MOTION & TRANSPORT

Reversible Dry Adhesion Without Glue or Suction

How geckos and insects achieve friction-independent adhesion at any orientation

5	3	3–5	5
convergent strategies	principle clusters	TRL range	featured strategies

PROBLEM FRAMING

Reversible adhesion on arbitrary surfaces — wet, dry, rough — is unsolved by chemical adhesives. Biological dry adhesion uses van der Waals forces through hierarchical contact geometry that maximises real contact area while maintaining reversibility through elastic recovery.

Application domains: robotics, materials, medicine

Principle cluster: van der waals forces, adhesion, hierarchical structure

Physics & Mechanism

Underlying physics

[DRAFT] Gecko adhesion operates through van der Waals (Lifshitz-van der Waals) forces — not interlocking or suction. The force scales as $F \propto A/d^3$, where A is real contact area and d is separation distance (typically 0.3–0.5 nm). The challenge is maximising A on non-ideal (rough) surfaces. Gecko setae solve this through hierarchical compliance: the seta (100 µm length, 1–2 µm diameter) allows the spatula at its tip (200 nm wide) to conform to surface asperities at the nanoscale without the proximal end losing contact. Pull-off forces perpendicular to the surface (~0.1 µN per spatula) cumulate across millions of setae. Critically, energy release rate (adhesion) scales with dA/dt — the rate of contact formation, not the equilibrium state. This enables directional adhesion: high friction parallel to the substrate, low adhesion perpendicular. Artificial implementations using PDMS micropillar arrays achieve ~10% of gecko performance — the hierarchy is necessary across at least two scales to replicate both compliance and contact area. [END DRAFT]

Biological Strategies

Attach Temporarily Honeybee · TRL 5/9 · 22 genera

Honeybees attach to smooth surfaces using microscopic hair-like structures known as setae on their feet. Such setae are arranged in spatula-shaped or mushroom-shaped patterns that maximize surface contact area without using adhesive secretions. When the bee presses its foot against a surface, the fine hairs conform to microscopic irregularities in the substrate, generating van der Waals forces acr…

Design principle: Design temporary attachment systems using arrays of microscopic fiber structures rather than wet adhesives or mechanical fasteners. The key is matching fiber geometry—spatula or mushroom tips work bes

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Move in/on Solids Tokay gecko · TRL 3/9 · 41 genera

Tokay geckos achieve reversible adhesion through hierarchical toe structures composed of toes with microscopic lamellae (flat plate-like substructures) that generate van der Waals forces with surfaces. The gecko's toe pad contains these stacked lamellar layers that can conform to surface irregularities and engage or disengage adhesion by modulating contact pressure. When the gecko applies downward…

Design principle: Engineer reversible adhesive devices using a two-layer hierarchical structure: an upper elastic actuator layer that deforms under bi-directional pressure, coupled with lower microstructured lamellae m

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Move in/on Solids Sandcastle worm · TRL 3/9 · 41 genera

Phragmatopoma californica, the sandcastle worm, moves through granular sand by coordinating two complementary strategies. First, the worm uses setae—flexible, hair-like bristles covering its body—that create asymmetric friction against sand grains. These bristles allow the worm to push backward against sand with high resistance while retracting with minimal drag, generating forward progress throug…

Design principle: Design subterranean robots using asymmetric friction surfaces inspired by biological setae to achieve directed locomotion in granular media. Equip the robot with flexible, directionally-oriented brist

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Protect From Excess Liquids Tokay gecko · TRL 3/9 · 136 genera ✦ Evidence File

The lizard's skin displayed a high density of hairs with lengths up to 4 µm which were spherically capped with a radius of curvature typically less than 30 nm. The adhesion of artificial hydrophilic (silica) and hydrophobic (C 18) spherical particles and natural pollen grains were measured by atomic force microscopy and demonstrated extremely low values comparable to those recorded on superhydrop…

Design principle: This surface exhibits underwater superoleophobicity with very low oil adhesion. It is then modified with stimuli-responsive polymer nano-brushes via surface-initiated atom transfer radical polymerizat

> What's actually hard: Balancing the low elastic modulus required for roughness conformity against the high stiffness required to resist lateral collapse. Replicating the functionally graded stiffness of natural setae at an industrial scale to prevent capillary matting rem…

Manage Tension Tokay gecko · TRL 3/9 · 19 genera

The tokay gecko manages adhesive tension through a hierarchical fibrillar structure on its toe pads. These microscopic fibers, called setae, split contact loads across thousands of nanoscale contact points rather than concentrating force on a single large surface. Each fiber terminates in a spatula-shaped tip that optimizes contact area and pressure distribution. This contact splitting mechanism d…

Design principle: Distribute tension through hierarchical contact multiplication rather than concentrated contact areas. Gecko-inspired adhesives should employ multi-scale fibrillar structures with optimized tip geomet

Combination Intelligence

Strategies that address different aspects of the same problem and are not redundant when combined.

Move in/on Solids + Protect From Excess Liquids

Shared principles: adhesion, enzymatic catalysis, hierarchical structure, surface microstructure, van der waals forces

These strategies share 5 underlying principles including adhesion and enzymatic catalysis and hierarchical structure. They may not be alternatives — combining them could address different scale regimes of the same problem simultaneously.

Move in/on Solids + Manage Tension

Shared principles: adhesion, elasticity, hierarchical structure, surface microstructure, van der waals forces

These strategies share 5 underlying principles including adhesion and elasticity and hierarchical structure. They may not be alternatives — combining them could address different scale regimes of the same problem simultaneously.

Attach Temporarily + Move in/on Solids

Shared principles: adhesion, hierarchical structure, surface microstructure, van der waals forces

These strategies share 4 underlying principles including adhesion and hierarchical structure and surface microstructure. They may not be alternatives — combining them could address different scale regimes of the same problem simultaneously.

EXPLORE THE INTERACTIVE VERSION

This report is a static synthesis. The interactive version includes live strategy cards, the Design Brief generator, Combination Intelligence engine, and filtering by TRL, scale, and principle.

`https://atlasofnature.org/challenge/dry-adhesion-reversible`

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