lab were unforgettable. Every time I think of a concrete mix design I will think of hamburger helper. The one that was the most memorable is the heat of hydration process and how it exactly correlates with Atomic Fireballs. Another very important aspect of these learning techniques is that it makes learning fun."* – Stephanie Spencer, junior civil engineering student at UCDHSC, Fall 2006.

> *"The atomic fireball is truly inspired! It's fun, the image is strong, and it stays with you as a mnemonic of the setting process."* – Chuck Wheat, graduated civil engineering at UCDHSC, Fall 2006.

> *"I would like to say that your methods of teaching are by far the most effective I have ever experience and it always helped me remember even until now. As far as the list starting with Hamburger Helper Analogy: it helped me remember that aggregate is just fillers and cheap, Atomic Fireball Experiment, was the best worst feeling to remember cement hydration, Traffic Gridlock Analogy still helps me determine the ,σ and ε relationship and the group of straws helped me remember which way the wood is stronger."* – Roxana Taghizadeh, junior civil engineering student at UCDHSC, Fall 2006.

> *"Let me respond by mentioning the fact that I can no longer walk down the grocery store aisle and look at a box of Cheesy Macaroni Hamburger Helper and not think about concrete. As Civil Engineering students we are bombarded with chalkboards of*

derivations, differential equations and textbook pages that sometimes appear as a foreign language. Taking some of these engineering principles and relating them to common items is helpful in understanding concepts." – Jim Fox, senior civil engineering student at UCDHSC, Fall 2006.

"My favorite is the hamburger helper because it's easy to relate to and provides a good laugh (sticks in my mind), and the atomic fireball because you are able to experience it. I don't think that I'll forget either one." – Josh Powell, junior civil engineering student at UCDHSC, Spring 2007.

"The hamburger helper analogy helped a lot and was a really good example. Traffic Gridlock is also good. Group of straws is also excellent. Those three examples are stuck in my head and I understand it very well. Last week when my Timber Design professor talked about wood for 30 seconds, all he talked about is wood being like a bunch of straws. If weren't for mechanics of material's lab, I would not know what is he talking about". – Hiep Nguyen, senior civil engineering student at UCDHSC, Spring 2007.

In future classes, the authors plan to help students develop their own analogies. It is expected that these student-built analogies will add to the learning effectiveness. In addition, this may lead to additional analogies and demonstrations being incorporated into the class discussion.

Conclusion

The authors have used the teaching aids presented in this paper as an effective method of explaining and demonstrating difficult topics in materials engineering. In addition, the laboratory experiments discussed by the authors provide students with the opportunity to observe factors that affect properties of concrete. As a result of including analogies, demonstrations and laboratory experiments, students appear to be more engaged in the course topics. Students have often commented on the benefits of these teaching aids, particularly how they relate common items to more technical topics in structural materials and materials testing. Furthermore, the visual aids, in-class experiments, and laboratory experiments present information in a way that provides students with a great learning experience.

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Biography

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