Synthetic Dry Adhesives For Human-Scaled Climbing of Vertical Surfaces

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Focus Area: Research
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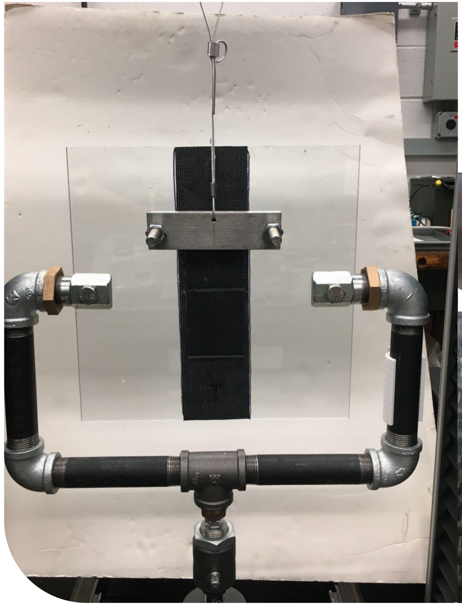
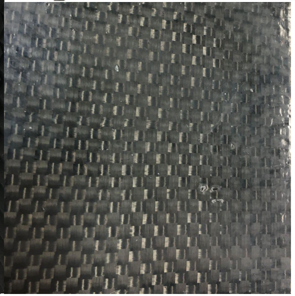
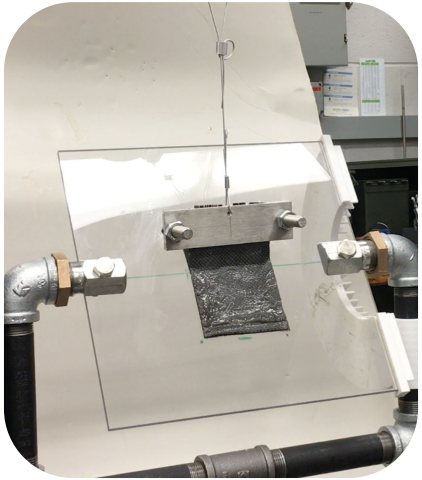
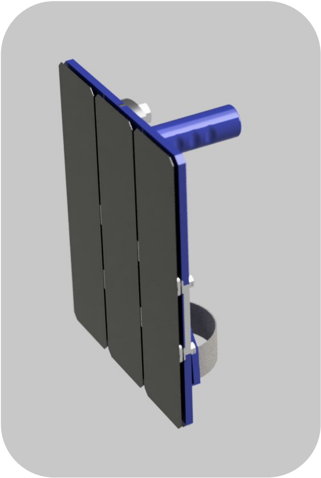




Project Goals

Demonstrate Dry Adhesive Capabilities of Composite Materials → Show Feasibility For Human Climbing Using Dry Adhesives → Demonstrate Human Climbing Using Dry Adhesives





Gecko Biomimicry Overview

Gecko climbing adhesion is achieved through microstructures called *setae* [1]

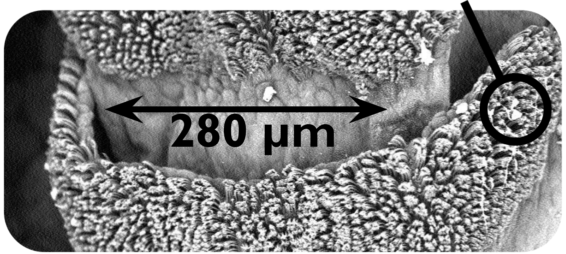


Image Source: NISE

These structures maximize molecular contact, multiplying the usually weak van der Waals interaction into large attractive forces.

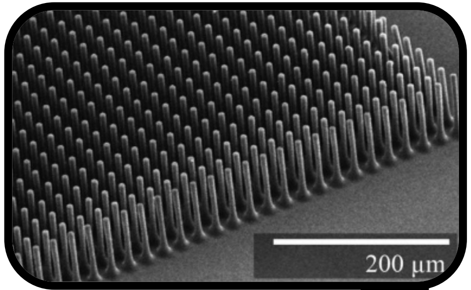


Image Source: [2]

Several methods of mimicry have been pursued, including:

Patterned synthetic setae from carbon nanotubes [1] - ~200 kPa for 16 mm² pad

Micro-molded polyurethane synthetic setae [2] - ~40 kPa for 300 mm² pad

Silicone micro-wedges for directional adhesion [3] - ~80 kPa for 650 mm² pad

An Accessible Approach: No Microstructures

Pioneered by Al Crosby and Duncan J Irschick (UMass Amherst) [4]

Image Source: [4]

Simple composite materials (i.e. fiber-reinforced matrix)

Fibers are stiff, matrix is compliant

Scaling theory [5]:

$$F_C \sim \sqrt{G_C}\sqrt{\frac{A}{C}}$$

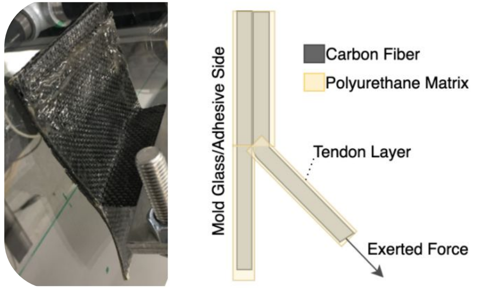
Carbon Fiber and 60A Polyurethane

Center-loaded tendon for other loading angles [4]

~300 kPa for 10,000 mm²

My Fabrication Approach

Borosilicate glass clamping
3D-printed molds

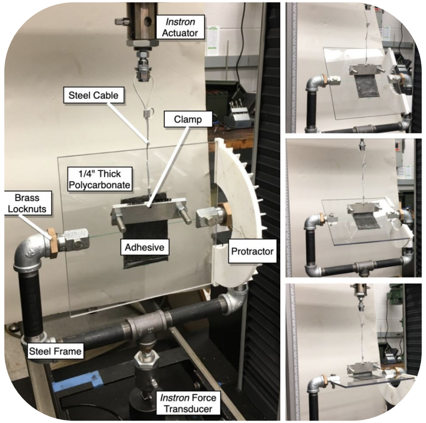


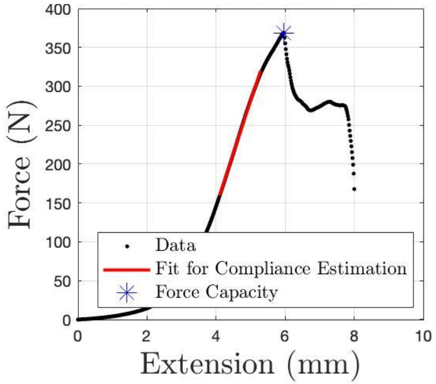
Center-loaded tendon

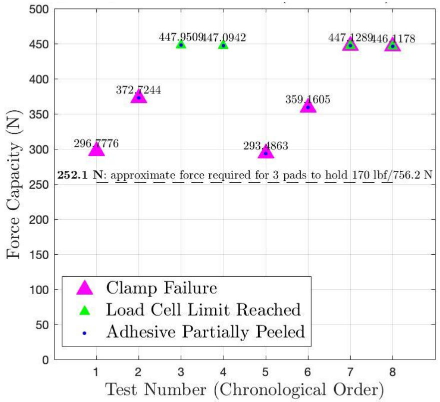
Defects: a learning curve

High quality adhesive is possible but rare

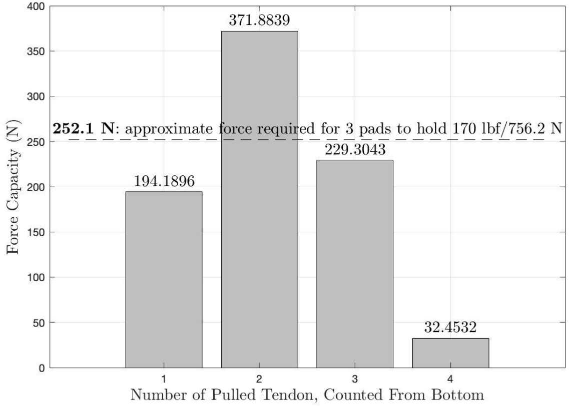
Testing



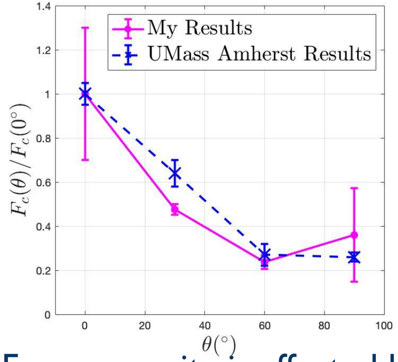




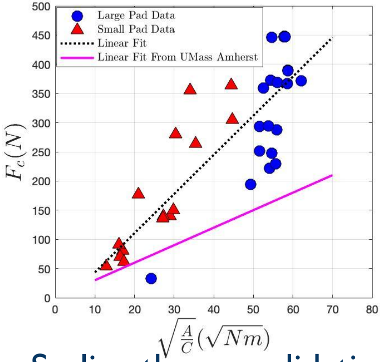
Force capacity/cycles of a high quality 23,200 mm² pad



Adhesives with multiple tendons



Force capacity is affected by angle of applied force



Scaling theory validation

~17 kPa for 23,200 mm²

Extra compliance from polycarbonate

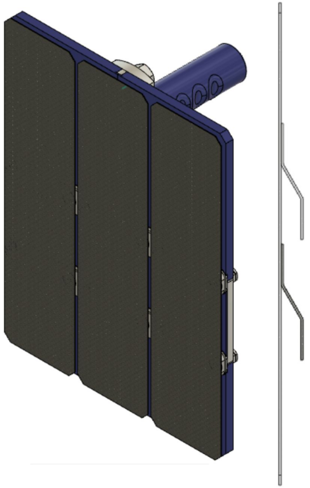
Climbing Paddle Design

Many Assumptions:
-Multiple pads are loaded perfectly in parallel, share the load equally
-Adhesive pad is loaded in the same way as in the testing setup
-All adhesive pads are high quality

Minimum Measured Force Capacity of One High Quality Adhesive Pad = **293 N**

Required Sustained Load of One Adhesive Pad if Three are to Share My Weight = **252 N**

Safety Factor For Design > 1.16

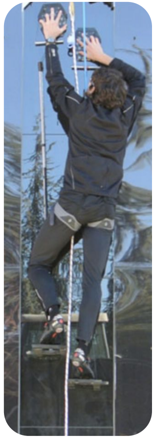


Can hold at least 50 N, or 11 lbf

Tipping loads the top tendon–a weak point–more

Can't hold me

Why Stanford uses footholds:



Solution: common woven tendon that is shared between pads, distributing equal load.

What went wrong?	***And especially:***
Inefficient scaling Low surface quality Multiple tendons add weak point Multiple pads are not sharing equal load	High handle placement leads to tipping condition about bottom contact

References

[1] Ge, L., Sethi, S., Ci, L., Ajayan, P., & Dhinojwala, A. (2007). Carbon Nanotube-Based Synthetic Gecko Tapes. Proceedings of the National Academy of Sciences of the United States of America, 104(26), 10792-10795.

[2] Aksak B, Murphy MP, Sitti M. Adhesion of biologically inspired vertical and angled polymer microfiber arrays. Langmuir : the ACS Journal of Surfaces and Colloids. 2007 Mar;23(6):3322-3332.

[3] Elliot W. Hawkes, Eric V. Eason, David L. Christensen and Mark R. Cutkosky 2015 Human climbing with efficiently scaled gecko-inspired dry adhesives J. R. Soc. Interface.1220140675

[4] Bartlett MD, Croll AB, King DR, Paret BM, Irschick DJ, Crosby AJ. Looking beyond fibrillar features to scale gecko-like adhesion. Adv Mater. 2012;24(8):1078‐1083.

[5] Bartlett, M.D., Croll, A.B., & Crosby, A.J. (2012). Designing Bio‐Inspired Adhesives for Shear Loading: From Simple Structures to Complex Patterns.

Acknowledgements

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