NanoCrete

Center for Nanotechnology Education

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NanoCrete

Abstract

This module introduces students to the nanotechnologies, processes, and methods being tested by industry to prepare strong and lightweight cementitious products and systems. The module takes the learner through processing a material (called microgrinding or powder milling) to reduce its size and use the new material (nanoparticles) as an aggregate to create a dense yet light and strong concrete. Hands-on activities include processing nanoparticles, creating nanocrete samples, and testing samples for tensile strength and durability (hardness).

Outcomes

In this module, students produce observable enhancements and changes in the material properties of concrete using (emulated) nanotechnologies and nanoprocessing.

Prerequisites

This module builds on Material Science topics/content already in use at the MatEdU National Resource Center for Materials Technology Education. It is suggested to review and/or complete the related MatEdU (linked) modules prior to teaching this Nanocrete module. See list in the Readings section.

Science Concepts

- Mechanical strength of materials
- Types of mechanical stress: tensile, shear
- The relationship between stress and strain
- The nature and structure of matter

Nanoscience Concepts

- Sense of scale (size of aggregate particles before and after processing)
- Surface area to volume ratio (more cement particles make contact with the Perlite)
- Priority of forces and interactions (density and particle packing, hydration at a smaller size, hydrogen bonds, and Van der Waals interactions)
- The tools of nanoscience (micro-grinding, scanning electron microscopy)

Background Information

NanoCrete

Concrete is the most widely used building material on the planet; we use 23 billion tons per year worldwide. Concrete is a composite, made up of aggregate, cement, water, air, and sometimes additives to impart special properties. Concrete plays a major role in our building and transportation systems.

Why concrete nanotechnology? Concrete is a reliably durable and strong building material. For this reason, concrete and other materials based on cement have not changed much over the years. Only recently, with the discovery of novel properties exhibited by concrete components at the nanoscale, and an interest in enhancing the material's properties, has concrete science evolved.

Nanotechnology has the potential to enhance the desirable properties of concrete, particularly the degree of hydration, which affects shrinkage, cracking, and reliability. Nanotechnology may also be applied to produce thinner, lighter final products, and to help address the challenges facing concrete sciences such as reducing the production of carbon dioxide (CO_2); at present, 0.9 tons of CO_2 is produced for each ton of cement.

Currently, the most active research areas dealing with cement and concrete nanotechnology are

- Understanding of the hydration of cement particles and the use of nanosized ingredients such as: titanium oxide, silica, carbon nanotubes, and nanosensors used to monitor and control hydration, cure time, etc..
- Super additives and admixtures (fly ash and citric acid).
- Concrete eventually needs to be replaced. Using nanotechnology to extend the life and durability of concrete is being explored. Using lighter/smaller material, while maintaining and enhancing concrete properties (corrosion resistance, hardness, and strength).

What is nanocrete? Nanocrete modifies one or more of the components used in concrete and/or introduces an admixture with chemistries that can alter and enhance the properties of the material. Modifications can be made to any one of the constituents--the aggregate, cement, water, or air content--to improve the physical properties and attributes of the finished concrete.

Currently, cement is produced with particles ranging from about 100 micrometers (roughly the thickness of a human hair) down to fine particles around a few micrometers in size. By processing the components differently, a concrete made with particles that are less than one half of a micrometer (500 nanometers) can be achieved. With concrete mixtures, the thorough mixing (or *dispersion)* of larger particles can be a problem. Poor dispersion can affect the strength and other properties of the concrete, but nanoparticles fix this problem. Further, when materials are processed into nanoparticles, their surface area to volume ratio increases, resulting in greater chemical reactivity of the nanoparticle material.

Material scientists hope to use nanotechnology to enhance composite properties such as corrosion resistance and strength. In addition, concrete science is moving from not just looking for the strongest and most reliable material used in building and transportation systems, to looking for a more durable and versatile material that can be used in future products. Future concrete may even have the ability to self heal, allowing it to be used as a bone substitute.

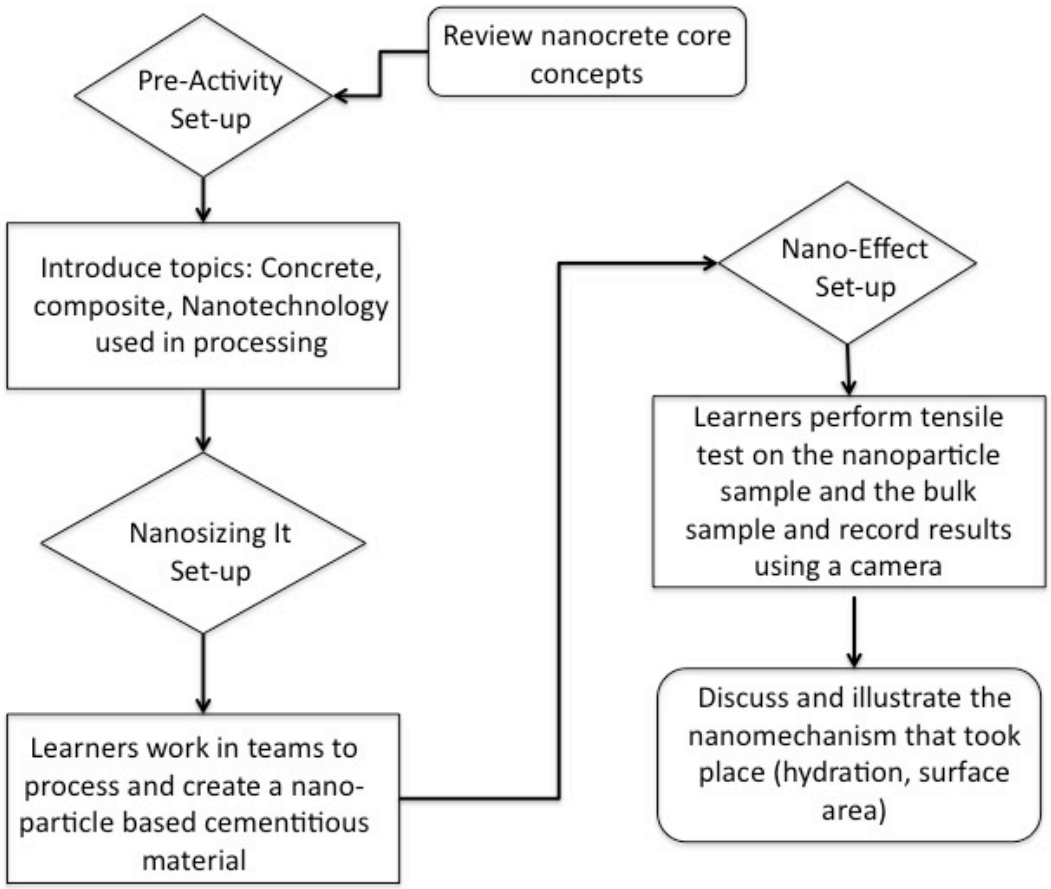
Current and Future Applications

Currently, the most active research areas dealing with cement and concrete nanotechnology are:

- Understanding of the hydration of cement particles and the use of nanosized ingredients such as titanium oxide, silica, and carbon nanotubes
- Adding nanosensors to monitor and control hydration, cure time, etc.
- Super additives and admixtures, such as fly ash and citric acid
- Using nanotechnology to extend the life and durability of concrete
- Using lighter material while maintaining and enhancing concrete properties like corrosion resistance, hardness, and strength.

Learning Activity: Nanocrete

Activity Flow Chart



Nanocrete

Nanosizing It

Materials and Equipment

Per person/team:

- Perlite
- Ground Perlite
- 6 molds
- 2 beakers
- Measuring spoon (tablespoon)
- 2 stir sticks
- 2 mixing cups/buckets – Clear vessels work best.
- A mold release, such as spray cooking oil or a commercial spray release from a hobby store
- Digital scale, tabletop type such as a kitchen/food scale.
- Latex gloves
- Safety glasses
- Aprons

Safety

Cement is an alkaline product. Avoid skin contact as much as possible. If contact does occur, or if liquid is accidentally splashed in the eyes, wash out thoroughly with clean water. You should wash hands after using cement, before eating or allowing hand-to-mouth contact. Should any liquid be swallowed, seek medical advice immediately.

Procedure

1. Follow these procedures to create 2 concrete mixtures (6:4:4 mix ratio):
    - Measure and combine dry constituents first
    - Measure and add water
    - Check for slump and flow

Concrete bulk mixture	Concrete nanoparticle mixture
• 6 parts Perlite • 4 parts water • 4 parts Portland cement NOTE: enough water must be added to create proper flow	• 6 parts microground Perlite powder • 4 parts water • 4 parts Portland cement NOTE: enough water must be added to create proper flow

2. Repeat two more times, creating a total of 3 sets of each sample per person/team.
3. The materials are quite different visually. Make comparisons in terms of size of the material, mass vs. volume, etc.

4. Pour the mixtures into the molds until they are completely filled. There should be no or very little material left in the mixing vessel.
5. Tap the molded samples to allow air bubbles to escape; this is also called vibrating.
6. Since cure time affects strength, maintain consistency between samples before testing. Five to six days of cure time is a good rule-of-thumb. Small samples cure quite quickly; beyond six days, cracking and fracturing may occur.
7. Optional: track and compare sample hydration using one of the methods described in the suggested MatEdU module in the Readings section.

<u>Observe and record the following.</u>

1. Compare the mixtures using bulk Perlite vs. the microground Perlite during sample preparation.
    - Measure the mass density (= mass/volume). Measure mass with a scale and calculate the volume of the sample by measuring length, width, and height (volume = LxWxH).
    - Observe how the two mixtures behave differently:
        - "Workability" of a concrete mix is defined as its ability to be placed and compacted without bleeding or segregation of the components. How do the two mixtures' workability compare?
        - "Viscosity" is defined as a fluid's resistance to flow. How do the viscosities of the two mixtures compare?
    - While tapping the mold on the table, take note of the appearance and disappearance of air bubbles. You should see fewer bubbles rise in the microground Perlite sample; this is due to better particle packing in the small scale constituents.

2. Compare the mixtures during curing
    - How do the different mixtures compare in their water retention? Observe the amount of water that collects on the top of the mold.
    - Compare cracking or aggregate segregation (where large aggregate "floats" to the top of the concrete) between the two mixtures.

The Nanocrete Effect

<u>Materials and Equipment</u>

- Cured samples
- 550 pound Paracord (knotted into a sling)
- Ladder or two tables
- Digital scale, two types:
    - Table top type such as a kitchen/food scale.
    - Hanging weight scale such as a luggage/fishing scale. The Berkley 50lb Fish Scale was used in module development.
- Digital camera capable of 60 fps recording speed.
- A camera tripod or a table to steady the camera.
- Computer with video playback software (QuickTime/Media player).

- Latex gloves and safety glasses. NOTE: hand protection is recommended, such as leather/handyman type gloves over the latex gloves.

Safety

- Safety glasses are required for the stress testing, during which the samples will break abruptly. Depending on the age and ability of your learners, the instructor may want to perform the suggested stress test. Other stress – strain test scenarios can be used as well. See suggested Materials module in the Readings section.

Procedure

1. De-mold the Nanocrete samples.
2. Measure and record the mass of the cured samples before testing.
3. It is necessary to video record the test. Smartphones with video capability can be used if the phone recording speed is at least 60 frames per second (fps); less than 60 fps produces choppy results and makes it difficult to read the output on the scale.
4. Follow basic procedures for tensile testing:
    a. Set up a base (ladder was used)
    b. Set up camera (on tripod or stabilizer)
    c. Construct a sling using the 550lb test Paracord)
    d. Cinch the sling around the sample
    e. Balance sample between two even rungs on the ladder
    f. Attach scale to the sling (NOTE: if using the fish scale, it will hang upside down)
    g. Focus camera tightly on the reading screen of the scale
    h. Begin pulling on the scale’s handle until the sample fails (breaks). NOTE: this will be abrupt.
5. Use video playback software such as QuickTime or MS Media Player to step through the frames and capture the reading on the scale at the break/failure point.
6. Discuss results.

Discussion Questions

These questions could be used as an informal evaluation of understanding (about the module objectives) at any time during instruction, written or oral. Make additions or change questions as needed, per topics covered.

1. What areas of nanotechnology are benefiting concrete science and how?

Answers will vary, these were introduced in the module; the bolded item is demonstrated in the module activities:

- Understanding of the **hydration of cement particles** and the use of nanosize ingredients such as titanium oxide, silica, carbon nanotubes, and nanosensors to monitor and control hydration, cure time, etc. Benefits include more durable/reliable product.
- Super additives: Admixtures (fly ash, citric acid) to replace cement and reduce environmental impact.
- Self-healing concrete. Using nanotechnology to extend the life and durability of concrete is being explored.
- **Using lighter/smaller material**, while maintaining or enhancing concrete properties (hardness and strength). Benefit is variety of applications, improvements to construction methods.

2. Which of the following could be used to describe a nanocomposite (check all that apply)?
   a. Lightweight
   b. Strong
   c. Dimensions in the 1,000nm range or smaller
   d. Matrixed

Answer: a, b, and d

3. Describe the nanotechnologies being used to reduce the size of millimeter-sized concrete components to a nanoscale.

Answer should include some/all of the following: Crushing and grinding bulk materials to reduce their particle components to be nanoscale (at or below 100 nm).

4. What influences the strength and durability of the final concrete-based nanocomposite (check all that apply)?
   a. Mix ratio
   b. Hydration control
   c. Curing time
   d. Size, shape, and quality of the aggregate

Answer: a,b,c,d

5. Explain how nanoparticles affect the properties of concrete-based systems.

Answer should include the following:

- Viscosity increased, better workability.
- Lighter weight yet forms a dense, durable material
- More particles available for reaction, improves strength
- As a filler, filling voids that may affect the strength/quality of the material (Surface area to volume)

NOTE: More may be included, it depends on the depth to which this concept was explored, i.e.: CO_2 production, reduced use of resources, better particle dispersion, hydration chemistry, curing time, etc.

6. Convert the following measurements to nanometers:
   2.92mm and 23.4μm

Answer: 2,920,000nm and 23,400nm

NOTE: these are the particle sizes of the module's Perlite and nanoPerlite examples in the Nanocrete slideshow, Analysis and Conclusions slide, SEM image. It is important to note that even though the particle size reduction after grinding is not yet to "nano" size, i.e.100nm or smaller, the size was significantly reduced and a particle powder that could be used in a lightweight, strong composite was the result.

Contributors

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Resources

Simulation: NSF Hydration of Cement archive.org/details/gov.fhwa.ttp.vh-438

Videos

- www.youtube.com/watch?v=TLW2FTbfiNs
- www.youtube.com/watch?v=p9WqCUzz6tc
- www.youtube.com/watch?v=a0qINbK2WkY (only 20 seconds)

Articles

Related MatEdU modules are linked from:
https://scout.wisc.edu/mated/index.php?P=BrowseResources&ParentId=186

Transportation Research Circular (2012). “Nanotechnology in concrete materials.”
Title search from: www.national-academies.org

Kumar, R.; Mathur, R.; Mishra, A.K. (2011). “Opportunities & challenges for use of nanotechnology in cement-based materials.”
www.nbmcw.com/articles/miscellaneous/others/25054-use-of-nanotechnology-in-cement-based-materials.html

Sahraeian, R.; Hashemi, S.A.; Esfandeh, M.; Ghasemi, I. (2012). “Preparation of nanocomposites based on Perlite.”
business.highbeam.com/436123/article-1G1-297137922/preparation-nanocomposites-based-ldpeperlite-mechanical