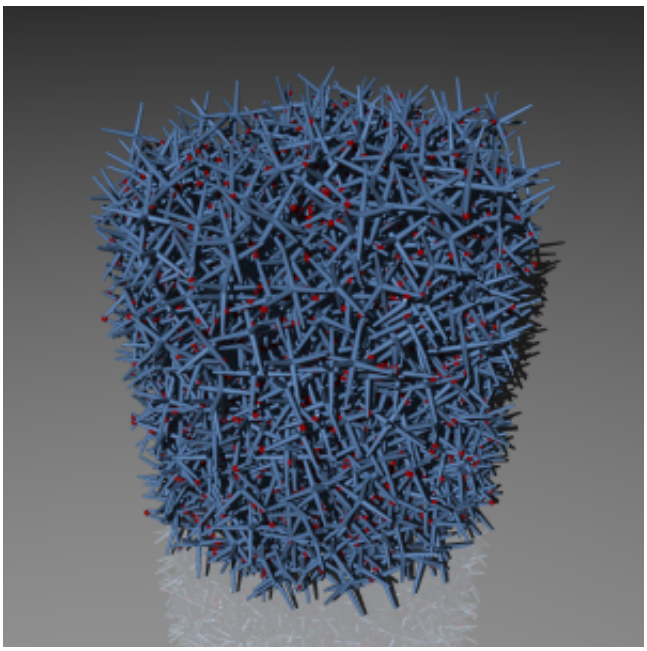
Sandcastles of star-shaped motes are stable structures

May 11 2016



A 3D illustration of a tower of stars reconstructed from CT-scan data. The red dots indicate the points of contact between the stars. Credit: Jonathan Barés.

Duke graduate student Yuchen Zhao has spent the last year studying such "sandcastles of stars"—towers crafted from hundreds of six-armed stars or "hexapods" which bear a remarkable resemblance to the jacks you might have played with as a kid.

To build these towers, Zhao simply pours the stars into a hollow tube, and then removes the tube. But unlike columns of sand, these towers

stand on their own, stay up when shaken, and can even bear up to twice their own weight.

"When you remove the support, you see that the star particles have really jammed together!" said Zhao. "Nobody understands exactly how this rigidity comes about."

Sand is a classic example of a granular material, and like other types of granular materials—rice, flour, marbles, or even bags of jacks—it sometimes pours like a liquid, and other times "jams" up, forming a rigid solid.

The physics of jamming has been well-studied for round and spherical particles, says Duke physics professor Bob Behringer, an expert on granular materials who advises Zhao. But much less is understood about jamming in particles with more complex shapes, like hexapods.

"As soon as you move away from spheres, you can create jammed systems at the drop of a hat," said Behringer. "People think they understand these systems, but there are still a lot of outstanding questions about how they behave: how do they break? Or how do they respond to shear stress?"

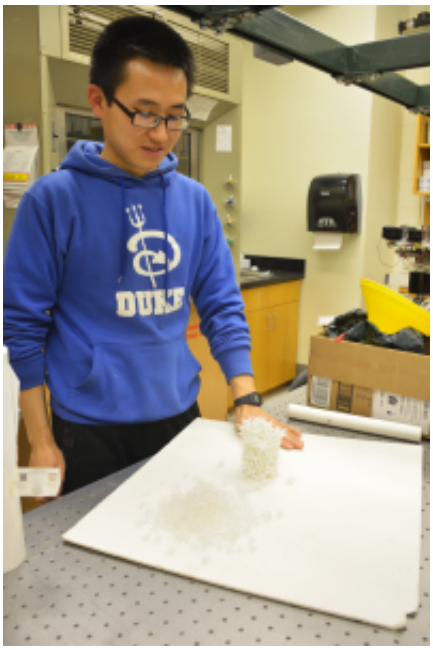
These questions aren't only interesting to physicists, Behringer says. Architects Karola Dierichs and Achim Menges, collaborators on the project, are experimenting with using custom-designed granular materials, from hexapods to hooks, to create structures like walls and bridges.

Similar to a sandcastle or a bird's nest, structures made this way can be porous, light, recyclable and even adaptable.

"One of their big ideas is, can you actually design a structure that could

build itself or be constructed at random, rather than designing something very precise?" said Zhao.

Zhaos says that the first goal of his project was simply to explore the physical limits of towers built from hexapods. To do so, he constructed towers out stars ranging in size from 2 to 10 centimeters and made from two different materials. For each combination, he investigated how high he could build the tower before it collapsed. He then subjected the towers to various stressors, including vibration, tilting, and added weight.



Duke graduate student Yuchen Zhao tests the stability of a tower made from six-armed stars or “hexapods.”

One of the most surprising findings, Zhao said, was that the friction between the particles—whether they were made of smooth acrylic or rougher nylon—had the biggest impact on the stability of the towers. He also noted that when these towers collapse, they don't just fall over in a

heap, they fall apart in a series of mini avalanches.

The team has published this initial study, which they hope will be used as a "handbook of mechanical rules" to improve the design of aggregate structures, in a special edition of the journal Granular Matter.

As a next step in the experiment, Zhao and collaborator Jonathan Barés are using a CT scanner in the Duke SMIF lab to take detailed 3D pictures of the "skeletons" of these structures. With the data, they hope to find a better understanding of how all the individual contacts between stars add up to a stable tower.

"It is amazing to see how these particles can make stable structures capable of supporting big loads," said Jonathan Barés, who is a former Duke postdoc. "Just changing a small property of the particles—their ability to interlock—creates a dramatic change in the behavior of the system."

More information: Yuchen Zhao et al. Packings of 3D stars: stability and structure, *Granular Matter* (2016). DOI: 10.1007/s10035-016-0606-4

Provided by Duke University