RESEARCH HIGHLIGHT

PURDUE MATERIALS ENGINEERING

Polymer and Surface Science in the Youngblood Group

In 2003, Professor Youngblood joined the School of Materials Engineering at Purdue University. Promoted to Associate Professor in 2009 and Professor in 2015, he uses his polymer expertise to investigate nanotechnology, surface science, advanced processing and biomaterials. Of late, he has been specifically interested in ceramic processing using methods similar to those for polymeric materials, composites and fabrication, sustainability of materials, cellulose nanocomposites, cementitious materials, Additive Layer Manufacturing (3D printing), and durable anti-ice coatings.

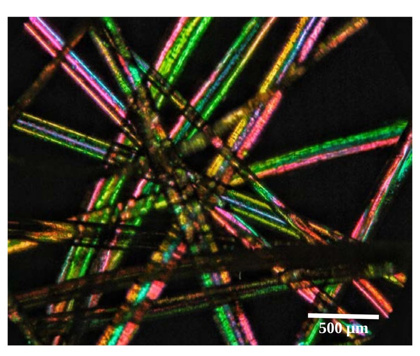
Sustainable Nanotechnology

Sustainable nanotechnology in the Youngblood group is primarily focused on cellulose nanomaterials (CN), which are sustainable, non-toxic, high strength, high stiffness, and derived from biomass. These materials are comprised of Cellulose Nanocrystals (CNCs) – rod-like liquid crystalline particles of 100nm length and Cellulose Nanofibrils (CNFs) – flexible fibrils of microns in length. Research into CNC and CNF spans new materials, new processing methods and fundamental property determination.

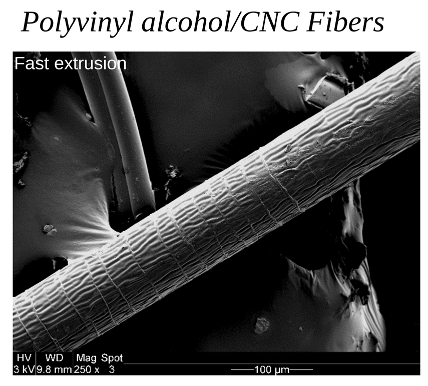
CNC and CNF Processing

i.) Fiber Spinning

Commercially available fiber spinning methods are being explored to produce high strength, high stiffness nanocellulose reinforced commodity polymer fibers where nanoparticle alignment and nanoparticle concentration are crucial to performance. We shown that CNC and CNF addition can increase modulus and strength of the fibers and can also add as a crystallinity nucleant.



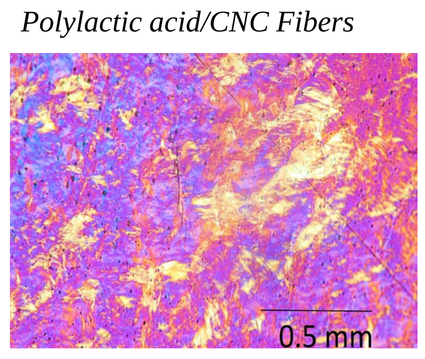
Polyvinyl alcohol/CNC Fibers



Polylactic acid/CNC Fibers

ii.) Roll to Roll (R2R) Continuous Fabrication

A large-scale continuous manufacturing process for cellulose nanocrystal (CNC) composite coatings on a flexible substrate was developed in this work. In microgravure R2R, the coating thickness (from 2μm to 6μm) and CNC alignment can be controlled via process parameters and ink viscosity. Such processing is useful for producing barrier films to prevent oxygen, CO_2 and water transmission for food packaging and anti-bleed layers for printing.



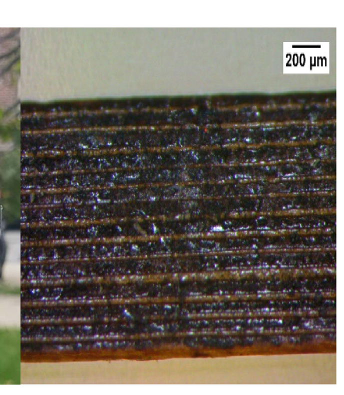
CNC R2R coating on PET film

New Composites

i.) Laminates

Laminates are made up of stacked layers of bio-friendly cellulose nanofibrils (oxidized CNF or mechanically fibrillated CNF) as the primary component with the addition of a thermoplastic polymer binder layer to achieve high strength, transparency and toughness.

CNF laminates are highly transparent



20 bilayer CNF laminate structure

ii.) Nanocomposites

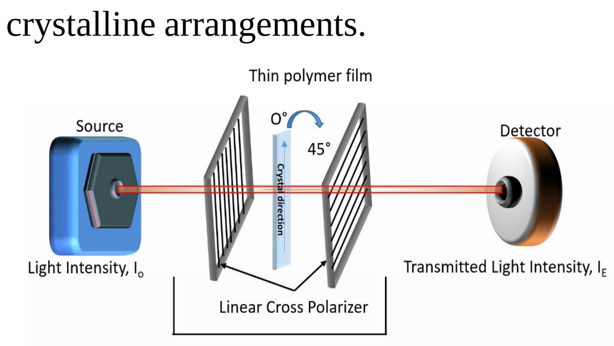
CNC and CNF are potential additives and fillers for various polymer systems where it can act as a structural reinforcement, promote nucleation, and enhance thermal, mechanical and transport barrier properties.

CNC Epoxy nanocomposites show good dispersion

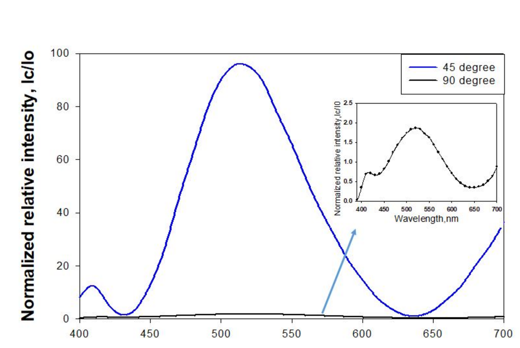
Fundamental Property Measurement

i.) Optical Birefringence for Anisotropy Measurement

Birefringence has been investigated for the determination of crystal orientation of a CNC film. The prime focus of our study is to establish a simple and low cost experimental technique using a standard UV–Vis spectrometer to determine the order parameter (S) for both isotropic and anisotropic configurations. The transmitted light intensity of CNC films between cross polarizers for the bright and dark fields were measured to calculate the linear dichroitic ratio, which were used to calculate the order parameters of different crystalline arrangements.



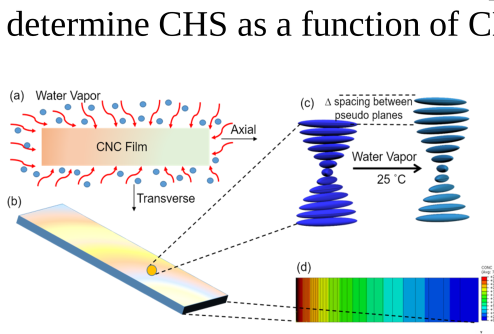
Optical birefringence method for anisotropy determination



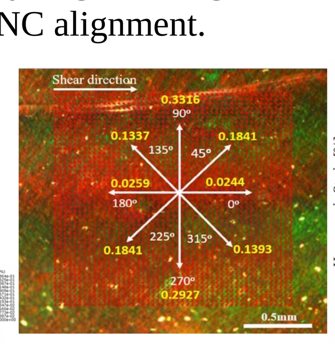
Transmittance peak intensity for a anisotropic film

ii.) Hygroscopic Swelling of CNC Films

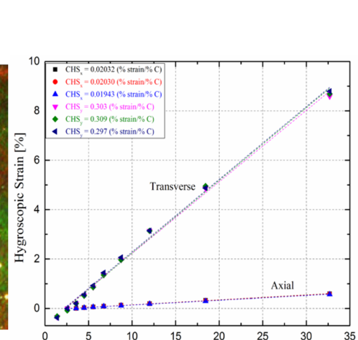
Hygroscopic swelling is commonly characterized by the coefficient of hygroscopic swelling (CHS), which correlates the degree of expansion of a material to the mass intake of water as a function of humidity. CHS of self-organized and shear-oriented CNC films was determined by capturing hygroscopic strains produced by water vapor intake in equilibrium. Here, we use contrast enhanced microscopy digital image correlation (CEMDIC) to determine CHS as a function of CNC alignment.



Schematic representation of moisture sorption of CNC films



CEMDIC image with CHS at an angular increment of 45°



CHS of CNC films with different CNC alignments

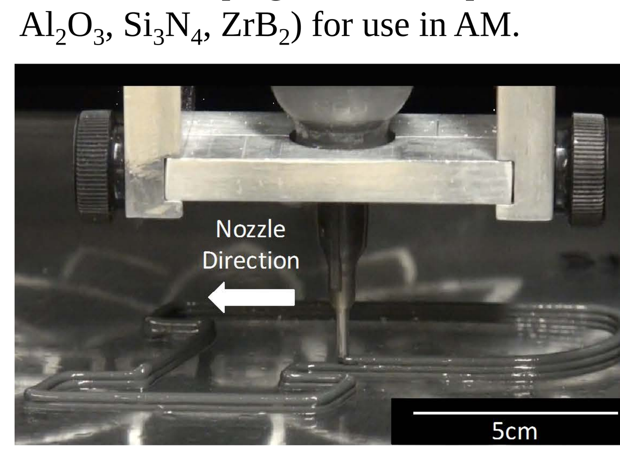
Advanced Ceramic Processing

Professor Youngblood's ceramic research focuses on structure-property-processing relationships of ceramic materials. In particular, we are investigating novel processing approaches for forming (ballistic and high temperature) ceramics and cements into complex shapes using powder-polymer suspensions as well as preparing transparent ceramic via alignment of α-alumina platelets for armor applications.

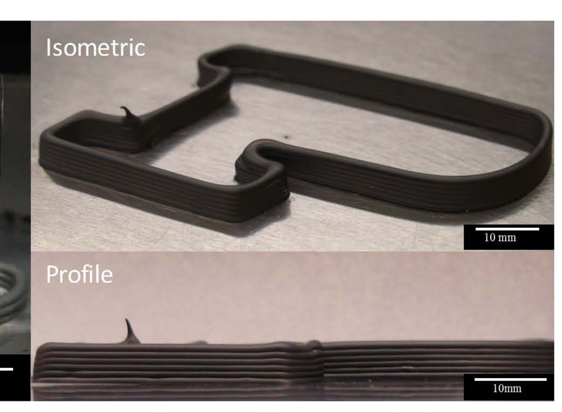
Aqueous Based Ceramic-Polymer Processing

i.) Additive Manufacturing

Current bulk ceramic forming processes are limited to simple structures or require secondary machining to add intricate features. Additive Manufacturing (AM) can be used with aqueous ceramic-polymer suspensions with tailored rheological properties to produce complex geometries. Presently, we are developing ceramic suspensions from different ceramic systems (B_4C, Al_2O_3, Si_3N_4, ZrB_2) for use in AM.



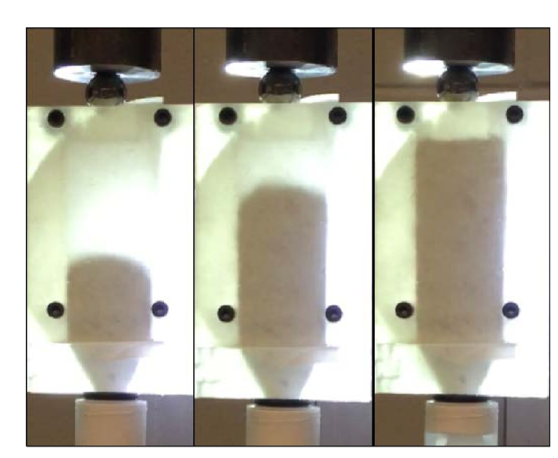
3D printing of a boron carbide slurry



3D printed sintered boron carbide part

ii.) Room-Temperature Injection Molding

By tailoring flow properties of aqueous ceramic-polymer suspensions, injection molding can be accomplished at room temperature to produce samples with complex geometries. Combined with pressureless sintering, this results in parts with high relative densities and mechanical properties comparable to samples prepared by traditional forming methods.

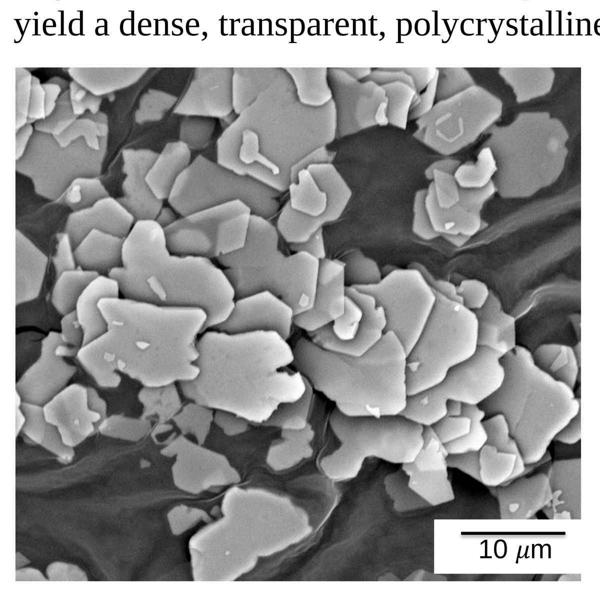


Injection molding of alumina slurry.

Structured Materials

Transparent Ceramics

Current methods for producing transparent ceramics involve extremely high sintering temperatures and/or complex and very large magnetic fields to align ceramic particles. By compression-molding a mixture of platelet-grain alpha-alumina in a thermoplastic polymer, a high degree of crystallographic alignment can be achieved. Subsequent binder burnout and densification will yield a dense, transparent, polycrystalline ceramic.

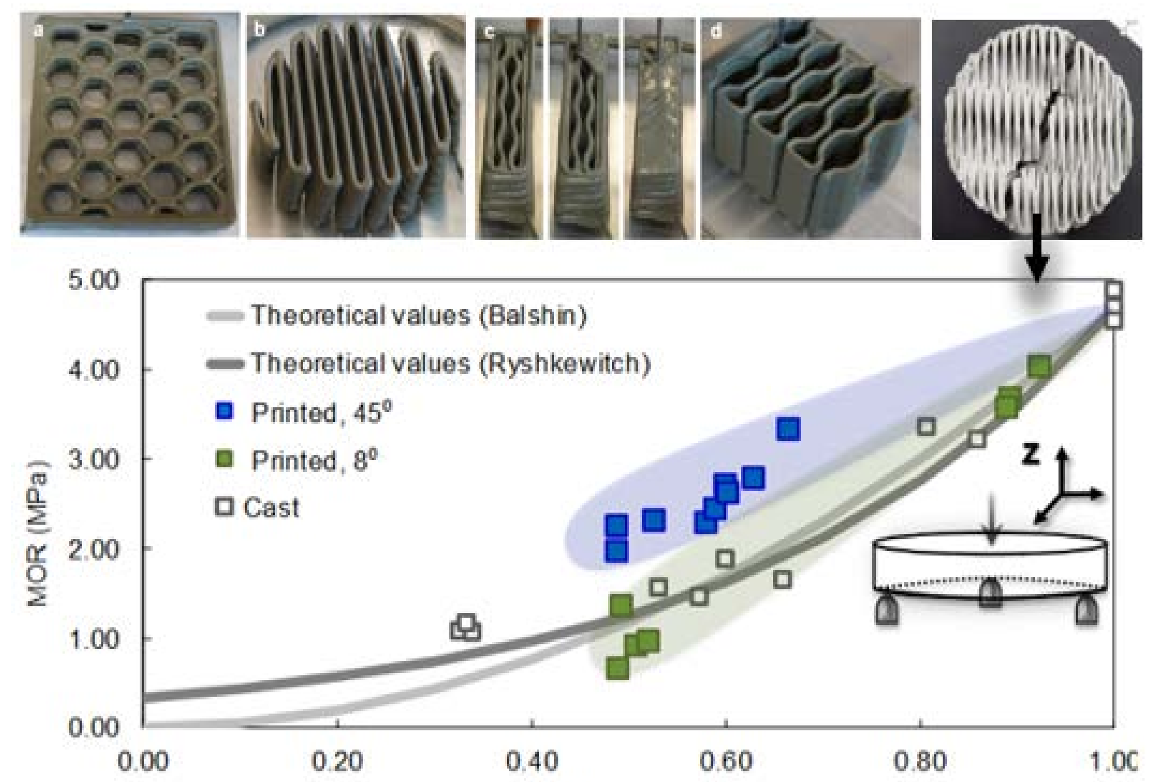


Platelet-grained alumina

Shadow visible behind hot-pressed alumina

3D Printing Cement with Controlled Architecture

Additive manufacturing offers unique opportunities to design and test architectured cement-based materials. We have shown that "Bouligand" architectures with a pitch angle of 45° demonstrate a higher specific strength than cast specimens over a wide range of porosity. As well, we have shown that some architectures can provide flexibility, much higher toughness, and crack deflection in brittle cementitious materials.



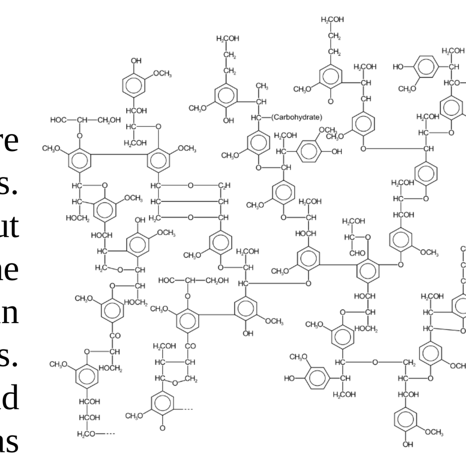
Top: Architectured cement – a. honeycomb, b. twisting layers, c. hollow box with internal structure, d. double-modulus cement "spring", e. Bouligand structure with 8 degree twist. Bottom: MOR vs density curve showing 3D printed architectures show anomalous strength behavior.

Functional Materials

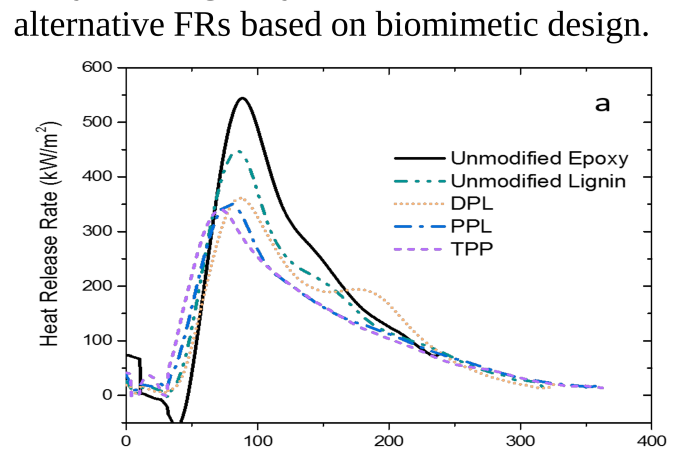
Functional Materials research in the Youngblood group seeks to create and investigate materials, additives and components that are "active" in some way – chemically, electrochemically, thermally, etc. The application fields can span the gamut of cement, batteries, polymer additives, anti-ice coatings and others.

Sustainable Flame Retardants

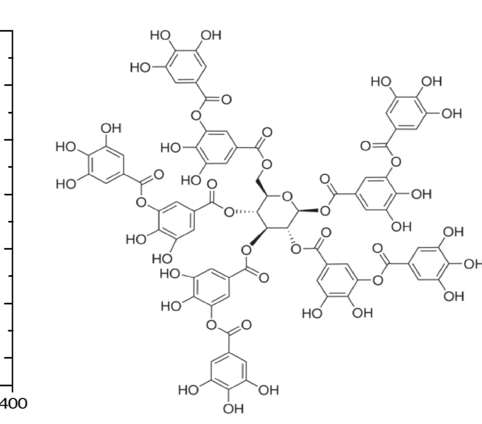
Halogenated flame retardants (HFRs) are used in a variety of polymer systems. However, there is currently concern about their negative effects on health and the environment as bioaccumulation of HFRs in humans can lead to a variety of health issues. The goal of this project was to develop and study biologically-sourced chemicals as alternative FRs based on biomimetic design.



Structure of Lignin (from Wikipedia)



Flame retardancy of natural products compare favorably to commercial FRs



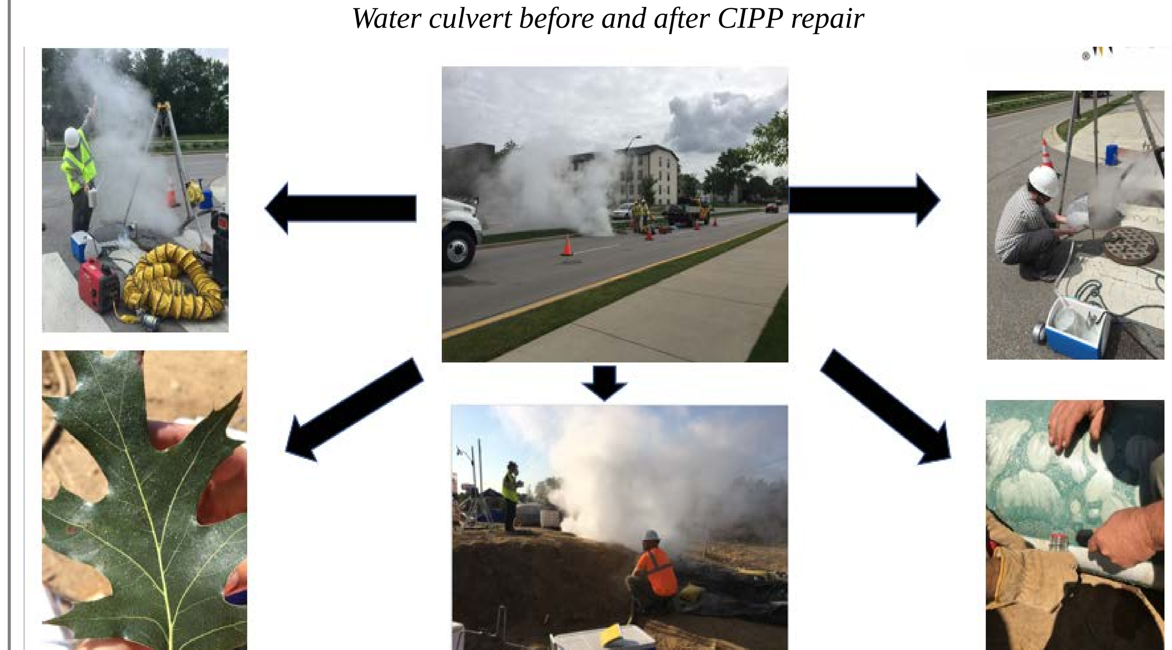
Structure of Tannic Acid

Advanced Polymer Composites

Cured-in-place pipe (CIPP) is the resin saturated fabric liner that is installed into a deteriorated pipeline and then cured using steam, hot water or UV Light. Our goal is to analyze possible environmental effect during, and after installation of cured-in-place pipe (CIPP).

Before CIPP Installation **After CIPP Installation**

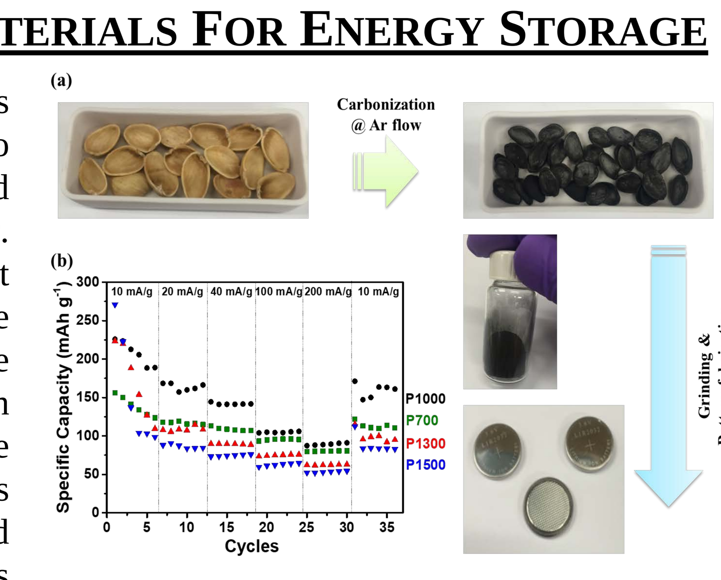
Water culvert before and after CIPP repair



Mutliphasic mixture of VOCs, water, and partially cured polymer are released to the environment during steam curing of CIPP.

Sustainable Materials For Energy Storage

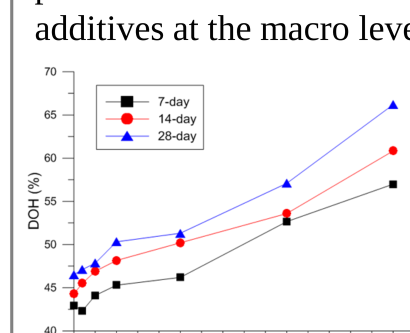
Sustainable energy sources need storage solution to reduce intermittency and provide stable power. However, current electrochemical storage are either too expensive or have to low capacity for such use. Here we investigate earth abundant materials such as biomass, sulfur and common metals such as sodium integrated with processing to lower cost.



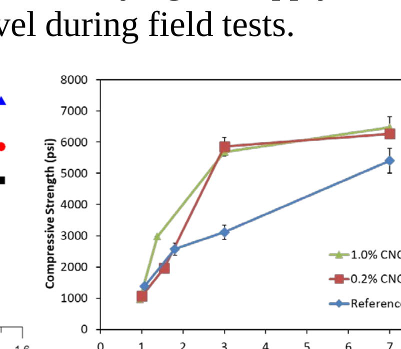
a. Waste biomass such as pistachio shell can be carbonized and used for batteries. b. Performance depends on carbonization temperature.

Additives for Cementitious Materials

CNCs reduce cement paste yield stress, yet improve degree-of-hydration (DOH) all at very low dosages. Lowered yield improves workability, while increased DOH increases strength. We are investigating the origin of these observations and how to improve CNC performance. We are now trying to apply CNC additives at the macro level during field tests.



CNCs increase Degree of Hydration (DOH) in cement



Increased DOH increases strength in cement

We have used these results to conduct field tests