

NEWS RELEASE

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Scientists develop chain mail fabric that can stiffen on demand

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 3D-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 behaviour 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 (12 Aug 2021) in *Nature*, this interdisciplinary research results from a collaboration between experts in mechanical engineering and advanced manufacturing.

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 ageing 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 armour, 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 aluminium, 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.

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 3D printing technology to print them as a single piece.

They then modelled 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 customising 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 neighbours, 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 metres 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 3D-printed the chain mail using aluminium 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 aluminium's higher stiffness and strength.

These metallic chain mails could be used in applications such as body armour, 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 fibres, 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.

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Note to Editors:

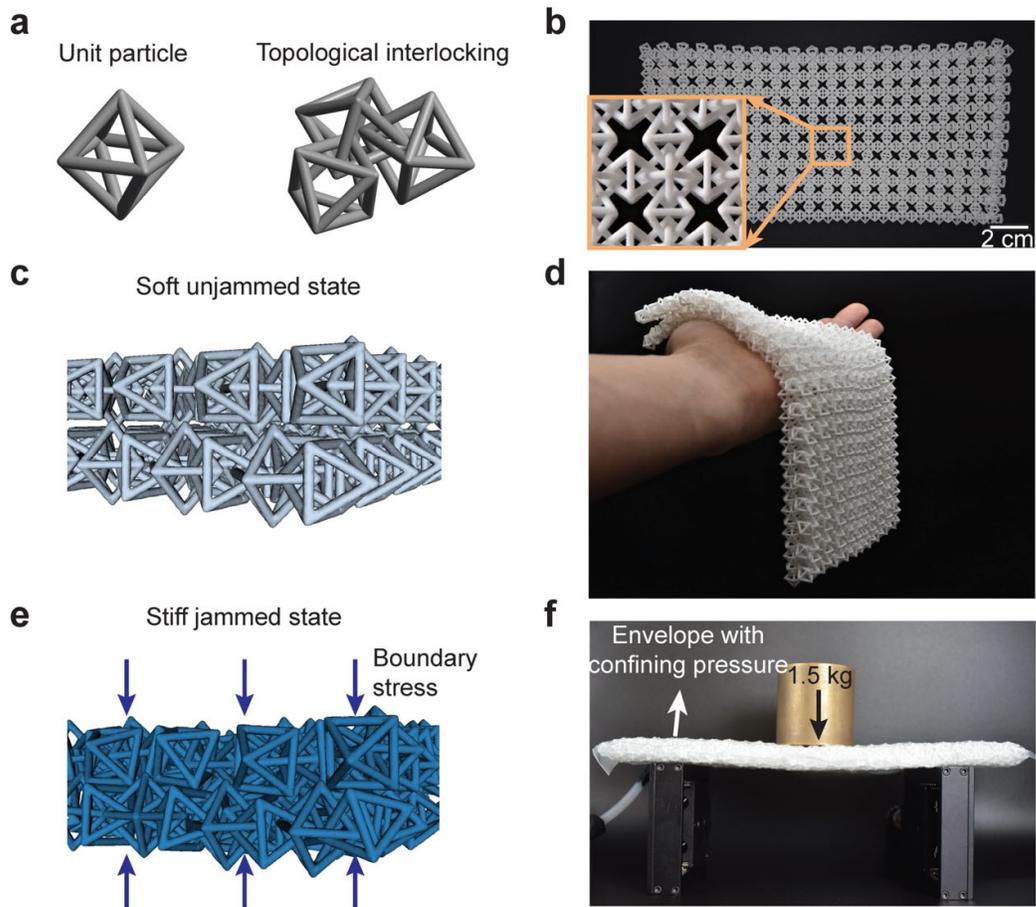


Figure 1

- A – diagram to show how the eight-sided triangles interlock with each other
- B – a 3D printed chain mail
- C – how the chain mail looks like when soft and non-compressed
- D – photo of two layers of chain mail put together when soft
- E – 3D models of how the chain mail is jammed together when compressed in a plastic envelop
- F – the two layers of chain mail enclosed and vacuum-packed in a plastic envelope, bearing a load that is 50 times its weight

Research paper titled [“Structured fabrics with tunable mechanical properties”](#), published in Nature, 11-Aug-2021. DOI: [10.1038/s41586-021-03698-7](https://doi.org/10.1038/s41586-021-03698-7)

Research video for media’s use here: <https://youtu.be/LoCoDawNIns>

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About Nanyang Technological University, Singapore

A research-intensive public university, Nanyang Technological University, Singapore (NTU Singapore) has 33,000 undergraduate and postgraduate students in the Engineering, Business, Science, Humanities, Arts, & Social Sciences, and Graduate colleges. It also has a medical school, the Lee Kong Chian School of Medicine, established jointly with Imperial College London.

NTU is also home to world-renowned autonomous institutes – the National Institute of Education, S Rajaratnam School of International Studies, Earth Observatory of Singapore, and Singapore Centre for Environmental Life Sciences Engineering – and various leading research centres such as the Nanyang Environment & Water Research Institute (NEWRI) and Energy Research Institute @ NTU (ERI@N).

Ranked amongst the world's top universities by QS, NTU has also been named the world's top young university for the last seven years. The University's main campus is frequently listed among the Top 15 most beautiful university campuses in the world and it has 57 Green Mark-certified (equivalent to LEED-certified) building projects, of which 95% are certified Green Mark Platinum. Apart from its main campus, NTU also has a campus in Singapore's healthcare district.

Under the NTU Smart Campus vision, the University harnesses the power of digital technology and tech-enabled solutions to support better learning and living experiences, the discovery of new knowledge, and the sustainability of resources.

For more information, visit www.ntu.edu.sg