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Materials for reversible adhesion: from biological systems to wall-climbing robots

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Surfaces and Interfaces

- sensorics
- attachment
- drag reduction
- optics (anti-reflection)
- grinding
- anti-friction
- sound generation
- respiration
- thermoregulation
- coloration pattern
- self-cleaning
  etc., etc....

Romalea microptera

studies on
ultrastructure,
material
properties,
force range,
motion in
biological
systems
to understand
functional
principles
studies on
ultrastructure,
material
properties,
force range,
motion in
biological
systems
to develop
methods
microscopy
techniques,
measurements of
stiffness, hardness,
adhesion, friction at
local and global
scales
to understand
evolutionary
tendencies
broad comparative
studies
to find interesting
properties of systems
transfer of the natural design
solutions in the material science

BIOMIMETICS PROJECTS

FUNCTIONAL PROJECTS

EVOLUTIONARY PROJECTS

Get a Grip

GECKOS YIELD THEIR STICKY SECRETS

Autumn et al. 2000; 2002; 2006

What Material Do We Want to Develop?

Sticky...

Do we want to use it
for walking on the wall and ceiling?

...and extremely fast
...to unpredictable surfaces
...and fast releasable (millions of cycles)
...non-conglutinating!

Ceiling Situation (Static)

Ceiling Situation

friction

weight

contact formation
- fast
- reliable
- minimal load on the ceiling
strong adhesion
contact breakage
- fast
- minimal force
Insect Terrain

structures for interlocking and friction enhancement on rough substrata
- claws
- stiff pointed hairs

structures for adhesion and friction enhancement on smooth substrata
- pulvilli
- arolia
- euplantulae
- etc, etc.

Blattaria
Orthoptera
Plecoptera
Hymenoptera
Homoptera
Heteroptera
Diptera
Coleoptera
Megaloptera
Raphidioptera

Two Designs of Animal Attachment Pads

Two Designs of Attachment Pads

Smooth Attachment System

Material Design
Hairy Pads of Insects

A. Dobsonfly 
Sialis lutaria
B. Beetle 
Priacma serrata
C. Beetle 
Rhagonycha fulva
D. Fly 
Bibio nigriventris
E. Fly 
Episyrphus balteatus
F. Earwig 
Forficula auricularia
G. Beetle 
Cantharis fusca

Bioinspired Patterned Surfaces

Campolo, Jones, Fearing, 2003
Sitti and Fearing 2002
Northen and Turner, 2005
Geim et al., 2003
Glassmaker et al., 2004
Gorb, Peressadko et al.
Yurdumakan et al., 2005

Example of the Hairy Attachment Pad

motions (arrangement of muscles)
joint design, movements during contact formation and breakage
sensorics
material structure and properties
forces and their directability
contact mechanics
potential substrate profile, surface energy
fluid (chemical composition, viscosity, transporting system)

Secretory Fluid

Reduviid bugs 
Bauchhenss and Tarkanian, 1970
Flies 
Bauchhenss and Renner, 1977; Bauchhenss, 1978; Walker et al., 1985
Beetles 
Ishii, 1987; Eisner and Aneshansley, 2000

A. Pulvillus of the syrphid fly Episyrphus balteatus in contact with the glass surface
B. Tenent setae tips surrounded by secretion
C. Footprints on a glass surface. Note the regular pattern of droplets

Design of Adhesive Setae

is adapted for the release of adhesive substances close to the area of contact

Microemulsion

Gorb, 2001
Carbon-Platinum replicas of the frozen footprints (black arrows indicate direction of coating)
SEM (A, G)
TEM (B, C, E-G)
A-F. Fresh prints
G. Dry prints
dr, drops
ns, nano-drops
AFM-Measurements of Attractive Forces

Fly Calliphora vicina


Range of Attractive Forces


Dimension and Density of Setae

Dependence of the hair density (terminal elements) of the attachment pads on the body mass in hairy pad systems of representatives from diverse animal groups

Arzt, Gorb, Spolenak, 2003, PNAS

Experiment with the Structured Polymer Surface

Peressadko and Gorb, 2004, J. Adhesion

Prototypes

40 g
Contact Shape

A. Bug
Pyrrhocoris apterus, smooth pulvillus

B. Grasshopper
Tettigonia viridissima, surface of the attachment pad

C. Fly
Myathropa florea, unspecialised hairs on the leg

D. Fly
Calliphora vicina, seta of the pulvilli

E. Beetle
Harmonia axyridis, seta of the second tarsal segment

F. Beetle
Chrysolina fastuosa, seta of the second tarsal segment

G. Male beetle
Dytiscus marginatus, suction cups on the ventral side of the foreleg tarsi

Function of Terminal Elements

Gekko gecko

- TE of the beetles
- Chrysolina fastuosa in contact

- Thickness of terminal elements ranges from 200 nm (in beetles) to 10-15 nm (in gecko)

Spatula Contacts (Cryo-SEM)

Fly

Spider
(data of S. Niederegger and P. Walther)

Gecko

Slope

Gekko gecko

- Functions: (1) To decrease the bending stiffness of setae. (2) To enhance adaptability of single contacts. (3) Part of the built-in detachment mechanism

Hierarchy

Insects

- setae with spatulae
- spatulae

Gecko

Detachment Movements in the Fly

- rotation
- twisting
- shifting
- pulling

Function: To enhance adaptability of single contacts at roughness of different levels of magnitude (reflection of real fractal world)
**2D Force Measurements on the Leg of the Freely-Walking Fly**

![Graph showing force measurements over time](image)

**Peeling of Two Sticky Tapes**

![Diagram showing peeling experiment](image)

**Pad Orientation**

![Diagram showing different leg orientations](image)

**Peeling**

![Diagram showing stress concentration in the crack](image)

**Challenge: to put all this together**

- dimension and density
- aspect ratio
- slope
- hierarchy
- shape of the contact
- asymmetry
- proper movements (during attachment and detachment)
- gradient materials
- non-conglutination

**Dry Adhesives**

![Imagery showing adhesives](image)
Dry Adhesives

**BIOSPIRED FEATURES**
- contact subdivision
- hexagonal pattern
- thin plate-like head
- joint-like neck
- high aspect ratio

**FUNCTION**
- increase of the total perimeter of contact
- prevention of the crack propagation
- tolerance to the contamination
- the highest packaging density of structures
- prevention of the crack propagation
- adaptation to uneven surfaces
- decrease of stored elastic energy


Properties of Dry Adhesives

- Tenacity, KPa

- BK, backing
- DP, dust particle
- LP, lip at the margin of the pillar tip
- NR, narrowing of the pillar close to the tip
- PL, pillars
- SH, shaft


Contamination of Dry Adhesives

- % of flak

- Number of cycles


Wall Walking Using Dry Adhesives

Daltorio et al., 2004, IROS Conference


Daltorio et al., 2005, CLAWAR Conference

Wall Walking Using "Dry Adhesives"

Daltorio et al., 2004, IROS Conference


Daltorio et al., 2005, CLAWAR Conference

with Daltorio, Horchler, Ritzmann, Quinn, Case Western Reserve University, Cleveland, OH, USA
Roughness Effects on Hairy Pad Attachment

Gorb and Peressadko, 2004, Bionik

Critical range of roughness

Gastrophysa viridula
Gorb and Peressadko, 2004, Bionik

Plant Surfaces

SMOOTH
not structured wax layers

STRUCTURED
trichomes

dry hairy felt-like

structured wax layers

Pruinose Plant Surfaces

Lactuca serriola (leaf, lower)
Chelidonium majus (leaf, lower)
Robinia pseudoacacia (leaf, upper)
Cheiropogon album (leaf, upper)

Smilax aspera (leaf, lower)
Acer negundo (stems)
Prunus domestica (fruit)

Group

www.flyfoot.de

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