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What keeps spiders on the ceiling?

A team of researchers from Kiel University and the Helmholtz-Zentrum Geesthacht deciphers the details of adhesive structures of spider legs

Hunting spiders easily climb vertical surfaces or move upside down on the ceiling. A thousand tiny hairs at the ends of their legs make sure they do not fall off. Like the spider's exoskeleton, these bristle-like hairs (so-called setae) mainly consist of proteins and chitin, which is a polysaccharide. To find out more about their fine structure, an interdisciplinary research team from the Biology and Physics departments at Kiel University and the Helmholtz-Zentrum Geesthacht (HZG) examined the molecular structure of these hairs in closer detail. Using highly energetic X-ray light, the researchers discovered that the chitin molecules of the setae are specifically arranged to withstand the stresses of constant attachment and detachment. Their findings could be the basis for highly resilient future materials. They have been published in the current issue of the Journal of the Royal Society Interface.

The tiny contact plates on the spider legs, which are only a few hundred nanometres in size, are subject to great forces when the spider is running or climbing. However, these adhesive structures easily withstand the heavy strain. "In comparison, artificially produced materials tend to break more often," says Professor Stanislav N. Gorb from the Zoological Institute at Kiel University. "That's why we want to find out what makes spider legs so stable in resisting strong pull off forces." Together with the members of his "Functional Morphology and Biomechanics" working group, the zoologist investigates mechanisms of biological adhesion and how they could be transferred in artificial materials and surfaces.

Gorb and his colleague, the zoologist and biomechanist Dr Clemens Schaber, assumed that the secret behind the stability of spider adhesive hairs lies in the molecular structure of their material. Given the hairs' small dimensions in the lower micrometre range, however, it is impossible to investigate their molecular material architecture using conventional methods.

Investigated with the best X-ray light sources worldwide

In order to verify their hypothesis, the scientists from Kiel collaborated with Martin Müller, Professor at the Institute of Experimental and Applied Physics and Head of the Materials Physics division at the HZG. Together with his team and doctoral researcher Silja Flenner, the scientists investigated the adhesive hairs of the spider species Cupiennius salei using methods of spatially resolved X-ray diffraction at the European Synchrotron Radiation Facility (ESRF) in Grenoble, France, and at the Deutsches Elektronen-Synchrotron (PETRA III at DESY) in Hamburg. These storage rings are among the best and most powerful X-ray sources in the world. And this is where the research team hit the spider material with X-ray beams. How exactly this radiation is scattered by the material provides insights of nanometre precision about the composition of the material. "This method revealed that the chitin molecules in the spider adhesive hairs have a very specific arrangement at the very tips of the hairs. The material of the tips strengthens the adhesive hairs in the direction of the pull off force because of the presence of parallel oriented chitin fibres," Müller said, summarising their findings.

“Another remarkable insight is that the chitin fibres in other parts of the spider legs run in different directions. This structure, which is similar to plywood, makes the hair shaft stable in different directions of bending,” explains Schaber, lead author of the study. The parallel alignment of the fibre molecules in the adhesive hairs, on the other hand, follows the traction and pressure forces acting on them. This structure allows the hairs to absorb the stresses that occur when the spider legs adhere and detach.

Bionics: Blueprint for new, highly resilient materials

Similar adhesive hairs can be found, for example, on the legs of geckos. The research team therefore hypothesises that this could be a key biological principle that allows animals to adhere to different surfaces. Their findings could thus have groundbreaking implications for the development of new materials with high resilience. However, to artificially simulate intelligent biomimetic molecular arrangements, such as those in chitin fibres at the nano scale, remains challenging. “Nature uses different methods: biological materials and their structure grow simultaneously, while the steps involved in artificial production are sequential,” said Gorb. New additive production technologies such as nanoscale 3D printing may one day contribute to the development of completely new materials that were inspired by nature.

Photos are available to download:
https://www.uni-kiel.de/de/pressemitteilungen/2019/022-spinne-1.jpg
Caption: In order to find out why the hunting spider Cupiennius salei adheres so well to vertical surfaces, the interdisciplinary research team investigates the tiny adhesive hairs on the spider legs.
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https://www.uni-kiel.de/de/pressemitteilungen/2019/022-spinne-2.jpg
Hunting spider Cupiennius salei
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https://www.uni-kiel.de/de/pressemitteilungen/2019/022-spinne-3.jpg
Zoologists Professor Stanislav Gorb (left) and Dr Clemens Schaber, both from Kiel University, and physicist Professor Martin Müller from the Helmholtz-Zentrum Geesthacht investigated the spider legs using state-of-the-art X-ray methods at DESY in Hamburg and at the ESRF in Grenoble.
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https://www.uni-kiel.de/de/pressemitteilungen/2019/022-spinne-4.png
Caption: Under the microscope, different areas of the adhesive hair become visible.
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https://www.uni-kiel.de/de/pressemitteilungen/2019/022-spinne-5.png
Caption: In the scanning electron microscope, the spider’s tiny adhesive contact plates can be seen at the tip of the adhesive hair. They are merely 20 nanometres thick.
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https://www.uni-kiel.de/de/pressemitteilungen/2019/022-spinne-6.png
Caption: The scattering of the X-ray beams allows conclusions to be drawn about the chitin distribution in the adhesive hairs. The red colour indicates their arrangement up to the tip.
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Details, which are only a millionth of a millimetre in size: this is what the priority research area "Kiel Nano, Surface and Interface Science – KiNSIS" at Kiel University has been working on. In the nano-cosmos, different laws prevail than in the macroscopic world - those of quantum physics. Through intensive, interdisciplinary cooperation between physics, chemistry, engineering and life sciences, the priority research area aims to understand the systems in this dimension and to implement the findings in an application-oriented manner. Molecular machines, innovative sensors, bionic materials, quantum computers, advanced therapies and much more could be the result. More information at www.kinsis.uni-kiel.de

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In order to find out why the hunting spider Cupiennius salei adheres so well to vertical surfaces, the interdisciplinary research team investigates the tiny adhesive hairs on the spider legs.
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