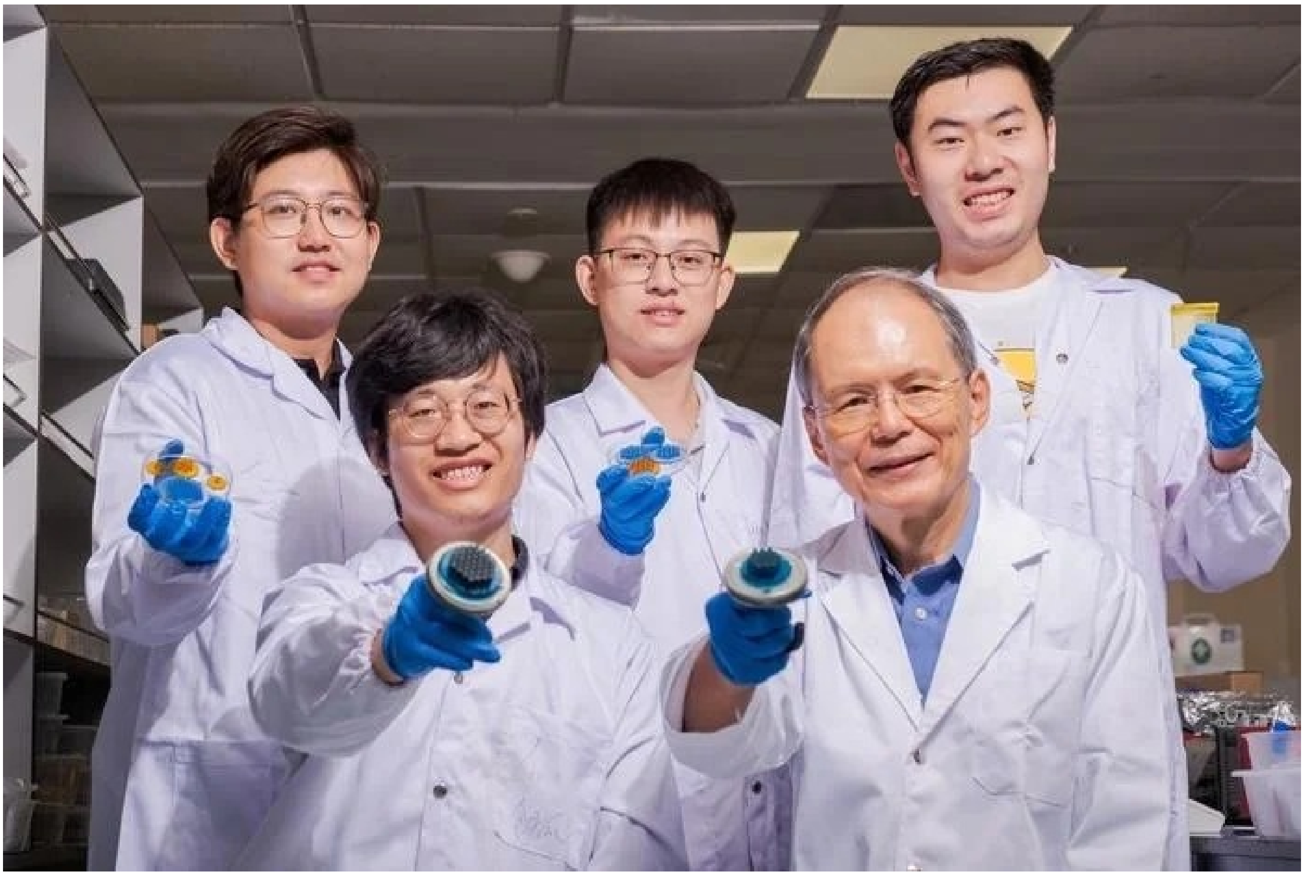
New Smart Adhesive with Unmatched Strength and Versatility

Reviewed by Bethan Davies Apr 30 2024

According to a study published in the *National Science Review*, scientists at Nanyang Technological University in Singapore (NTU Singapore) have developed a smart, reusable adhesive. This new adhesive surpasses the adhesion strength of gecko feet by more than ten times. The breakthrough could lead to the creation of advanced reusable superglues and grippers capable of handling heavy loads on both rough and smooth surfaces.



(from left to right): Project officer Mr. Li Yan, NTU Research Fellow Dr. Linghu Changhong, Research Fellow Dr. Liu Yangchengyi, Professor K Jimmy Hsia, President's Chair in Mechanical Engineering, and PhD student Mr. Huo Yucheng. Image Credit: NTU Singapore

The NTU research team, coordinated by Professor K Jimmy Hsia, discovered a technique to improve the adhesion of smart adhesives by employing shape-memory polymers, which can attach and release easily when heated.

The team describes how they designed the shape-memory polymer material to resemble hair-like fibrils, which led to a breakthrough in adhesion.

This innovative adhesive can support extremely heavy weights, presenting new opportunities for robotic grippers. These grippers could enable humans to effortlessly scale walls or allow climbing robots to adhere to ceilings for surveying or repair tasks.

> *This research is based on a fundamental understanding of the mechanisms of adhesion forces on rough surfaces. It can help us develop very strong, yet easily detachable, adhesives adaptable to rough surfaces. The technology will be very useful in adhesive grippers and climbing robots and might one day let humans climb walls like a real-life Spider-Man.*
>
> *K Jimmy Hsia, Professor, President's Chair in Mechanical Engineering, School of Mechanical & Aerospace Engineering, Nanyang Technological University in Singapore*

It is rubber, It is glue; It Remembers its Shape and Clings on to You

Shape-memory polymers are materials that can "remember" their original form and revert to it after being deformed when stimulated by external factors such as heat, light, or electrical current. These properties make them ideal for creating switchable adhesives that can adjust to different surfaces.

Researchers used a shape-memory polymer called E44 epoxy in their tests. At room temperature, this material is stiff and glass-like. However, when heated, it transforms into a soft, rubber-like state that can mold to and grip microscopic irregularities on surfaces. As it cools, it solidifies, forming strong adhesive bonds through a shape-locking effect.

Upon reheating, the material returns to its rubbery state, allowing for easy detachment from the surface it was adhered to.

The researchers discovered that the optimal adhesion was achieved by shaping the polymer into an array of hair-like fibrils. They determined that larger fibrils offered weaker adhesion, while smaller fibrils were challenging to produce and prone to collapse and degradation. The ideal size for the fibrils was between 0.5 mm and 3 mm in radius, balancing strong adhesion with structural integrity.

In their experiments, a single fibril with a 19.6 mm^2 cross-section could support up to 1.56 kg. Additional fibrils increased the supportable weight significantly. For example, a palm-sized array of 37 fibrils, weighing about 30 grams, could support up to 60 kg—the weight of an average adult.

> *Our smart adhesive exemplifies how shape-memory polymers can maintain and even enhance adhesion as surface roughness increases. This overcomes the ‘adhesion paradox’, which scientists have been puzzling over, where there is a decrease in adhesion strength on rough surfaces despite having more surface area for molecules to adhere to. Our tests showed that adhesion strength of the polymer increases along with surface roughness when in a solid state and decreases when in the rubbery state.*
>
> *Dr. Linghu Changhong, Study First Author and Research Fellow, Nanyang Technological University in Singapore*

Co-corresponding author Professor Gao Huajian, formerly a Distinguished University Professor from NTU’s School of MAE and currently the Xinghua University Professor at Tsinghua University, added, “*For practical gripping purposes, the adhesive needs to be strong enough to stick onto a surface, yet also easily detach when needed. Switching between the two modes is vital for practical applications. Stronger adhesives can support heavier loading but tend to be harder to detach – this is what we call a ‘switchability conflict’. Our research into shape-memory polymers has resulted in an adhesive that can easily harden to stick onto surfaces, and just as easily soften to detach, all the while being able to bear heavy weights including that of a human being.*”

Professor Hsia further added, “*The shape-memory polymer adhesives we designed to overcome both the adhesion paradox and the switchability conflict, providing guidelines for developing stronger and more switchable adhesives adaptable to rough surfaces.*”

Paving the Way for Sticky Climbing Gear

Detaching the shape-memory polymer while it is in its solid glass state can be quickly achieved in less than a minute by heating it to 60 °C using a hair dryer. Conversely, for the material to attach securely, it takes about three minutes to cool down and lock into place.

The transition temperature of the polymer, where it shifts between states, can be finely controlled by altering the ratios of the components used in its formulation. This adaptability enables the use of the polymer in extreme conditions, such as in hot climates. For their experiments, the researchers set the detachment temperature at 60 °C, a level typically above most everyday environmental temperatures.

This heat-responsive characteristic allows the polymer to function as a reusable superglue that leaves no sticky residue. Additionally, it can be used to make soft grippers that adhere to objects with varying surface textures, holding them securely for prolonged periods.

Changhong added, "*At this current stage, the heating and cooling times, as well as switching temperature, restrict the number of real-world use cases. However, our findings show that reducing the wait times to mere seconds is possible, and the switching temperatures can be lowered to near body temperature, dramatically opening up application possibilities. The stimuli to switch the material from one state to another can also be different, such as using electrical current or light instead.*"

Moving forward, the research team aims to reduce the cooling time required for the adhesive to set. They hope that this adhesive could eventually be used in climbing equipment, such as gloves and boots, enabling climbers to stick to and scale walls. Additionally, robots could be outfitted with this material, creating wall-climbing robots that are useful in industries like construction and building surveying.

Journal Reference:

Linghu, C., *et. al.* (2024) Fibrillar adhesives with unprecedented adhesion strength, switchability and scalability. *National Science Review*. doi:10.1093/nsr/nwae106

Source: https://www.ntu.edu.sg/