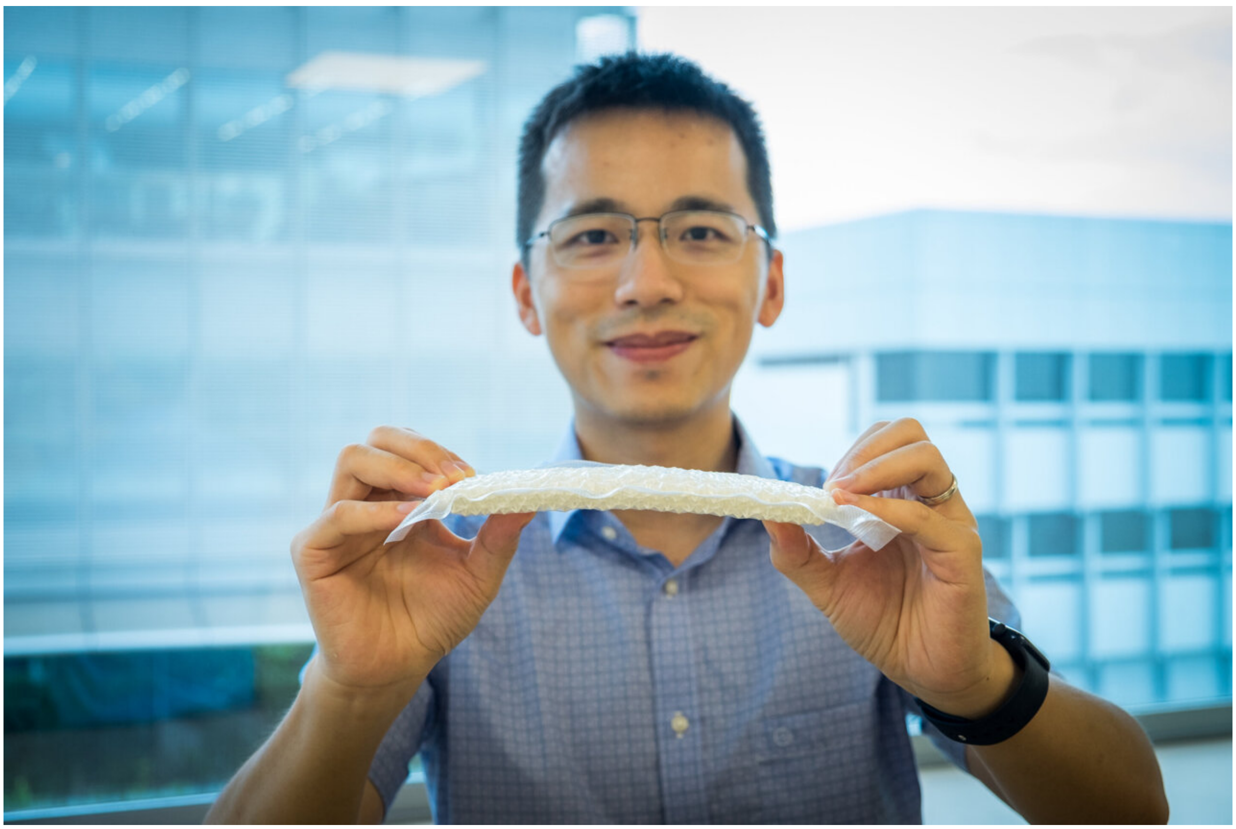
A chain mail fabric that can stiffen on demand

August 11 2021



NTU Asst Prof Wang Yifan bending the nylon chain mail, encased in a plastic envelope and vacuum-packed, which makes it 25 times stiffer than usual. Credit: NTU Singapore

Scientists from Nanyang Technological University, Singapore (NTU

Singapore) and the California Institute of Technology (Caltech), United States, have developed a new type of 'chain mail' fabric that is flexible like cloth but can stiffen on demand.

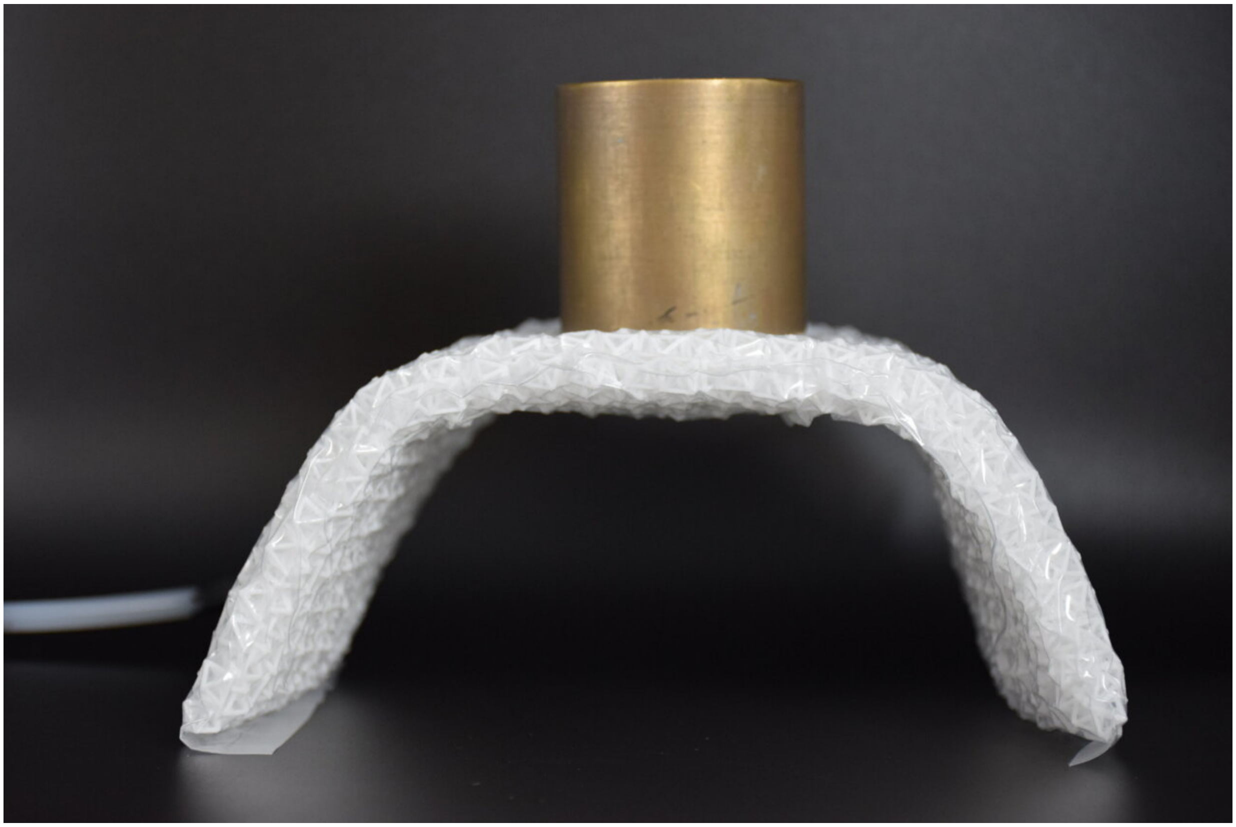
The lightweight fabric is 3-D-printed from nylon plastic polymers and comprises hollow octahedrons (a shape with eight equal triangular faces) that interlock with each other.

When the soft fabric is wrapped within a flexible plastic envelope and vacuum-packed, it turns into a rigid structure that is 25 times stiffer or harder to bend than when relaxed. The physical principle behind it is called "*jamming transition*", similar to the stiffening behavior in vacuum-packed bags of rice or beans.

Known as 'wearable structured fabrics', the development could pave the way for next-generation smart fabrics that can harden to protect a user against an impact or when additional load-bearing capacity is needed.

Potential applications may include bullet-proof or stab-proof vests, configurable medical support for the elderly, and protective exoskeletons for high-impact sports or workplaces like construction sites.

Published today in *Nature*, this interdisciplinary research results from a collaboration between experts in mechanical engineering and advanced manufacturing.



When stiffened, the new chain mail fabric developed by scientists from NTU Singapore and Caltech can withstand up to 50 times its own weight. Credit: NTU Singapore and Caltech

Lead author of the paper, Nanyang Assistant Professor Wang Yifan, said that their research has fundamental significance as well as industrial relevance and that it could lead to a new platform technology with applications in medical and robotic systems that can benefit society.

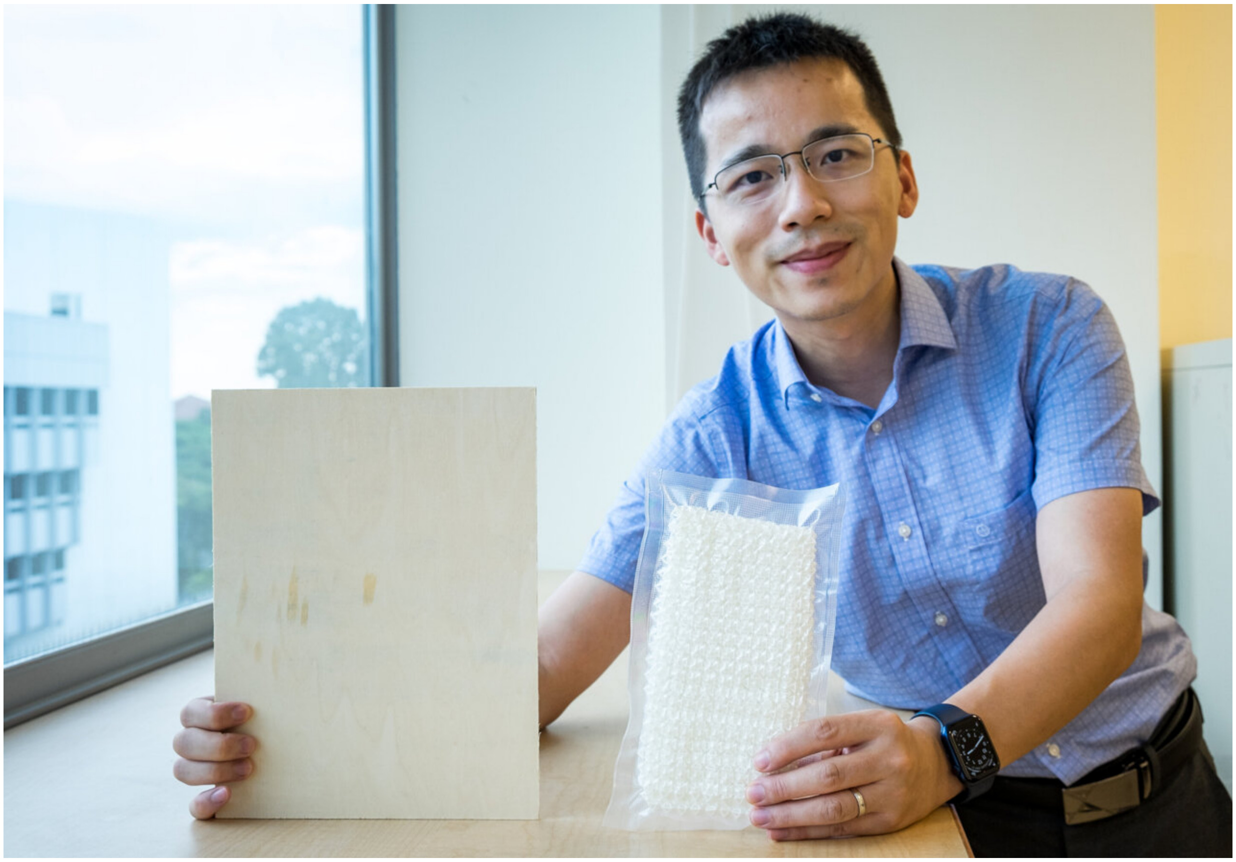
"With an engineered fabric that is lightweight and tuneable—easily changeable from soft to rigid—we can use it to address the needs of patients and the aging population, for instance, to create exoskeletons that can help them stand, carry loads and assist them with their daily tasks," said Asst. Prof Wang from NTU's School of Mechanical and

Aerospace Engineering, who started this research when he was a post-doc researcher at Caltech.

"Inspired by ancient chain mail armor, we used plastic hollow particles that are interlocked to enhance our tuneable fabrics' stiffness. To further increase the material's stiffness and strength, we are now working on fabrics made from various metals including aluminum, which could be used for larger-scale industrial applications requiring higher load capacity, such as bridges or buildings."

Corresponding author of the paper, Professor Chiara Daraio, Caltech's G. Bradford Jones Professor of Mechanical Engineering and Applied Physics, said, "We wanted to make materials that can change stiffness on command. We'd like to create a fabric that goes from soft and foldable to rigid and load-bearing in a controllable way."

An example from popular culture would be Batman's cape in the 2005 movie *Batman Begins*, which is generally flexible but can be made rigid at will when the caped crusader needs it as a glider.



NTU Asst Prof Wang Yifan comparing the stiffened chain mail fabric to a piece of wood. Credit: NTU Singapore

The science behind the interlocking fabric

The scientific concept behind the variable-stiffness fabric is called "jamming transition". This is a transition in which aggregates of solid particles switch from a fluid-like soft state to a solid-like rigid state, with a slight increase in packing density. However, typical solid particles are usually too heavy and do not provide enough tensile resistance for wearable applications.

In their research, the authors designed structured particles—where each particle is made of hollow frames—in the shape of rings, ovals, squares, cubes, pyramids and different shapes of octahedrons that are then interlocked together. These structures, known as topologically interlocked structures, can then be formed into chain mail fabric that has a low density and yet high tensile stiffness, using state-of-the-art 3-D printing technology to print them as a single piece.

They then modeled the number of average contact points per particle and how much each structure will bend in response to the amount of stress applied. The team discovered that by customizing the particle shape, there was a trade-off between how much weight the particles will have versus how much the fabric can bend, and how to balance the two factors.

To add a way of controlling the stiffness of the fabric, the team encapsulated the chain mail fabric in a flexible plastic envelope and compacted the fabrics using a vacuum, which applies pressure from the outside. The vacuum pressure increases the packing density of the fabric, causing each particle to have more contact with its neighbors, resulting, for the octahedron-based fabric, in a structure that is 25 times more rigid. When formed into a flat, table-shaped structure and vacuum-locked in place, the fabric could hold a load of 1.5kgs, more than 50 times the fabrics' own weight.

In another experiment, the team dropped a small steel ball (30 grams, measuring 1.27cm in diameter) onto the chain mail at 3 meters per second. The impact deformed the fabric by up to 26 mm when it was relaxed, but by only 3 mm when it was stiffened, a six times reduction in penetration depth.

To show the possibilities of their fabric concept using different source material, the team 3-D-printed the chain mail using aluminum and demonstrated that it has the same flexibility and 'soft' performance as nylon when relaxed and yet it could also be 'jammed' into structures that are much stiffer compared to nylon due to aluminum's higher stiffness and strength.

These metallic chain mails could be used in applications such as body armor, where they must protect against hard and high-speed impacts from sharp objects. In such a case, the encapsulation or envelope material could be made from aramid fibers, commonly known as Kevlar, used as a fabric in bulletproof vests.

Moving forward, the team is looking to improve the material and fabric performance of their chain mail and to explore more methods of stiffening it, such as through magnetism, electricity or temperature.

More information: Yifan Wang et al, Structured fabrics with tunable mechanical properties, *Nature* (2021). DOI: 10.1038/s41586-021-03698-7

Provided by Nanyang Technological University

Citation: A chain mail fabric that can stiffen on demand (2021, August 11) retrieved 6 May 2024 from https://phys.org/news/2021-08-chain-mail-fabric-stiffen-demand.html