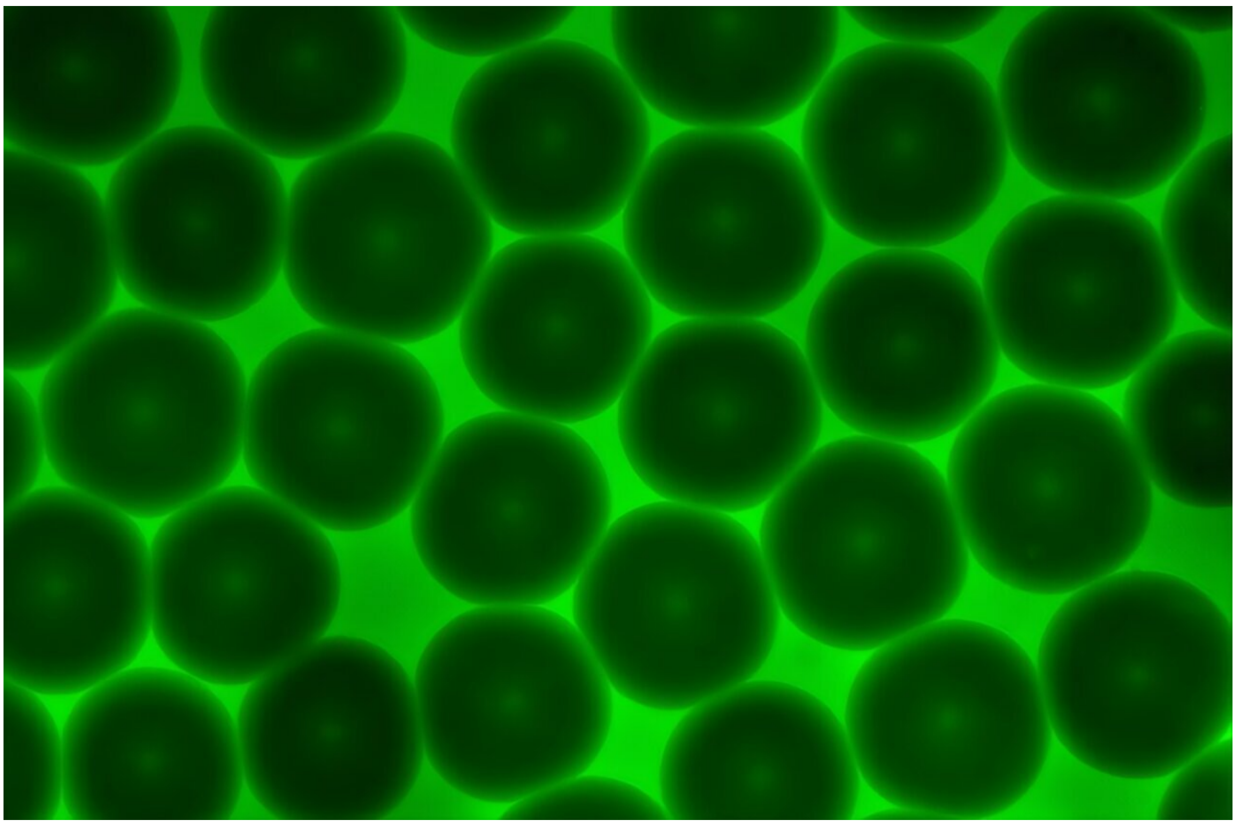
Advanced model unlocks granular hydrogel mechanics for biomedical applications

September 2 2025



Granular hydrogels' unique properties are influenced by individual particle interactions. Shown here is the bottom layer of a packed granular hydrogel, comprising particles of ~200 μm diameter. The interstitial space is illuminated with a large FITC-dextran probe that cannot penetrate the microgels. These soft hydrogel microparticles, or microgels, may deform when packed or when subjected to flow, such as when extruded for 3D printing applications. Credit: Gunnar Thompson

Researchers at the University of Illinois Urbana-Champaign have developed a novel framework for understanding and controlling the flow behavior of granular hydrogels—a class of material made up of densely packed, microscopic gel particles with promising applications in medicine, 3D bioprinting, and tissue repair.

The new study, published in *Advanced Materials*, was led by chemical and biomolecular engineering professors Brendan A. Harley and Simon A. Rogers, whose research groups specialize in biomaterials engineering and rheology, respectively.

Granular hydrogels have a unique ability to mimic the mechanical properties of living tissue, which makes them ideal candidates for encapsulating and delivering cells directly into the body. By integrating material synthesis and characterization with rheological modeling, the researchers created a predictive model that captures the essential physics of how granular hydrogels deform—reducing a complex problem to a few controllable parameters.

"To use granular hydrogels, you need to be able to put them inside of a body," Rogers said. "This typically involves some sort of injection or printing type process, which then means that we have to understand how these materials flow and deform—or their rheology. Previous researchers have taken what I would consider to be a traditional rheological approach and reported measures that we know are incomplete and we know don't accurately represent the physics that's taking place."

Here, the team applied an advanced rheological model previously developed by the Rogers research group, known as the Kamani-Donley-Rogers model, which factors in the concept of "brittility" to describe where a material sits on the spectrum between ductile and brittle failure. By quantifying this property alongside yield stress behavior, the model builds a comprehensive picture of the granular hydrogels' rheology and allows researchers to tailor those properties during the synthesis process to match the needs of specific tissues.

"Knowing how well our model works, we could then calculate how the granular hydrogels are going to behave under any flow condition or deformation type, such as being printed into the body or injected into the body," Rogers said. "Or what would happen once they're in, say, a shoulder joint or a knee joint, or wherever they're going to be injected into it."

For Harley, whose lab specializes in engineering implantable biomaterials as well as biomaterials that can be used as models of tissues outside of the body such as the bone marrow, the implications are far-reaching.

"A healthy bone marrow is essential for lifelong health," Harley explained. "It's where we produce all the blood and immune cells we need daily. As humans age, we have changes in the dynamics of how the bone marrow behaves, and we have changes in the frequency of hematopoietic malignancies, like multiple myeloma. The ability to create and characterize increasingly sophisticated granular models of the bone marrow is offering an entirely new way to understand how this evolution in properties over time affects how these essential cells behave."

Harley and Rogers agree that bringing together their separate areas of expertise was key to producing the new framework and laying the groundwork for real world application.

"We're starting to see a fundamental shift in biomedicine where our communities are increasingly using engineered tissue models, and that means we have to have a better understanding of how to create increasingly sophisticated, increasingly realistic tissue models," Harley said. "The work that we're doing is fundamental to having high quality models of tissue you could use to understand disease progression and aging, and to validate new therapeutics."

"This level of understanding will allow us to design new materials that will make people healthier, faster—and help them stay healthier for the long term," Rogers said.

Predoctoral fellows Gunnar B. Thompson and Jiye Lee are co-first authors on the paper. Rogers is a Westwater Professorial Scholar in chemical and biomolecular engineering (ChBE) in the College of Liberal Arts & Sciences. Harley is the Robert W. Schaefer Professor in ChBE and is affiliated with the Carl R. Woese Institute for Genomic Biology and the departments of Materials Science & Engineering and Bioengineering in The Grainger College of Engineering, and is a Program Leader in the Cancer Center at Illinois.

More information: Gunnar B. Thompson et al, Granular Hydrogels as Brittle Yield Stress Fluids, *Advanced Materials* (2025). DOI: 10.1002/adma.202503635

Provided by University of Illinois at Urbana-Champaign