Website address:
https://www.biooekonomie-bw.de/en/articles/news/intelligent-adhesives-inspired-by-nature

Intelligent adhesives inspired by nature

The holes that look like they've been made by a machine gun are actually the marks left behind by the adhesive discs of Boston ivy. Attempts to rip plants like vine from walls without leaving behind ugly holes in the masonry are often rather unsuccessful. Boston ivy, ivy and other woody vines have unusually strong adhesive forces. The question researchers are asking is can they transfer the surface adhesion principle of ivy to technical applications? The Plant Biomechanics Group led by Prof. Dr. Thomas Speck in Freiburg is working on a project that focuses on using nature as a model for intelligent adhesive bonds. The bionics researchers are using methods that provide them with insights into ingenious technological solutions on a microscopic scale. In cooperation with materials researchers, Prof. Speck's group hopes to go one step further than nature.

A single Boston ivy tendril has on average seven to nine so-called adhesive discs. An adhesive disc is around three millimetres in diameter and looks like a small head. Creepers use adhesive discs to attach to the façades of masonry buildings or the bark of trees. If the owner of the building tries to pull a branch off to stop the plant from growing, the branch either breaks off leaving the adhesive pads on the wall, or the plaster comes off the wall bringing the adhesive pads with it. Why is it virtually impossible to remove branch and adhesive pads without causing any damage?

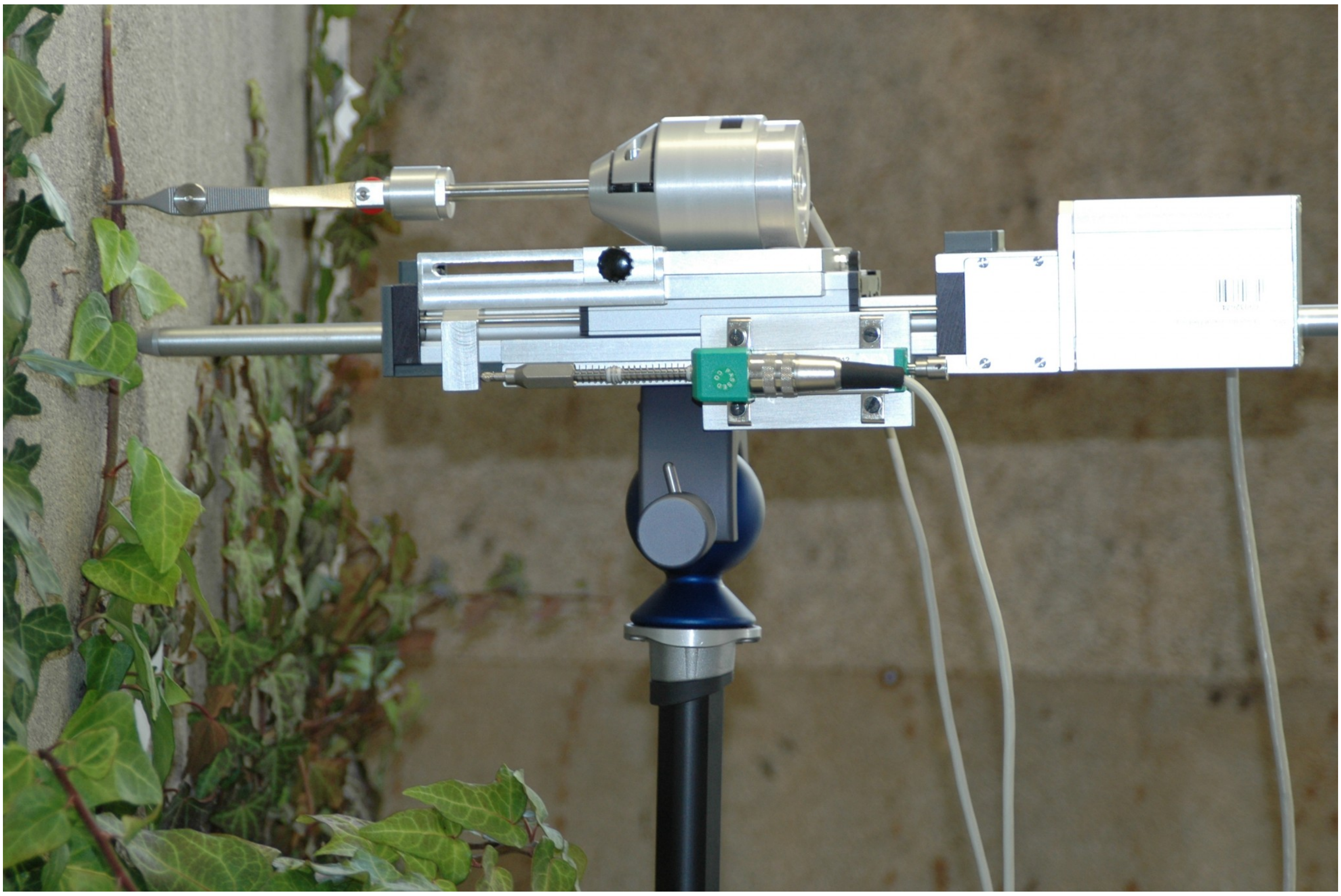
"During evolution, creepers such as Boston ivy or ivy have developed biomechanical strategies that enable them to adhere optimally to surfaces," said Prof. Dr. Thomas Speck, head of the Plant Biomechanics Group and the Botanical Garden of the University of Freiburg, and spokesperson of the Baden-Württemberg Biomimetics competence network. "Different plant species adhere to surfaces in different ways. Our goal is to achieve a detailed understanding of these strategies, both on the micromechanical and molecular level. We want to use the know-how gained to develop technical applications that will take us one step further than nature."

A spiral of increasing insights

Boston ivy tendril with nine adhesive discs

Adhesives are used in virtually all industries, which is why it is not difficult to find applications for new adhesives. Speck cites the automotive sector and the aerospace industry where new adhesives could be used as alternatives to welding and soldering, two processes that are being used less and less. Many different industrial sectors are all looking for intelligent adhesive technologies. Innovative adhesives could also be used in the medical area, for example for closing wounds using a material that not only does away with sutures, but is also eventually absorbed by the tissue.

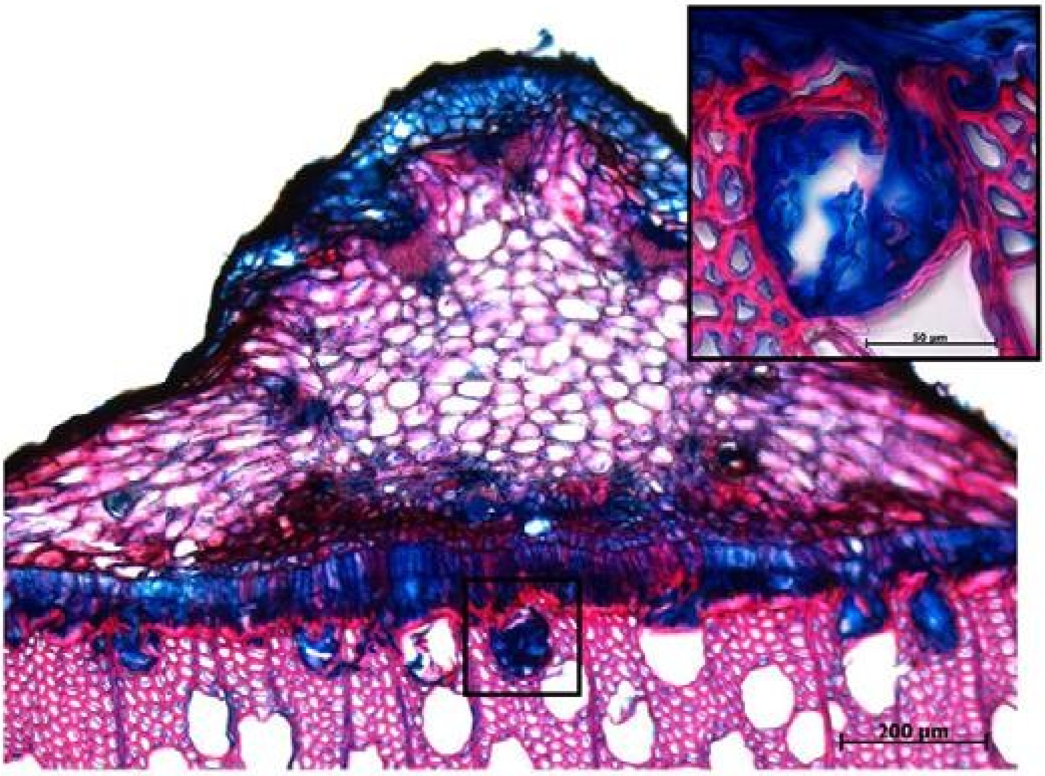
In order for such visions to become reality sometime in the future, Speck and his group of researchers have joined forces with physicists, chemists and materials researchers from the University of Freiburg in a project funded under the Baden-Württemberg government's "Molecular Bionics" funding programme. The biologists are now looking closely at the creepers in order to understand how the plants adhere to surfaces. They have already deciphered how Boston ivy and ivy operate, and are now focussing on exotic plants such as monkey trees, creeping figs and vanilla orchids.



The bionics researchers led by Prof. Dr. Thomas Speck from Freiburg use an apparatus like this to measure the forces and force paths that play a role in the vines' ability to attach to surfaces.

"We are first and foremost biomechanics and functional morphologists," said Speck. "Our job is to come up with an understanding and an abstraction of the strategies used by the biological models that we focus on. Our colleagues from the Department of Macromolecular Chemistry and the Department of Macromolecular Physics in Freiburg and from the Department of Materials Research at the Karlsruhe Institute of Technology (KIT) then take our findings and work on a technical implementation." Speck emphasises that the work process is far from being a one-way street and explains that the most important step is something he calls reverse bionics. Once the cooperation partners have found and characterised materials with properties similar to those of the biological models, the case is then taken up once again by the biologists. The biologists are able to look at the finding from a different angle according to their particular process of cognition and this potentially leads to an even more detailed understanding of the whole. "It is like a spiral of increasing insights," said Speck. "Modern bionic research depends on the close and constant exchange between the different disciplines involved. And I am pleased that the cooperation with our colleagues has led to a common language that works well."

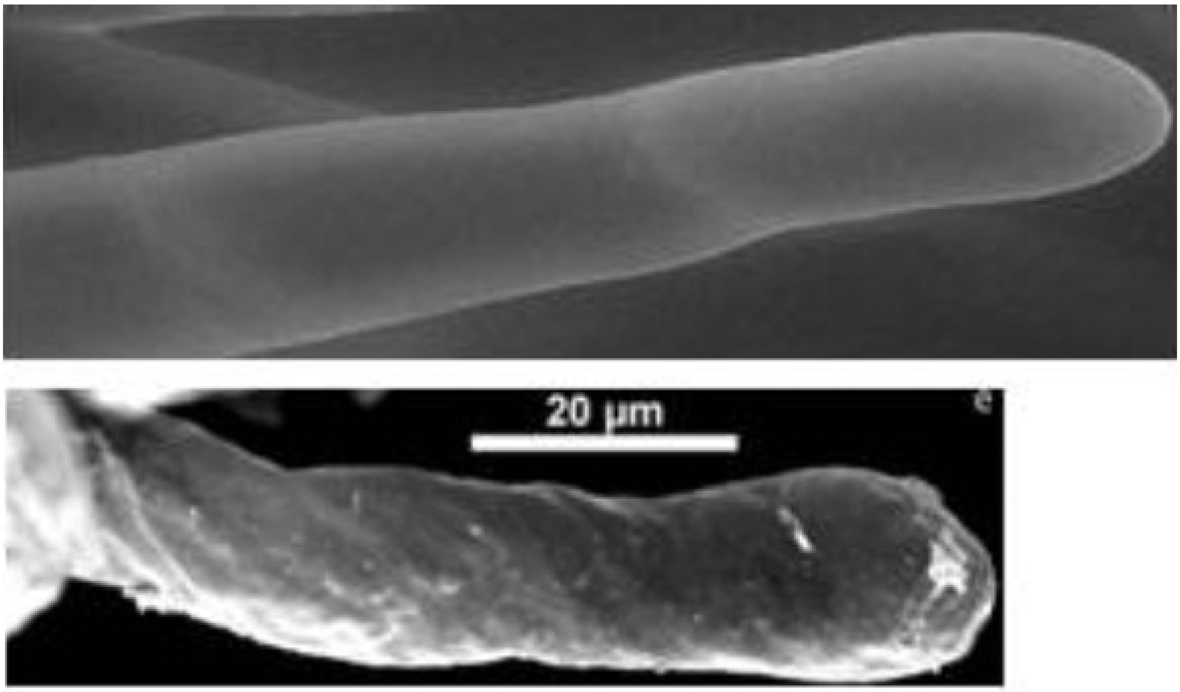
Screws, hooks and strong adhesives



Microscopic image of an adhesive pad of Boston ivy. The glue that enables the plant to adhere to surfaces is dyed blue.

What insights into natural models have Speck and his team obtained so far? Using electron microscopes, high-velocity cameras and own apparatus developments that are capable of measuring forces and force paths on the microscopic level, the biologists have deciphered the principles of how Boston ivy and ivy attach to surfaces. A single Boston ivy adhesive disc attached to a surface can support a weight of around 600 grammes.

The reason why the discs can support so much weight is because the cells on the underside of the disc grow into the indentations of walls or bark. The cells also secrete an adhesive liquid that solidifies when it comes into contact with the surface. "The glues produced by Boston ivy and ivy harden very quickly and become so inert that our cooperation partners from the Department of Organic Chemistry at the University of Tübingen have not yet succeeded in elucidating their chemical structure," said Speck. The adhesive quality may be excellent, but this inability to elucidate the chemical structure is a big obstacle in terms of being able to imitate the plant adhesive. In a next step sometime in the future, the researchers intend to extract the substances directly from the small vesicles in the cells of the adhesive discs and ivy roots and examine them before the materials have hardened.



The root hair of ivy twists and shortens while desiccating in a crack of a house wall or tree bark.
© Plant Biomechanics Group Freiburg

Ivy is an impressive example of the ingenuity of nature. Ivy climbs up walls with its small roots. These roots have root hairs that are 10 – 15 micrometres in diameter and 100 – 200 micrometres long. Each root hair consists of a single cell and has vesicles on its surface that contain a sticky liquid. Regularly arranged cellulose microfibrils sit at an angle of around 40 degrees to the longitudinal axis. The angle at the outer tip of the hairs is approximately 55 degrees.

Speck and his team have gained detailed insights into how the root hairs adhere to surfaces. The root hairs grow into a microscopically small indentation of a wall or bark. The glue-containing vesicles burst when the vesicles come into contact with their environment and the hair affixes to the wall or bark. During this process, the hair dries out, which is why it twists and shortens, a process that is brought about by the specifically arranged cellulose fibrils. As the angles are greater at the tip, the tip of the hair turns into a kind of hook which provides additional hold inside the surface indentation. The shortening of the hair brings the ivy twigs closer to the wall of the house or the tree bark.

Controllable adhesive properties?

Using techniques such as electrospinning which is used to produce very fine material fibres, the cooperation partners from the Departments of Materials Research and Macromolecular Chemistry have already produced materials that behave in a similar fashion to ivy hair roots. “In future, we aim to make the materials better and smarter than natural materials,” said Speck. Will it be possible to produce glue that hardens on command and dissolves again? One approach might be the modification of materials in such a way as to reversibly change their properties upon UV irradiation or temperature changes. Another future vision involves coupling the glue with a colour indicator that provides information as to whether the glue has hardened completely or whether ineffective adhesion has occurred.

Such applications are realistically achievable. Speck and his partners hope to have developed a smart adhesive bond demonstrator by the end of this year and a prototype in the following eighteen months. Some companies have already expressed their interest in the glue, but industrial application depends on whether the glue can be produced cheaply, a smart glue on its own is not enough. “But these are issues we will deal with in the distant future,” said Speck explaining that they will initially carry out basic research on ape trees, fig trees and vanilla. How do these plants adhere to walls and bark? And how can these adhesive principles be improved?

Further information:

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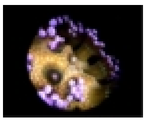

Molecular bionics – inspirations from the microworld for the macroworld