Energeia

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Tekcrete: a Solution for Mine Safety and National Security

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The Department of Homeland Security was formed as a consequence of the terrorist attacks on September 11, 2001. The protection of the nation's critical infrastructure was made part of its mandate, and included in this is the rapid repair and stabilization of shock-damaged structures. In response, the National Institute for Hometown Security, a subcontractor of the Department of Homeland Security, awarded a grant to the University of Kentucky Center for Applied Energy Research (CAER), and Minova USA, Inc. to develop a rapidly deployable system to quickly stabilize and repair shock-damaged structures and avoid catastrophic failure.

A researcher uses a hose to spray Tekcrete Fast™ onto the joint of a beam.

Shocks from explosions or earthquakes are catastrophic to a concrete structure, and the rapid stabilization of shock-damaged structures falls outside the purview of normal construction practices, due to the critical time issue and the nature of the damage itself. Blast or earthquake shocks can put loads on buildings that exceed their structural capacities and slabs, roofs, and foundations face blast-induced vertical and overturning forces. The reinforcement of these damaged concrete structures requires a product that has the ability to be sent into the field immediately with the first responders and be usable at a safe distance. The material itself needs to gain strength almost instantly, so as not to add to the load of an already weakened structure. It also must be able to adhere to a multitude of surfaces that are not prepared or conditioned and may be fractured, dusty, wet, and possibly hot.

The material developed by CAER and Minova, USA, Inc. is Tekcrete Fast™ a single-bag shotcrete, a concrete conveyed through a hose and

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High School Students' CAER-mentored Projects Win at Recent Science Fairs

Four local high school students who were mentored by University of Kentucky Center for Applied Energy Research scientists have proved experience gained by working in laboratories with mentors is invaluable.

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Math DOES Count

The second CAER MathCounts event took place on the evening of Friday, March 22. The fun-filled evening, staffed by CAER outreach staff, researchers, and volunteers was jam packed with a variety of STEM-centric activities and games all geared toward MathCount Math-letes. STEM stands for 'Science, Technology, Engineering, and Mathematics' education.

The students were from middle schools across Kentucky, in town for the state competition the following Saturday morning. Students, parents, and teachers arrived on charter buses to try their hands at building the tallest spaghetti tower, the best K'NEX ping-pong launcher, and bounciest balloon.

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Math DOES Count...continued

They crafted mini-gondolas to race down homemade zip lines, and took a turn at designing paper airplanes to fly across the building's atrium – aiming for targets.

The newest addition to the event was the Biofuels Obstacle Course, designed by renewable fuels researchers, which challenged the visitors to make creative decisions regarding fuel generation and consumption in order to reach the finish line. The researchers participated as team leaders, wearing bright blue hard-hats and encouraging the kids to look at biomass vs. fossil fuel energy choices.

At the end of the evening, CAER staff handed out ice cream to the excited visitors.

(Top Right) A researcher discusses fuel choices during the biofuels obstacle course. (Left) A successful K'NEX Catipult. (Lower Right) Spaghetti and marshmallow tower.

Tekcrete: a Solution for Mine Safety and National Security...continued

pneumatically projected at high velocity onto a surface as a construction technique that is capable of extremely rapid strength development. Tekcrete Fast™ also has unusual bonding characteristics quickly adhering to most construction materials without the need for pretreatment. In addition, a complimentary delivery vehicle capable of shotcreting and grouting pre-packaged, rapid-hardening, fiber-reinforced cements, grouts, and micro-aggregated concretes was designed. This complete configuration will stabilize structures like ceilings in mines, airport runways, tunnels, bridges, and dams that have been shocked and damaged.

Shotcreting, the technology for the rapid delivery of large volumes of cementitious materials to vertical or even overhead surfaces, is an established construction method that has played a major role in the construction of structures like the Washington D.C. Metro subway station and the England-to-France undersea rail connector, "The Chunnel." Rapid hardening cements are already commercially available, and they are used for speedy repair of surfaces such as bridge decks, pavements, and commercial floors, as well as structural repairs of vertical and overhead surfaces.

The majority of rapid hardening cements that are currently available are based on, at least in part, ordinary Portland cement (OPC) as the primary component. Other components are added that help provide early strength, like High Alumina Cement (HAC), organic polymers, chemical accelerators, and calcium sulfate hemihydrate (gypsum plaster). Mortars prepared with some of these cements can achieve compressive strengths of 1000-2000 psi in one hour. However, Portland cement mortar and concrete typically require many weeks of proper curing to reach significant levels of their ultimate strengths, even when used with set accelerators. Additionally, high early strengths can require the use of large proportions of Portland cement in the concrete mix, which can lead to high heat evolution, excessive shrinkage of the material, and cracking.

Alternatives to Portland cement are also capable of rapid strength development, which include calcium sulfate hemihydrate, and calcium sulfoaluminate (CSA) cements. Unlike Portland cement, these rapid hardening cements can gain 75-80 % of their strength within one day, which means less cement can be used in the mix to achieve comparable early strength. CSA cement and calcium sulfate hemihydrates can also be fabricated, for the most part, from coal combustion by-products including fluidized bed combustion spent bed materials, and forced air oxidation flue gas desulfurization by-products (synthetic gypsum).

CSA-based shotcrete materials can be formulated with lower cement content than Portland-based shotcrete, higher water-to-cement ratio, and lower viscosity, and still achieve very high early strengths. These properties are difficult to achieve with Portland cement-based rapid setting materials, but can be achieved with CSA-based cement due to its primary cementitious hydration product, ettringite.

Tekcrete Fast™, a patent pending formulation, is based in part on CSA cement, and is a specially designed, extremely rapid hardening, high performance shotcrete material. This material is superior to other materials on the market because of its ultra-rapid, immediate strength gain, and its ability to adhere to any structural surfaces, whether it is fractured, dusty, or wet, regardless of temperature. Tekcrete fast is fiber-reinforced, offers formulations with rapid strengths of over 8,000 psi, and can be used in conventional, dry-process shotcrete equipment.

When comparing the compressive strengths of Tekcrete Fast™, CSA-based cement, with Ordinary Portland cement, the gains in strength shown by Tekcrete Fast™ are considerable.

Compressive Strength Development of CSA-based Tekcrete Fast™		Compressive Strength Development of Ordinary Portland cement	
15 Minutes	2,500 psi	1 Day	1,900 psi
30 Minutes	3,500 psi	3 Days	4,800 psi
1 Hour	4,500 psi	7 Days	6,200 psi
3 Hours	6,000 psi	28 Days	7,600 psi
1 Day	8,000 psi	56 Days	8,100 psi
7 Days	9,000 psi	112 Days	8,600 psi
28 Days	11,000psi		

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In addition to developing the Tekcrete Fast™ material, University of Kentucky Center for Applied Energy Research and Minova USA Inc., developed a rapidly deployable, low cost structural support that can be engineered into a facility, or deployed by first responders to prevent catastrophic failure. The rapid deployment of the system and the rapid-setting strength of the materials, combined with the ability to stabilize shock-damaged structures from a distance, are crucial. In an emergency situation, the rapidly deployable system would be dispatched directly to the impacted area and set up quickly. Structural shotcrete and foundation stabilization could begin almost immediately, even as other emergency crews are taking necessary action. The system could be used to temporarily prevent the collapse of structures damaged by a blast or earthquake, and it could be used to quickly stabilize rubble in previously collapsed structures.

Rapidly deployable delivery system used in single-delivery vehicle.

The delivery system consists of four main components: water supply, air supply, cementitious material, and a shotcrete applicator machine. These necessary components are assembled onto a single delivery vehicle which enables first responders to immediately take action on location without consuming valuable time to find an external water or air supply. Each of these components is mounted on a heavy-duty trailer, with the forward-section of the trailer housing the static components, i.e. the air compressor and water tank. The aft-section of the trailer is the working area of the system and houses the dynamic components that require operator access, i.e. the shotcrete machine, water booster pump, hose reels, and material supplies. The water booster pump, and specially designed low dust delivery system allows for spraying materials dust-free with low rebound at an exact preset water quantity. The water tank attached to the water booster pump is a free standing, horizontal storage tank with an approximately 150 gallon capacity, with heater.

By teaming up with Minova USA, Inc., a leader in mine ground control and ventilation solutions, based out of Georgetown, Kentucky, the research team was able to develop Tekcrete Fast™, a CSA-based, sprayable-concrete mix. Tekcrete Fast™was designed to gain strength rapidly, and has been shown to gain structural strengths within 15 minutes after spraying. Moreover, Tekcrete Fast™ is a single bag mix which allows for ease of use in shotcreting applications with the rapidly deployable system.

Tekcrete Fast™ has unique properties which make it of value in other applications. A variant of the formula, developed specifically for mining, Tekcrete Fast M™, is currently on the market being sold for use in underground mining applications all over the world.

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Kentucky's Energy Economics

Len Peters, Kentucky Secretary of Energy and the Environment

As much as we seek to identify and implement meaningful policies and programs to develop our energy resources in a way that is appropriate for our state, we are of course not immune to national and international forces affecting energy supply and prices. With a per capita carbon footprint 50 % higher than the national average, Kentucky is becoming even more vulnerable to these forces.

The EPA's New Source Performance Standards (limiting carbon dioxide from new power plants) will preclude construction of any new coal-fired generation anywhere in the United States. Whether the same emissions threshold will be applied to existing units is not known, but it is relatively certain that there will be standards for these units as well. Of course, the shifting national energy landscape is not entirely a factor of more stringent environmental regulations. As some people are saying today, the nation is "awash in cheap natural gas," as a result of production from unconventional shale plays in such states as Pennsylvania, Ohio, West Virginia, and Texas. Even though Kentucky produces natural gas, our production represents only 58 % of our total in-state consumption. As utilities in other states have made the switch to natural gas from coal for electricity generation, Kentucky's coal exports to these states have declined dramatically.

The changing energy landscape at the national level is already having an economic impact in Kentucky. In one year alone, coal-mining employment in the state has declined by about 22 %. These job losses have all occurred in eastern Kentucky. The surprisingly steep decline in coal production is having an unprecedented economic impact, with coal severance tax receipts continuing to decline—down 24% through the first seven months of the fiscal year.

It is this vulnerability to factors beyond our control outside our state's borders that compels us to continue to seek a diversified energy portfolio. Determining the proper mix of resources that are economically and environmentally reasonable is the challenge. It's not a challenge that can be addressed by a single entity, and there will be no single resource remedy. The reality is, however, that we will not likely be generating 92 % of our state's electricity from coal in 10 to 15 years. What is at risk, if we aren't wise and proactive, is our state's robust manufacturing economy—an economy that is especially vulnerable to both electricity price increases and price volatility.

Manufacturing accounts for more than 200,000 jobs statewide and represents close to 20 % of the state's GDP. In fact, when measured in kilowatt hours per GDP, Kentucky ranks as the most energy-intensive state in the nation. In Kentucky, we have many industries that use substantially large amounts of energy in their production processes—think aluminum production and processing, iron and steel mills, chemical production, etc. These industries have been integral to the state's economy for decades—they use more kilowatt-hours of electricity to produce one dollar of GDP than less energy intensive industries, and they have located here for the obvious reason—low electricity rates.

From an energy-economics standpoint, Kentucky is therefore vulnerable on two fronts: (1) Our coal exports to other states are declining as utilities switch to natural gas, reducing in-state coal production and creating economic hardship, especially in eastern Kentucky; and (2) Our ability to rely primarily on coal within the state for electricity generation is going to be curtailed, which could place upward pressure on electricity prices if we are not able to make a rational transition to other affordable baseload power options.

I see no reason to expect these shifts in our energy situation to change. The historical trend with environmental regulations is one of increasing and broadening controls on emissions, not fewer, and the nation's supply of natural gas will likely keep costs competitive for some time. How long these natural gas costs remain low will be influenced by a host of factors, including environmental regulations governing hydraulic fracturing.

Many analysts predict resurgence in U.S. industrial growth as natural gas, currently very inexpensive, puts downward pressure on electricity prices in many states. Already, you can follow announcements of new industrial plant openings in other states linked to the availability of low-cost natural gas both as feedstock and as energy source. How Kentucky fares as the national energy picture changes will depend largely on our ability to provide a diverse, affordable, and reliable energy mix using Kentucky's domestic renewable and fossil resources.

We all want to see our state prosper, we want good jobs for our citizens, and we want the economic security inherent to a

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High School Students' CAER-mentored Projects Win at Recent Science Fairs...continued

Valerie Sarge, a junior at Paul Laurence Dunbar High School, placed first in the Energy and Transportation category at the Central Kentucky Regional Science and Engineering Fair, going on to win first place in the same category at the state competition. This qualifies her to go on to Intel's International Science and Engineering Fair (ISEF) to be held in Phoenix. Valerie was mentored by Chemistry Professor/CAER Faculty Associate, John Anthony. In her work with the solar energy group she is using organic compounds called furan-based materials. These can be derived from agricultural waste products to create new semiconductors for use in low-cost solar cells. She is has been working on synthesis, but may soon move toward creating solar cells.

Will Kimmerer, from Sayre School, won top awards at the regional and state fairs in the Environmental Science category, including second in the Physical Sciences category. Kimmerer obtained carbon material samples for use in his project from CAER and worked closely with Director Rodney Andrews during the project. He was selected for the I-SWEEP 2013 conference (International Sustainable World Energy Engineering Environment Project) in Houston, where he will present his work. Additionally, he was selected for the Stockholm Junior Water Award.

"Mentoring high school students shows them how much fun science is, while reminding researchers why they entered the field in the first place."

-Matt Weisenberger
Associate Director, Carbon Materials Group

Additionally, two Dunbar CAER interns placed well at the regional level and went on to compete at the state competition. Rohin Lohe placed first in the "Engineering: Materials and Bioengineering" category, and went on to place third at the state competition. Lohe will compete at the Kentucky Junior Academy of Sciences on April 27th. John Luan also won in the "Energy and Transportation" category at regionals.

Matt Weisenberger, Associate Director for Carbon Materials, is mentoring Lohe with a project titled "Finite Element Analysis of Heat Conduction through Interfaces: Modeling and Experimental Verification with Stainless Steel, Copper, and Multiwall Carbon Nanotube Arrays as Thermal Interface Materials." Lohe has been conducting his research at the UK CAER laboratory facilities and working directly with the Carbon Materials Research staff in completing the tests.

Lohe's project included part of the expertise gained while working with CAER's Electrochemical Power Sources group under the direction of Associate Director Steve Lipka. John is working on a project entitled "Carbon-based Capacitive Thin Films for AC Line Filtering" in which the goal is to demonstrate whether carbon-based supercapacitors can be used as a lower-cost, more-dependable replacement for traditional electrolytic capacitors in electronic devices.

Kentucky's Energy Economics...continued

good quality of life. We have so much at stake—the old way of looking at our state's strengths might not serve us well going forward. I'm convinced that we've seen our last boom-bust cycle for Kentucky coal. It's a sobering reality, in my mind, but one we have to talk about to make sure a different way of thinking helps us to prosper in the twenty-first century.

Together we need to start the discussion that helps define our path forward—a path that ensures a vibrant manufacturing industry for Kentucky that is based on affordable, reliable electricity prices. Our future depends on it.

For more information on Kentucky's Energy and Environment Cabinet go to:

http://eec.ky.gov/Pages/default.aspx

To learn more about employment and markets for coal visit the link below:

2012 Kentucky Coal Facts

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