THE UNIVERSITY OF UTAH

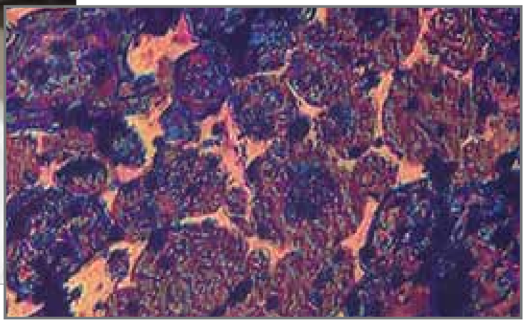
SPRING 2011 UTAH ENGINEERING

Building a Concrete Future

IMPROVED MATERIALS MEANS HIGH-IMPACT, LONG-LASTING STRUCTURES

LEFT: Paul Tikalsky, professor and chair of civil and environmental engineering

BELOW: The microscopic structure of a cement particle containing calcium silicates and calcium aluminates.



Concrete has been used in construction for thousands of years. Concrete materials allowed ancient civilizations certain freedom that brick and stone could not provide in terms of design, structural complexity and dimension. Some examples of ancient concrete construction still standing today include the Pantheon and the Baths of Caracalla in Rome.

Today, concrete—made from a combination of portland cement, limestone and other cementitious materials—is even more prevalent as the building material used in nearly every structure, including highways, bridges, buildings, dams, tunnels, and foundations for pipelines, homes, and other structures around the world.

Professor Paul Tikalsky, chair of the Department of Civil and Environmental Engineering at the University of Utah, has made improving concrete materials the focus of his research for more than a quarter of a century. He has developed and helped to construct hundreds of millions of dollars in more durable, longer-lasting concrete structures that reduce the environmental footprint of construction and provide a more enduring civil infrastructure.

Building the Hundred-Year Highway

Tikalsky is currently leading a multiple-year study to develop better concrete bridges and roads for the United States Department of Transportation Federal Highway Administration (FHWA), along with transportation agencies from ten states, several industrial organizations and an investigator at Iowa State University.

"We want our bridges and highways to last longer than they do now—a minimum of 100 years for bridges—and to use less new natural resources," says Tikalsky. "That means they will have only one-third of the environmental impact on natural resources and emissions, meet higher technical requirements, but cost nearly the same as other bridges being built today." >>

INSIDE

RESEARCH

The FHWA and state transportation agencies have begun installing bridges and highways using concrete materials designed by Tikalsky and his research team. Tikalsky's lab receives samples of materials from each region in the country, so that his team may design concrete mixtures with resources that are available near the construction site. "There are no simple concrete recipes," he says. "We use local materials to design effective, high-performance mixtures based on what's available in the area. That reduces environmental impacts, control costs and supports a sustainable community."

Five years ago, Tikalsky designed 10 different concrete mixtures for Interstate 99 bridges in Pennsylvania. The older bridges in this area had average lives of only 27 years before being replaced. Once the new bridges were completed, Tikalsky's team tested the engineering properties of the concrete. They measured strength, corrosion resistance, resistance to freezing and thawing cycles, and other chemical and physical durability characteristics, including the number and size of hairline shrinkage cracks—which form in all concrete. Five years later, the team reinspected the same bridges and found that the concrete was substantially stronger, had fewer cracks, and was more corrosion-resistant than when the bridges were constructed.

The team also looked at the electrical resistivity of the concrete to calculate how far winter deicing salt and moisture had diffused into the concrete. Salt that penetrates to the level of the reinforcing steel will corrode and weaken the bridge. At five years, the group found that salt had diffused only a few millimeters into the concrete. "Many levels of protection help preserve the life of the bridge," says Tikalsky. "With better concrete and coated rebar, we anticipate the bridges will last four times longer than the previous generation of bridges."

Creating a Better Concrete

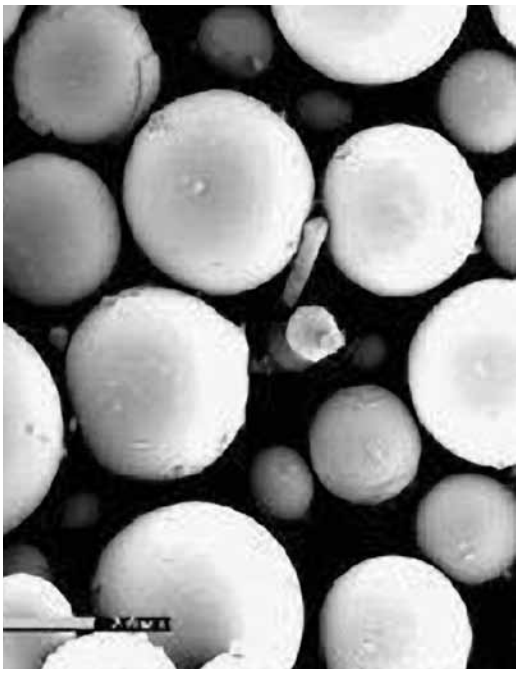
Tikalsky and his team have been improving concrete mixtures by replacing some of the portland cement with fly ash—the ash by-product generated by coal-burning power plants. Fly ash particles have nearly the same size and bulk chemistry as portland cement and volcanic ash used by the Romans.

Fly ash is a pozzolan—a material that when combined with calcium hydroxide (or lime) becomes cement-like. Pozzolans such as fly ash, iron slag, volcanic ash, or silica fume are added to concrete mixtures to improve the long-term strength and engineering properties of concrete. Fly ash is a lot cheaper than cement, and its use in concrete helps the environment because it would otherwise be disposed of in landfills.

"There are 50 million tons of fly ash collected each year from power plants in the United States, and we use about 20 million tons in place of portland cement," says Tikalsky. "It makes concrete stronger, and it saves tax payers hundreds of millions of dollars annually through less expensive concrete and a longer life infrastructure."

In the past year, Tikalsky has included calcite in his cements—a finely ground limestone material that improves the efficiency of cement by providing a substrate for chemical compounds to grow, allowing more of the cement to react with water. This material has almost no environmental footprint and reduces the amount of cement used by 10 percent. The new Meldrum Civil Engineering Building at the U uses this type of long-lasting cement with 25 percent fly ash, reducing the carbon footprint of the concrete in the building by nearly 35 percent.

Tikalsky says the majority of the laboratory study is now completed. His team is currently overseeing the construction of highways and bridges in 10 states and will report to federal agencies on their findings. Tikalsky and his associates are now working on new ways to produce special concretes for nuclear power plants, highways that clean the air during weather inversions, and even translucent concrete for both art and architecture.



TOP: Fly ash particles collected from coal-burning power plants have nearly the same bulk chemistry as portland cement.

BOTTOM: University of Utah graduate researchers inspect Interstate 99 bridges in Pennsylvania five years after being built. The bridges were designed using sustainable, long-life concrete formulations developed in Paul Tikalsky's lab.

Security in the Cyber World

MAKING COMPUTER SYSTEMS IMPENETRABLE TO ATTACK

Matthew Might
Assistant Professor in the School of Computing

Not long ago, one of the biggest concerns related to Internet security was the potential for computer users to have their identities or account information stolen. But in today's connected world where some two billion people have Web access, many computer hackers have bigger nefarious motives, including committing large-scale cybercrimes.

"Cyber criminals aren't necessarily looking to steal your information," says Matthew Might, assistant professor in the School of Computing at the University of Utah. "They more commonly break into your computer without your knowing to use your computational resources to take down Web sites and extort businesses for money."

Cyber criminals infect computers with viruses and other malware when users click on suspicious links in emails or visit untrustworthy Web sites. Sometimes they can break into a computer simply because it is on and plugged into the Internet. "Some worms can exploit flaws in operating systems and spread worldwide within minutes, infecting every vulnerable computer," says Might.

Once they have control over millions of infected computers—grouped into networks called botnets—cyber criminals can target businesses for money. If a company refuses to pay, the criminals unleash a flood of traffic that disables the company's computer servers. "Often a company's only choice is to pay the fee," says Might.

The U.S. government is particularly concerned about cyber security after being the victim of numerous attacks that have compromised classified information, such as weapons blueprints, operation plans, and surveillance data. For example, "the most significant breach of U.S. military computers ever" occurred in 2008, says U.S. Deputy Defense Secretary William Lynn, when an infected flash drive uploaded malicious computer code onto a U.S. Central Command network, then spread undetected on classified and unclassified systems, allowing attackers to transfer data to servers under foreign control.

To combat such attacks, Might is part of a team of researchers working on a multi-year project to develop an impenetrable computer system for the U.S. military, which he says starts with how software is developed. The current way is for programmers to write software code and then test it for flaws—a method fraught with human error. "There are many common flaws that programmers mistakenly put in software," Might says. "That leaves the door open for attacks."

Might and his associates propose a new way of writing software that uses mathematical proofs to demonstrate the impenetrability of software. Instead of writing code and then testing it, the researchers first write a specification (or blueprint) for software, followed by the software code, and finally a mathematical proof.

This way of treating software as a mathematical object is important, Might says, because "it engineers software correctly from the start. It brings a mathematical proof that there is no security vulnerability."

To simplify the process, the team is breaking down the software into smaller modules that use the least computationally complex language, so that the group can generate proofs automatically for each module. This process will help the researchers create a secure operating system faster—perhaps within four years.

"This project is important because we need to make our systems more resilient to attack," Might says. "But even before we have systems that are impervious, we will have much stronger systems and we can make it a lot harder to break in."

Meet Our New

Professor Alan Davis is the newly appointed director of the School of Computing. A faculty member in computer science at the University of Utah since 1993, Davis has spent half of his career working for companies such as Burroughs, Hewlett Packard, Fairchild, Schlumberger, and the other half of it in academia.

"Both have advantages. Industry is a great place to move ideas into mainstream products, and academia is a great place to work on ideas from a research perspective," says Davis, who currently has three main research projects.

The first project involves improving rendering techniques by replacing graphics processing units (GPUs) with ray processing units (RPUs). GPUs support z-buffer rendering, while RPUs support ray-tracing rendering. Certain realistic effects are more easily achieved through ray tracing, such as shadows, indirect lighting, and reflective and refractive material properties.

The second project seeks to improve the performance and energy efficiency of main memory systems. As the number of processor cores increases in microprocessor chips, the promised performance of these new processors will only be realized if the memory system can keep pace. Historically this has not been the case and the need has now become critical, Davis says.

A third project involves replacing electrical long wires in circuit boards and chips with an optical interconnect. The fundamental advantage of optics is reduced bit-transport energy (the energy it takes to transport a bit of information from sender to receiver) and the opportunity to increase bandwidth density through the use of multiple wavelengths of light in the same fiber or waveguide.

As the School of Computing's new director, Davis's goal is to strengthen research areas, including machine-learning, formal verification of complex systems, robotics and large-data analysis. "We want to help faculty amplify their research efforts," he says. "We also want to recruit the best and brightest in these areas."

Technology Commercialization at the U

A cap system designed by bioengineering assistant professor Robert Hitchcock (pictured far right) to cover and disinfect infusion access points when they are disconnected between treatments.

After advancing in the corporate world over the course of two decades, Robert Hitchcock returned to school to get a Ph.D. in bioengineering from the University of Utah in 2001. Since then, Hitchcock started teaching at the U where he is currently an assistant professor of bioengineering, and has become one of the champions behind medical device development and commercialization on campus.

Hitchcock is a co-founder of a new University of Utah startup called Catheter Connections, which specializes in developing medical devices to help prevent catheter-related infections during intravenous (IV) therapy. Its first product is called the DualCap™, which is a cap system designed to cover and disinfect infusion access points when they are disconnected between treatments. Nothing like the device is on the market today, even though the concept is relatively simple.

Faculty Leaders

Professor Patrick Tresco is the newly appointed chair of the Department of Bioengineering. A faculty member at the University of Utah since 1992, Tresco initially studied medicine in school. "But after doing some research, I decided that doctors needed better tools," says Tresco, who left medical school to pursue a PhD at Brown University in Rhode Island.

Tresco currently has two major research focuses. First, he seeks to improve existing medical devices, particularly those that interact with the human body's central nervous system. "We want to help individuals who wear neuroprosthetics to gain control over these devices," he says. "So we focus on neural interface technology, such as electrical, recording and stimulating devices."

The second research emphasis involves developing new technology for tissue repair. His research group has developed a technique to harvest the extracellular matrix (proteins and carbohydrates) that all living cells manufacture. These cell building blocks provide the scaffolding and fabric that gives strength and mechanical properties to living tissue. "We're the only group I'm aware of that has developed a technique for harvesting in bulk the matrix from any living cell," says Tresco. He hopes to use the bulk material to build tissue and organs, such as artificial tendons and vocal cords, that may be damaged by disease or injury.

"Our approach lets us harvest the extracellular matrix from the patients themselves," he says. "The biggest application will be as a vehicle for delivering stem cells and bioactive bandages." For instance, for a gunshot injury, this material would provide the scaffolding needed to heal the injury without leaving a large depression. The material is absorbable and would be replaced in time with the person's own tissue.

In his new role as the chair of bioengineering, Tresco seeks to expand the department's budget and build new partnerships with the U's School of Medicine, the private sector and bioengineering alumni.

A DEVICE TO REDUCE IV INFECTIONS

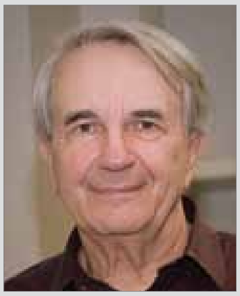
"These types of devices are absolutely necessary to protect patients," says Hitchcock, who got the initial idea for the device from nurses at the VA hospital. "This is something that should be used with virtually all types of catheter infusion systems."

Typically, when health care workers disconnect catheters between treatments, they leave the lines open and exposed to a variety of contaminants. The results can be disastrous. Every year in the U.S., nearly 500,000 people acquire catheter-related bloodstream infections and over 31,000 die. The DualCap™ may reduce these complications by providing an easy way to lower the risk of catheter-related infections.

"The number of preventable deaths is staggering," Hitchcock says. "It's simple devices like this that can have a significant impact on people's health."

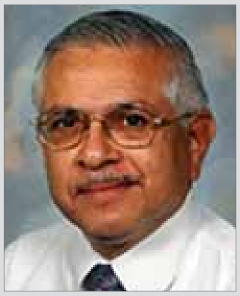
One of the major improvements provided by the device is the elimination of human error. Standard practice usually requires that a health care worker swab the catheter line to disinfect it, but this is often overlooked or done poorly. The DualCap™ eliminates the need to do anything except twist a small cap onto the catheter end and infusion line.

Hitchcock is quick to point out that he has not succeeded by working alone. Help has come from outside collaborators, University physicians, talented students, the U's Technology Commercialization Office and many other sources. "This is clearly a team effort," he says.



JINDRICH KOPECEK NAMED TO NATIONAL ACADEMY OF ENGINEERING

Jindrich Kopecek, distinguished professor of bioengineering and of pharmaceutics and pharmaceutical chemistry who pioneered the use of chain-like molecules called polymers to deliver medicines to their targets, has been elected to the National Academy of Engineering. Kopecek, along with 67 other new members and nine foreign associates, were honored for making "outstanding contributions to engineering research, practice, or education." Kopecek was honored specifically "for contributions to the design of hydrogel biomaterials and polymeric drug delivery systems."

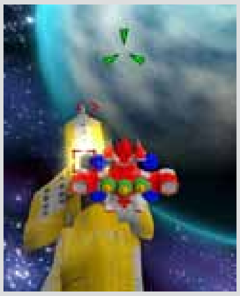


ANIL VIRKAR NAMED HIGHLY CITED RESEARCHER

Professor Anil Virkar, chair of the Department of Materials Science and Engineering, was recently ranked among the top cited researchers in his field by *ISIHighlyCited.com*, a Web site run by information company Thomson Reuters. "Citation is a direct measure of influence on the literature of a subject," according to the Web site, which also stated that Virkar was highlighted among "the top 250 preeminent individual researchers in each of 21 subject categories who have demonstrated great influence in their field as measured by citations to their work."

THREE NEW NSF CAREER AWARDS ANNOUNCED

Three faculty members recently received National Science Foundation (NSF) CAREER Awards: P. Thomas Fletcher, USTAR assistant professor in the School of Computing and a faculty member of the Scientific Computing and Imaging Institute, will develop nonlinear statistical models for time-varying shape and apply them to biomedical image analysis problems; Ramesh Goel, assistant professor of civil and environmental engineering, will study bacteriophages in engineered bioreactors; and Rajesh Menon, USTAR assistant professor of electrical and computer engineering, will work in scalable nanopatterning to enable the manufacture of nanostructures for photovoltaic applications.



VIDEO GAME DESIGN PROGRAM AT THE TOP

The University of Utah's School of Computing and film department's Entertainment Arts & Engineering (EAE) undergraduate program, which started in 2007, is now ranked #2 in the country for video game design. EAE started its Master Games Studio in the fall of 2010, and just six months into its first year, the graduate program was ranked #6 in the nation. Both rankings are by *Princeton Review* and GamePro Media. The U's games program builds upon a history of graphic design, technological advancement and entrepreneurship that sets the university apart from its peer institutions.

Eric Eddings Named Associate

Professor Eric Eddings is the newly appointed associate dean for research in the College of Engineering. A professor in the Department of Chemical Engineering, Eddings also works with the University of Utah's Institute for Clean and Secure Energy. Prior to joining the U of U in 1998, Eddings spent six years with Reaction Engineering International, a research and development company in Salt Lake City, where he served as senior engineer, manager and then vice president.

Eddings' research is energy-related, with a focus on the utilization of fossil, biomass and waste-derived fuels in a variety of industrial high-temperature processes. "We're seeking to reduce the environmental impacts of the use of such fuels, as well as mitigating operational detriments that result from the implementation of environmental controls," he says.

Building ROBOTICS AT THE U

Stephen Jacobsen, distinguished professor of mechanical engineering, has recently returned to the University of Utah College of Engineering to help build the robotics program. Jacobsen is also an alumnus of the mechanical engineering program at the U, where he received his undergraduate and master's degrees. He went on to earn a PhD at the Massachusetts Institute of Technology in Cambridge, Massachusetts.

Over the years, Jacobsen has built several successful companies while serving as a member of the U of U faculty. The former president of Raytheon Sarcos, Jacobsen has developed new technology that ranges from robots for the entertainment industry and the military, to breakthrough medical devices, such as the artificial kidney, high-tech prosthetic arms for amputees, and micro-catheters for accessing complex areas of the anatomy.

Jacobsen and his Sarcos team created the robotic dinosaurs at Universal Studios Jurassic Park in Hollywood, including the 80,000-pound T-Rex that moves and roars. They developed the water jets for the robotized fountain at the Bellagio Hotel and Casino in Las Vegas. They also designed and built a groundbreaking exoskeleton for the military that humans can wear to perform superhuman tasks. "You put it on and it allows you normal freedom of movement," he says. "But it also gives you 17 times the strength that you put out."

Stephen Jacobsen (right) is pictured with the exoskeleton he and his team created.

PHOTO CREDIT: John B. Carnett

One of Jacobsen newest projects is expanding the activities and funding base for the robotics and design program at the U's College of Engineering. Both students and professors will be involved in developing research projects that can be successfully commercialized.

"Students need to have exposure to ideas that can be made into reality," says Jacobsen. "My goal is for professors to help students with new ideas and to actually make things happen."

Elected to the National Academy of Engineering and the National Academy of Sciences' Institute of Medicine, Jacobsen is the recipient of numerous other awards and honors. Most recently he was recognized as one of the University of Utah's most prolific inventors.

Dean for Research in the College of Engineering

His current research projects include oxy-coal combustion to facilitate carbon dioxide capture; biomass pyrolysis for the production of transportation fuels; underground thermal treatment of coal for the production of gaseous and liquid fuels with higher hydrogen content than the parent coal; experimental studies of pollutant formation and control from coal, biomass and other solid and liquid fuels; and the development of detailed kinetic mechanisms for complex hydrocarbon mixtures.

Eddings is currently working with inventors on a start-up company to commercialize a pyrolysis technology that converts various types of biomass and waste materials into oil that will substitute for petroleum crude oil to allow for production of "green" transportation fuels.

Eddings aims to apply his research experience in industry and academia to his new role as associate dean for research.

"Having been the principal investigator on numerous large and small government- and industry-funded grants, and participated in many multi-disciplinary research programs, I know what works and what is required to put together successful programs," he says. "I want to bring faculty together and assist them in adapting their different technical backgrounds to large, multi-investigator grants that can be of benefit to their research and to the College."

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FROM LEFT: **Joyce Lin,** mathematics postdoctoral fellow; **Cindy Furse,** electrical & computer engineering professor; **Ken Golden,** mathematics professor; **David Lubbers,** electrical engineering student

STUDENT LIFE

Journey to ANTARCTICA

Growing up in Salt Lake City, student David Lubbers always knew he wanted to be an inventor. He was good at math and enjoyed taking apart objects to see how they worked. He says his career aspirations included "leaving something behind in the world that could help other people."

After working in computer programming following high school, Lubbers came to the University of Utah to pursue a degree in electrical engineering. "I specifically chose electrical engineering because I wanted to explore something totally new to me. Among the engineering disciplines, it was the one I knew the least about," he says.

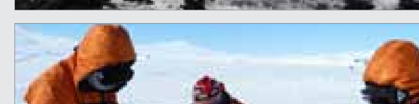
Now a senior at the U of U, Lubbers is working on his thesis project, an undertaking that has sent him to Antarctica and, in a couple of months, will take him to Alaska to conduct similar research.

Lubbers was part of an expedition led by U math professor Ken Golden to study the electrical properties of sea ice in Antarctica. Seawater naturally contains a lot of salt. In places such as Antarctica where seawater freezes, salt becomes trapped in "brine inclusions" that form within the ice. As the ice warms, the inclusions become connected and form channels—similar to branches in a tree's root system—where the extra-salty brine stays in liquid form. As sea ice melts from the surface, brine can drain through these channels and enter the upper ocean. Since the brine in the channels conducts electricity, electrical measurements of sea ice can facilitate studies of the melting process.

The project was conducted to help researchers understand how the flow of electricity is related to the flow of fluid through sea ice. The researchers' goal is to understand the dynamics of sea ice to help them better predict climate change.

Lubbers traveled as a student of electrical engineering professor Cindy Furse, associate vice president for research at the U, who also went on the trip. The team also included Joyce Lin, a postdoctoral fellow in mathematics at the U, and a group of physicists from New Zealand. Team members who did not make the trip include U of U electrical engineering students Jacob Hansen and Eric Gamez.

Lubbers says the experience taught him a lot about conducting successful research. Even though not everything worked initially as planned, the group did get the sea ice measurements they were looking for. "We did a lot of brainstorming before we left and ultimately we developed methods we were able to use there," says Lubbers. "But I hadn't anticipated the failure we would experience on the road to being successful in our research."



University of Utah researchers traveled to Antarctica to study the electrical properties of sea ice.

After graduating this coming May, Lubbers plans to work on a master's degree and then a PhD in electrical engineering while continuing to work on the sea ice project.