Friction Forces in the Hairy Adhesive Pads of Beetles

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1. How do beetles attach to smooth surfaces and how do the hairs function?

2. How do beetles detach from surfaces and are their pads direction-dependent?

Why are beetle pads important models for biomimetic adhesives?

A. Diverse hair designs allow attachment to smooth and rough surfaces, and prevent crack propagation.

B. An impressive self-cleaning ability allows the pads to be continually reused, without becoming contaminated.

C. The angle of the hairs and anisotropic tip shapes allow rapid and effortless detachment during running.

Hairs adhere using the capillary forces of secreted fluids.

1. Single hair measurements

*In vivo* recordings of individual hairs

Experiments performed using a self-built micro bending beam

Measuring the adhesive properties of single hairs

- Using the glass bending beam, the adhesive forces of individual hairs could be measured in a live beetle. Discoidal, male-specific hairs perform better on smooth surfaces:
  - Force on discoidal hair: 919±105 nN
  - Force on spatula hair: 582±56 nN

2. Direction-dependence

Pulling and Pushing Slides of the distal pad

Friction Force  
Contact Area  
Shear Stress

During the push: Force, contact area and stress all decrease

So how does the beetle push whilst climbing?

- Each pad of the leg has evolved a different stiffness, giving the soft distal pad high adhesion and direction-dependence, but allowing the stiff proximal pad stability during pushing.

Conclusions:

- Beetle attachment pads offer many important advantages over conventional synthetic adhesives.
- The hairs confer several functional properties and attach with impressive forces, however the pads are able to adhere dynamically, detaching quickly.

Direction-dependence may be explained by both area loss and a decrease in contact quality, allowing the pads to detach during running. However stiff, stable rear pads also allow pushing when climbing up or down.