FALL 2019

MECHANICAL ENGINEERING

UNIVERSITY OF WISCONSIN-MADISON

FUTURE ENGINEERING LEADERS WORK TOGETHER ON BIG CHALLENGES

CHAIR'S MESSAGE

Greetings!

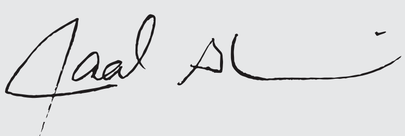
They say that the only constant is change, and that is definitely true in the department these days. We were extremely successful in our hiring last year, and this fall we had five new assistant professors join the department. You will read about them in future newsletters, but briefly, Joseph Andrews works on printable and flexible electronics for sensor development, Lianyi Chen studies metal additive manufacturing and opportunities for new material development, Josh Roth (whose primary appointment is in orthopedics) investigates treatments of musculoskeletal injuries and disease (think joint replacement), Dakotah Thompson researches nanoscale energy transport, and Xiangru Xu studies the control of autonomous and cyber-physical systems.

In addition, we also were fortunate to add Professor Douglas Reindl to our tenured faculty. Doug has most recently been chair of the Department of Engineering Professional Development and is a leading researcher in the area of refrigeration (and the recipient of the 2019 ASHRAE Crosby Field Award, see page 7). All of these faculty augment our current activities in new and exciting ways, and I look forward to seeing their research accomplishments in the years to come.

The best part of this job is to see the success our students enjoy when they participate in engineering competitions. In spring 2019, a group of our students took part in the Land O'Lakes Bot Shot—a robotic game of H-O-R-S-E. The UW-Madison team won the event, besting fellow Big Ten teams from Purdue and Minnesota, among others. Our students also participated this spring and summer in a variety of vehicle competitions, including the Hyperloop competition at SpaceX in Hawthorne, California. An exciting new student team is being started and led by Glenn Bower—an autonomous vehicle challenge that is run as an international design competition by Formula Student Germany. Essentially, students build and compete a driverless Formula car. This will be an interesting endeavor to follow!

Thank you for your continued interest in and support of the department. I look forward to seeing you on campus soon.

ON, WISCONSIN!



Jaal Ghandhi
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In June 2019, UW-Madison's chapter of the Society for Women Engineers hosted its summer camp for high-school-aged girls called Engineering Tomorrow's Careers. The weeklong camp was an opportunity for 65 young women from across the Midwest to stay on campus, interact with engineering professors, and try their hands at real-world lab experiments. The girls also got a firsthand lesson in aerodynamics, fluid mechanics and the laws of buoyancy during a sailing excursion on Lake Mendota.

MIN EARNS NSF CAREER AWARD

Cutting ceramics loose from their difficult reputation

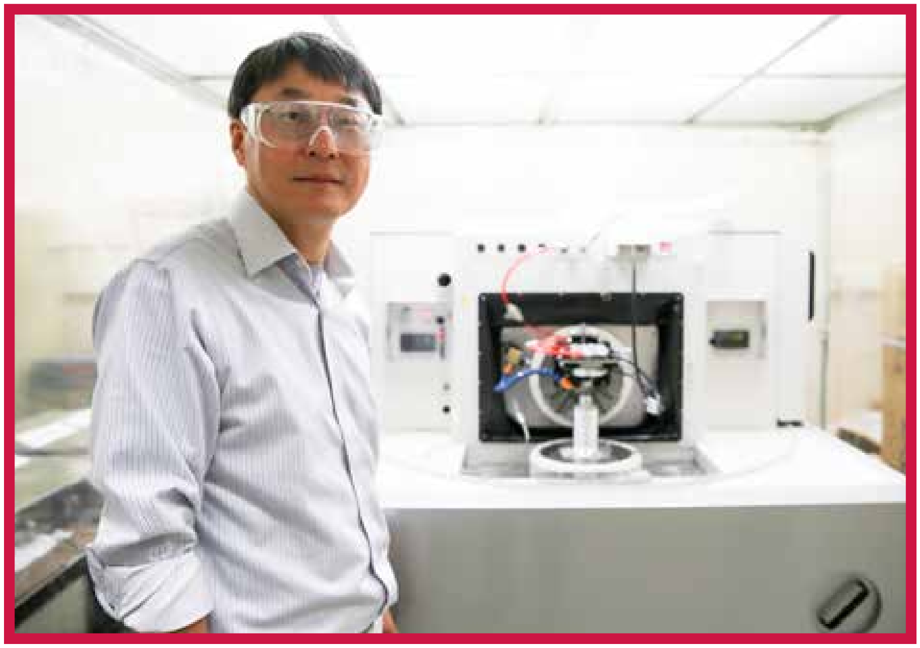


Photo: Sarah Page

Many of us can relate to the dreaded experience of dropping our smartphone and desperately hoping the screen doesn't break as we watch the precious device crash onto the ground.

But if that phone's screen happened to be made of sapphire, it would be practically shatterproof. That's just one example of the ways that ceramic materials such as sapphire and zirconia, which boast many superior mechanical, chemical and optical properties, could enable innovative products and new applications.

Ceramic materials are exceptionally strong; sapphire, for instance, is the strongest material after diamond. But that strength, as well as the materials' brittleness, presents some challenges to overcome.

"Ceramic materials have a lot of potential, but the reason they are not widely used by industry is because of limitations with the processing technology," says Assistant Professor Sangkee Min. "It's not possible to fabricate these materials in mass quantities using conventional manufacturing technologies."

Min seeks to develop new machining strategies for ceramics that would enable companies to adopt these materials for a wide variety of applications.

First, Min needs to deal with the problem of cracks. Conventional machining creates cracks on ceramic surfaces because the crystal structure of the material is prone to fracture.

With support from a prestigious CAREER Award from the National Science Foundation, Min will explore how the forces generated from cutting cause cracks in ceramic materials. Then, with this understanding, he will devise new strategies for machining that will avoid creating those cracks in the first place.

Min says an earlier breakthrough from his lab points to a promising approach for achieving this goal: He made cuts in a ceramic material at a depth of mere nanometers, and he identified certain machining parameters that enabled very smooth cuts, creating super-fine surfaces without any cracks.

Essentially, at that super-small scale, ceramics can be machined like metals—although we don't yet know the reasons why.

"Why does a brittle, strong ceramic material behave like a soft, ductile material that we can nicely cut in some circumstances?" Min says. "I'm trying to understand the fundamental mechanism for when this material behaves differently than the conventional way. Once we know that, we can come up with different strategies to enable ceramic materials in many industry applications."

> **"I'm trying to understand the fundamental mechanism for when ceramic material behaves differently than the conventional way. Once we know that, we can come up with different strategies to enable it in many industry applications."**
>
> **— Sangkee Min**

Min's groundbreaking work in this area is made possible by the unique ultra-precision ROBONANO machine in his lab. The 3D nanoscale milling machine, which Min acquired from the Japanese robotics manufacturer FANUC, is the only machine of its kind in the United States.

In fact, the ROBONANO is so astoundingly precise that Min can make nanoscale cuts through areas where the bonds between individual atoms are weaker. This is a key advantage, he says, because these types of cuts allow him to shape the material without generating the kind of forces that will cause it to fracture.

Min is not only excited about the fundamental science he's investigating with this project but also about the ways his work could benefit industry. He notes that companies are eager to use ceramic materials because of their highly desirable properties.

"For example, the medical industry is very interested because ceramic materials are biocompatible," Min says. "So you can put them inside the body and their lifespan is going to be much longer than implants made out of titanium or other materials. There is huge potential."

CLEARING THE FOG

Interdisciplinary effort targets traumatic brain injuries

Increasingly, concussions prematurely end the careers of athletes young and old, and for many of those individuals, they inflict life-changing short- and long-term damage. Yet surprisingly, there's much researchers still don't know about how concussions actually develop in the brain.

There's no objective clinical test for diagnosing concussions, a mild type of traumatic brain injury, with certainty. In fact, many concussions don't produce noticeable symptoms and can easily go undetected, potentially putting people at increased risk for brain damage in the future.

UW-Madison researchers aim to drive scientific advances they hope will better help detect, treat and, perhaps most importantly, prevent, traumatic brain injuries.

Their effort, a U.S. Office of Naval Research-sponsored interdisciplinary hub, dubbed PANTHER, brings together researchers across academia, industry and the federal government to address this pressing societal issue.

Associate Professor Christian Franck, who directs PANTHER, says an interdisciplinary approach is crucial for making progress in this area, given the highly complex nature of the brain—healthy or injured.

"There are thousands of published journal articles related to traumatic brain injuries, but researchers are mostly doing studies in isolation," says Franck. "There's not enough interdisciplinary communication, and that has really hindered our progress in this field."

Franck wants PANTHER to serve as a one-stop shop that brings together a diverse group of people who frequently exchange information and ideas across disciplines. These ongoing conversations could influence research directions and accelerate novel solutions for addressing traumatic brain injuries. He is seeking to add more partners and collaborators from across UW-Madison and beyond.

From left to right: Postdoctoral fellow Jing Zhang, and graduate students Harry Cramer, Luke Summey and Angel Chukwu researching cellular traumatic brain injuries in Christian Franck's lab. *Photo: Sam Million-Weaver.*

Franck says PANTHER is unique among such efforts because of its scope, which includes basic and applied science, as well as technology transfer and product development. "This structure will allow us to move basic science breakthroughs forward into the consumer space and to spin off companies relatively quickly, delivering new products and approaches that will help people," he says.

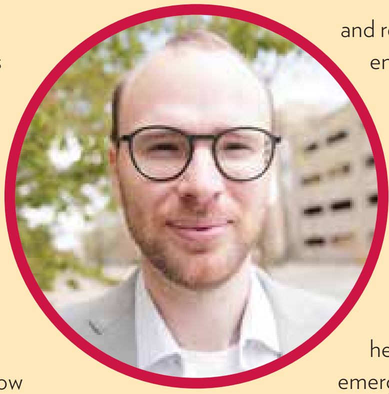
Discoveries that emerge from PANTHER could enable a number of innovative products—for example, helmets that are much more effective at preventing concussions. Today's helmets are designed to prevent skull fractures, but they fall short in protecting the brain from concussions, Franck says. "That's not for lack of trying by the helmet manufacturers," he says. "One challenge for designing a better helmet is that we don't yet know what key parameters brain cells respond to during an impact."

It's a challenge that Franck addresses in his research, which involves studying how physical forces from an impact cause trauma in the brain and lead to cell loss. His approach is iterative and focused on continuous improvement; as he identifies specific parameters that affect brain cells, he and his collaborators will work with industry partner Team Wendy, which specializes in helmets, to design the next generation of helmets and helmet materials that target each parameter.

Beyond innovative products, the program also seeks to raise public awareness of the potential long-term health consequences of traumatic brain injuries. PANTHER researchers plan to make their research findings publicly available and serve as a trusted source of science-based information on traumatic brain injuries.

"This program is meant to provide objective data, not subjective opinions," Franck says. "For example, for parents who may have questions about their children participating in youth sports, we want to share what we currently know and don't know about concussion risks without bias. We want to empower people to make their own decisions."

POWERFUL PATTERNS: DISCOVERY COULD UNLOCK NEW ABILITIES FOR SOFT MATERIALS



Soft materials, with their ability to dramatically change shape, hold promise for applications such as soft robots that are able to sense and respond to their environment.

And now, soft materials— such as rubber or polymers that can regain their initial shape after being stretched or squeezed—could get a performance boost and increased functionality thanks to an advance from engineers at UW-Madison.

Led by Assistant Professor Stephan Rudykh, the researchers discovered a new phenomenon in how soft composite materials rearrange their internal structure at the microscopic scale. They detailed their findings in the journal *Advanced Materials*.

Rudykh says this phenomenon can provide a powerful design tool for engineering soft materials with tailored properties.

"This is an exciting discovery because it gives us the means to control and fine-tune the properties of these soft materials by controlling their microstructures," he says. "It enables us to control the mechanical, thermal and acoustic properties, to name a few, and to switch different properties on and off if we want."

The researchers demonstrated and analyzed the new phenomenon using a soft elastomeric material they created with 3D printing. Inside these soft materials, the researchers embedded small particles of stiff material in a simple periodic pattern.

When they compressed the soft material to a certain point, they found that the internal stiff particles geometrically rearranged themselves in a surprising way—changing from a simple pattern into a more complicated new pattern. Crucially, this complex new pattern is very highly organized and repeating, which allows researchers to leverage it to engineer desirable new properties.

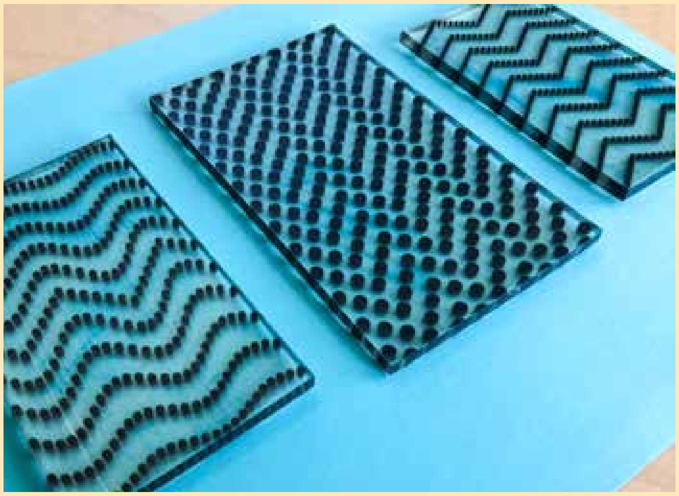
Rudykh and his team triggered the microstructure rearrangement by inducing instability in the material. "It's like if you have a beam supporting a bridge. If you apply enough loading, it will cause instability in the beam's structure and that can lead to buckling," he says. "I'm interested in harnessing this buckling within a material to make it switch configurations."

Through experiments and numerical analysis, he and his team showed they could tailor the emerging patterns by fine-tuning the soft material's initial microstructure—for example, by adjusting the concentration of the stiff particles and their periodicity within the material.

"We can now entirely predict when this microstructure rearrangement will happen and design a particular point where it will switch from one configuration to another," Rudykh says.

As he explores potential applications, Rudykh is excited by the rich opportunities for interdisciplinary collaboration with leading researchers across the college and, in particular, within its Grainger Institute for Engineering.

"We've found something very interesting with this new behavior of pattern formation and there's lots of potential," he says. "By leveraging the college's interdisciplinary strength in the areas of 3D printing, material design and optimization, materials science and polymer physics, I think we're well positioned to find many applications for this advance."



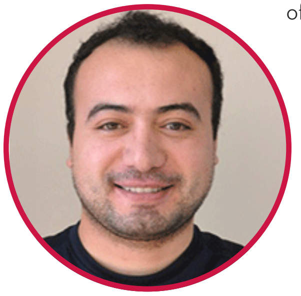
Some examples of new patterns that are formed as the internal structure of a soft composite material is rearranged. The researchers created these samples using 3D printing, embedding small particles of stiff material (the dots) inside a soft elastomeric material to demonstrate the microstructure rearrangement. *Photos: Sarah Page.*

AWARD WINNERS

Grad student research could benefit industry

Three members of Professor Lih-Sheng (Tom) Turng's research group won top awards for their exceptional research papers at the Society of Plastics Engineers annual technical conference in Detroit in March 2019.

PhD student Galip Yilmaz won the best paper award from the SPE injection molding division for his paper, "Injection molding and injection compression molding of ultra-high-molecular weight polyethylene: minimized thermal degradation and delamination layer formation."


Galip Yilmaz

The paper, which was published Dec. 5, 2018, in the journal *Polymer Engineering and Science*, details a way to use injection molding technology to mass-produce ultra-high-molecular-weight polyethylene (UHMWPE), a high-grade specialty polymer.

For more than four decades, industry has used UHMWPE as an advanced material in total joint replacements because of its excellent properties. But due to its difficult-to-process nature, its application in injection molding—one of the common polymer processing technologies—has left much to be desired.


Tom Ellingham

Yilmaz's paper showed that producing quality UHMWPE parts in mass-production processes is possible if proper injection molding methods and production parameters are used. By employing the injection-compression method and optimizing the process, Yilmaz and his collaborators were able to process UHMWPE gently without jeopardizing its molecular structure.

"Being able to injection-mold UHMWPE gives industry a way to take advantage of UHMWPE's superior mechanical properties and surface quality," Yilmaz says.

Tom Ellingham (MSME '14, PhDME '19) won the best paper award from the SPE extrusion division for his paper, "Non-linear rheological response as a tool for assessing dispersion in nanocomposites and blends made with sub-critical gas-assisted processing."

The paper explores a new way to characterize how well two materials are blended by measuring tiny changes in the way the blend responds to deformation. This new method is able to capture differences in blend quality that traditional methods cannot. Applications of this research include quality-control methods for process engineers who work on blending, compounding and nanocomposites.

"Obtaining a good blend with certain materials can be difficult," says Ellingham. "This method can help discern whether or not the process the engineer employs is effective or not. Likewise, the main difficulty with nanocomposites is getting a good dispersion of mixture, and this method can help measure the quality of the dispersion where other methods may not be able to."

After earning his PhD, Ellingham joined 3M as a senior research scientist/engineer.

Visiting PhD student Shujie Yan won the best graduate student paper award from the SPE bioplastics and renewable technologies division for her paper, "A novel small-diameter eggshell membrane/TPU double-layered vascular scaffold with wavy structure."

Yan and her collaborators are working to create small-diameter artificial vascular grafts that mimic the mechanical performance of native blood vessels. These synthetic grafts with inner diameters smaller than 4 millimeters would eliminate the need to harvest vessels from the patient for bypass surgeries.


Shujie Yan

"Vascular tissue engineering is a promising strategy in vascular replacement and can overcome the limitations of autograft implantations such as pain, infection and slow healing at donor sites," Yan says.

To improve the performance of synthetic grafts, the research team developed a way to allow the graft to function as the scaffolding upon which the endothelial cells will adhere and grow outside of a patient's body.

Specifically, Yan developed a unique eggshell membrane, from a raw chicken egg, as an artificial scaffold to allow for the seeding of endothelial cells on thermoplastic urethane (TPU) grafts. Yan used this natural biomaterial in conjunction with an outer TPU membrane layer fabricated by electrospinning to create the double-layered, small-diameter scaffolds.

The researchers worked with the Wisconsin Alumni Research Foundation to patent their technology related to the sub-critical gas-assisted processing method Ellingham detailed in his paper as well as their artificial blood vessel work, with some additional patents pending.

GRAD EDUCATION POWERS ALUM'S CONTRIBUTIONS TO APOLLO 11 MISSION

Fifty years ago, Jyotindra (Joe) V. Mehta (MSME '64) watched the Apollo 11 landing from his small apartment in Clear Lake, Texas, with a personal interest: He had helped engineer the simulator that prepared Neil Armstrong for landing on the moon's surface.

As he and his wife watched the landing on July 20, 1969, on their small black-and-white TV with a rabbit-ear antenna, he was moved by the enormity of the historic achievement.

"That moment when Neil Armstrong landed, we were thrilled beyond words and jumping with joy," he recalls. "I felt an enormous amount of pride—not just for myself, but for the entire team that made that moment happen successfully."

Mehta grew up in India and came to the United States to study engineering at UW-Madison. He says his graduate education played a crucial role in enabling him to contribute to the Apollo 11 mission.

"I am fortunate to have been educated by the superb engineering faculty at UW-Madison, especially my advisor, the late Professor Ronald Daggett, who designed an outstanding academic program for me that laid a strong foundation for my subsequent career path," he says. "It included courses in systems analysis, automatic controls, statistics and operations research, numerical analysis and Fortran programming, which were instrumental in developing the engineering and programming skills I would need in my career."

Mehta started his engineering career at Sperry Flight Systems in Phoenix, Arizona, where he developed software for aircraft and helicopter flight control systems and simulators. His skills were in high demand for the Apollo 11 mission, so he was transferred to the NASA Manned Spacecraft Center (now the Johnson Space Center) in Houston, Texas, to join a team dedicated to simulator complex (SIMCOM) labs.

From 1968 through 1969, he worked as an engineer on the Apollo 11 project, where he programmed computers that controlled simulators the astronauts used for training. Notably, he worked on the simulators that trained the astronauts on how to land the lunar module on the moon's surface.

"This training was key to Armstrong manually controlling the lunar module during the last 1,000 feet when the automatic computer-controlled landing was causing the lunar module to overshoot the landing site," he says.

Read more: **go.wisc.edu/engrnews-081519**

Nellis, Reindl and PhD alumna win ASHRAE Crosby Field Award

Greg Nellis

Doug Reindl

Professors Greg Nellis and Doug Reindl, along with their former graduate student Amy Van Asselt (PhDME '18), have received the prestigious Crosby Field Award from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

ASHRAE presents the award annually to the authors of the highest-rated paper presented at a technical session, a symposium or a poster session, or at a society meeting in a given year.

The researchers were honored for their paper, "Strategies to increase deployment of renewables using cool thermal energy storage." The paper shows how cool thermal storage is a strategic technology that will enable increased penetration of renewable energy production into the utility grid.

At the time the paper was published, Van Asselt was working as a PhD student under the supervision of Nellis and Reindl. She is now an assistant professor of mechanical engineering at Lafayette College.

The researchers received their award at ASHRAE's annual conference in Kansas City, Missouri, in June 2019.

2019 Engineers' Day Award Recipient

Dan Adamany: Distinguished Achievement Award

Founder and CEO, AHEAD LLC (BSME '97)

Since Adamany earned his bachelor's degree in 1997, technology has changed dramatically—and not only has Adamany kept pace with that change, he's leveraged it in AHEAD, the business he founded to help other organizations stay ahead of the information technology curve.

AHEAD has 10 offices and 400 employees and develops holistic information technology solutions that fit the unique requirements and constraints of each of its clients. It is a tier-1 advisor to many Fortune 500 and Fortune 1000 companies.

The college is honoring Adamany as an entrepreneur whose focus on strategy, solutions and technical expertise in enterprise information technology has enabled his company's success.

CRACKING CARTILAGE

New insight on cartilage failure

For athletes from pee-wee to pro, cartilage plays a crucial role in protecting joints during activities such as running and jumping.

All too often, however, we read reports of high-profile players forced to make an early exit from sports such as football or basketball because their cartilage has crumbled.

The tough but flexible tissue that covers the ends of bones at joints in the human body is quite effective at dissipating energy—but if enough force is applied, cartilage will fracture.

"Once there is a structural failure in cartilage, the cells can't rebuild it," says Assistant Professor Corinne Henak. "So we want to understand how those structural failures occur so that ultimately we can prevent them, or reduce the effects of that failure."

Now, thanks to the work of Henak's graduate student Guebum Han (PhDME '19), who was co-advised by Associate Professor Melih Eriten, we have a better understanding of how fractures occur in cartilage.

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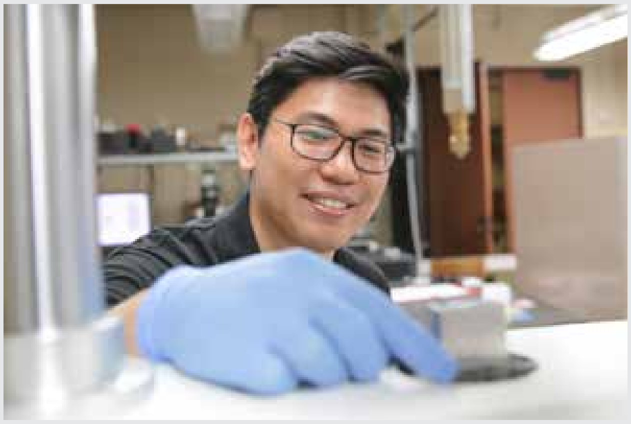


Recent PhD graduate Guebum Han uses a state-of-the-art experimental setup to study how fractures occur in cartilage.

This important information could eventually help clinicians more accurately predict an individual patient's risk of developing incurable osteoarthritis. And it could have implications for training regimes in a variety of high-impact sports by providing insight into which athletes might be predisposed to injuring their cartilage.

"For example, if we had some information about the state of a patient's cartilage, that could give us insight into whether that patient should do swimming rather than basketball to keep active," Henak says.

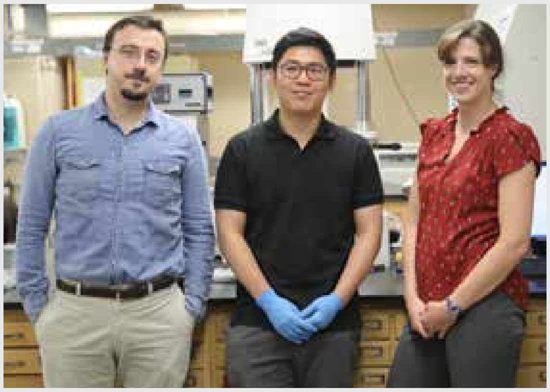
Han's research has provided some much-needed experimental data showing how much loading cartilage can handle before it fails. He studied differences in how cartilage fractures when a load is applied quickly, and when it's applied at a slow rate.

The researchers found that a fast impact significantly reduces the cartilage's strength. In comparison, when they slowly applied the displacement, they found the cartilage could withstand about 10 times the mechanical work before fracturing.

A state-of-the-art experimental setup that Han developed with Henak and Eriten enabled him to make these research advances. He conducted well-controlled experiments using a technique that involved poking cartilage samples with a very small indenter to take measurements.

"A big advantage of this micro-indention technique is that we can perform many more tests on each sample because of the very small size of the indenter tip, and that gives us better, more consistent data. That, in turn, helps us better understand the trends," says Han, who started a postdoctoral position at the University of Minnesota after earning his PhD in August 2019.

Read more: go.wisc.edu/engrnews-081419



Han (center) with co-advisors Melih Eriten and Corinne Henak.

Photos: Sarah Page