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Biomimetic adhesion devices along the lines of the adhesive organs of stick insects

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Biomimetic adhesion devices

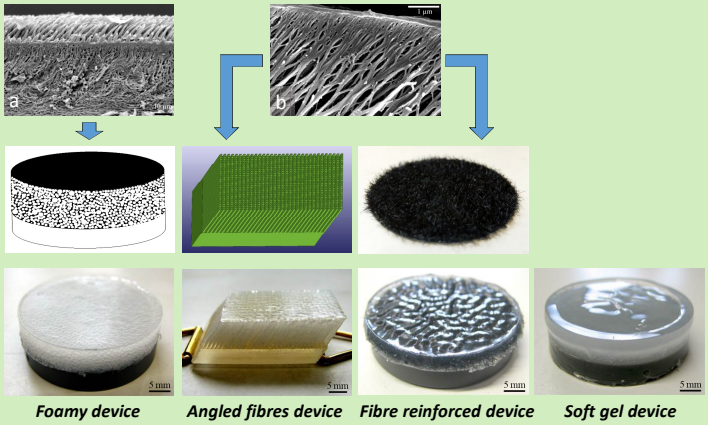


Figure 1: Abstraction of the ultrastructure of hairy and smooth adhesive organs of the stick insect *Carausius morosus* and construction of four different biomimetic adhesion devices on the basis of these abstractions. **a** SEM image of a freeze fracture of a hairy adhesive organ, **b** SEM image of a semi-thin section of a smooth adhesive organ.

Adhesion forces of the adhesion devices

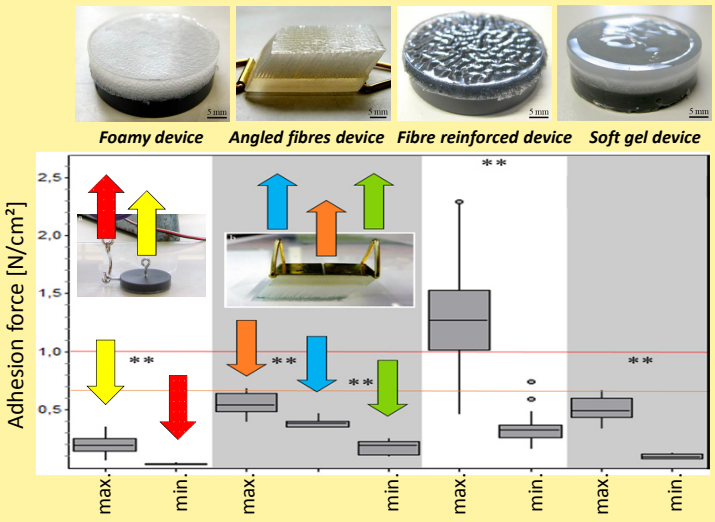
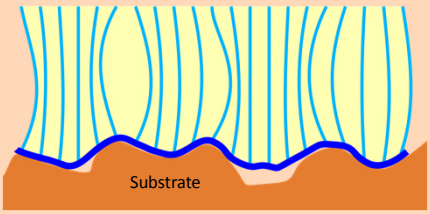


Figure 2: Adhesion forces of the adhesion devices. The arrows in the insets show the points, where the pulling forces were applied. The upper red line shows the adhesion force of *C. morosus* without friction. The lower red line shows the adhesion force of pure SkinTite. ** significance level: 0.01.

New construction plan for fibre reinforced adhesion devices



Thin membrane with high Young´s modulus
Reinforcing fibres: resilient, but high tensile strength
Resilient and elastic matrix

Biomimetic adhesion devices build according to this construction plan should show:

- Adjustment to smallest and larger roughnesses
- Resistance against abrasion and contamination
- Uniform stress distribution over the whole contact area during load without a reduction of the resilience of the matrix
- High adhesion forces

Background

Adhesive organs enable insects to reversibly adhere to substrates even during rapid locomotion. These abilities had aroused high interest by scientists many years ago, trying to create artificial reusable adhesion devices. Here the detailed ultrastructures of the adhesive organs of the stick insect *Carausius morosus* were analysed and, based on the obtained data, artificial adhesion devices were constructed and finally validated.

Materials and Methods

Founded on the morphological results, four construction plans for the fabrication of artificial adhesion devices were developed. All construction plans contain an outer, thin, flexible and adhesive membrane made of the silicone SkinTite, which is supported by different resilient substructures. In the ***Foamy device*** the substructure consists of a silicone foam and in the ***Angled fibres device*** the substructure is formed by an array of parallel fibres, orientated at an angle of 57°. The ***Fibre reinforced device*** includes thin flock fibres, which are orientated about perpendicularly to the adhesive surface of the adhesion device and which are infused with a highly elastic silicone gel. In the ***Soft gel device*** the substructure is solely made out of the same elastic silicone gel, which found a use in the Fibre reinforced device.

Results

Among the four biomimetic adhesion devices the ***Fibre reinforced device*** shows the highest adhesion force of about 1.25 N/cm², which is slightly higher than the adhesion force of stick insects without the contribution of friction.

Discussion

The high adhesion force of the ***Fibre reinforced device*** seems to be based on the reinforcement of this adhesion device with fibres, by which pulling forces are uniformly transferred to the contact area of the adhesion device to the substrate. A non-uniform loading of the contact area easily leads to a local detachment at the area of the highest loading, which could lead to a gradual detachment of the whole adhesion device.

New construction plan

Taking into account all results, a new construction plan for the fabrication of artificial adhesion devices was developed. According to this plan adhesion devices should be covered with a preferably thin membrane with a high Young´s modulus. This membrane should be supported by a substructure made of a resilient and elastic foam or gel. Besides, the substructure should be reinforced by very thin fibres, which equip the adhesion devices with a high tensile strength without reducing the resiliency of the substructure. Biomimetic adhesion devices fabricated according to this construction plan should show high adhesion forces as well as high resistances against abrasion and contamination.

For more detailed information please download my PhD thesis "Biomimicry of the adhesive organs of stick insects (*Carausius morosus*)" here (54.8 MB):

http://publications.rwth-aachen.de/record/565092