Microfabricated Dry Adhesive Displaying Frictional Adhesion

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We present in this abstract the fabrication and testing of an anisotropic dry adhesive that exhibits frictional adhesion, a behavior observed in the geckos' adhesive.[1] We have taken inspiration from the architectural principles of the gecko's adhesive to create an anisotropic artificial adhesive from PDMS. This adhesive is created by a molding process that utilizes SU-8 as the mold material and PDMS as the cast material. By using an angled two-sided exposure process on a transparent substrate, we are able to create an asymmetrical structure of microwedges (Figure 1). This arrayed microstructure exhibits frictional adhesion. That is, its capacity to adhere to surfaces is described by a model unlike the familiar embedded friction cone models (Figure 4) exhibited by pressure sensitive adhesives such as tape or Post-it® Notes. We have only previously observed this model in the gecko.

The mold is created by a dual sided lithography of SU-8 on a transparent substrate. The process flow is depicted in Figure 5. An aluminum masking layer is deposited and patterned followed by layer of SU-8. The wafer is placed on a tilting stage and is flood illuminated by UV light. A mask is aligned to the front side and another exposure is performed. After develop, the SU-8 has an array triangular pits. We cast and spin PDMS in the mold, yielding a flat backing layer with wedged tips protruding from the surface. We believe this process to be novel and of use to other researchers.

Once fabricated, we test the microwedge adhesive on a force testing apparatus with three axis motors to control friction and loading. An adhesive patch of $\sim$1cm^2 is affixed to a load cell. A flat glass slide is brought into compressive contact and then pulled at a given angle. We collect data for both shear force and normal force adhesion during the period of contact. We perform the familiar load-drag-pull test that mimics the geckos adhesion mode. A more detailed test with multiple exit angles allows for the mapping out of a limit surface curve for the adhesive. The force trace plot (Figure 6) allows us to see the forces exerted by the adhesive as a function of time. As we see in Figure 6, dynamic sliding adhesion is obtained. The adhesive is able to simultaneously maintain 0.4 N/cm^2 of adhesion and 2.0 N/cm^2 of shear. We have not seen another adhesive that displays this dynamic adhesion property that the gecko displays. This property allows the microwedge adhesive a graceful failure mode desirable for robotics or locomotion applications. The force space plot (Figure 7) parameterizes the force trace plot using time and allows us to see the path through force space. The higher density of points in the lower left represents the dynamic sliding adhesion in another way. Lastly, the limit surface (Figure 9), obtained through many trials over a range of preload angles, preload depths, and exit angles, is a map of the release points for different shear to adhesion ratios. If we observe the limit surface (Figure 9), we see that the sample increases its adhesive strength as it is put into shear. If we compare this limit surface to that of a flat control (Figure 10), we see that it is different than the embedded friction cone model. We have also performed repeated testing of the adhesive over as many as 30,000 cycles. When loaded to a constant displacement depth, the microwedges retain 50% of their adhesion and 86% of their shear over the 30,000 trials. This is in contrast to conventional pressure sensitive adhesives which degrade quickly with repeated use.

We believe that this adhesive is an important advancement in applications where shear force, anisotropy, and reusability are key properties.

References

[1] K. Autumn, A. Dittmore, D. Santos, M. Spenko, and et al. Frictional adhesion: a new angle on gecko attachment. *Journal of Experimental Biology*, Jan 2006.

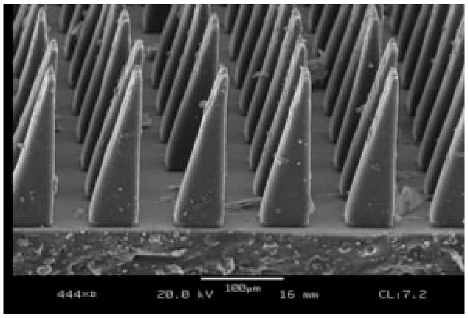


Figure 1: SEM Image of 50 μm Microwedges. Structures are 50 μm square at the base and are 200 μm tall.

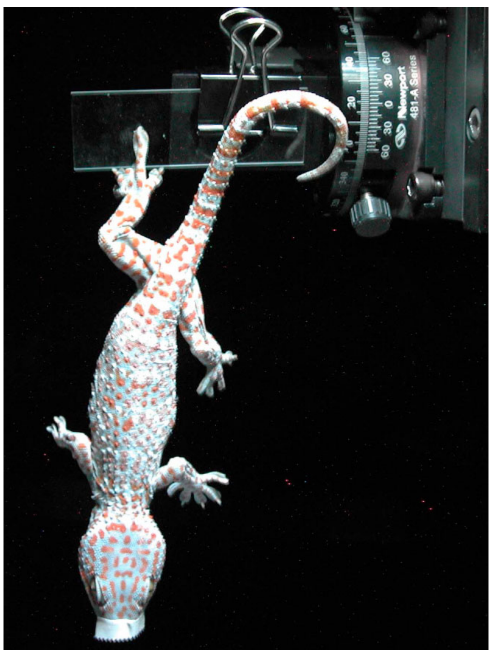
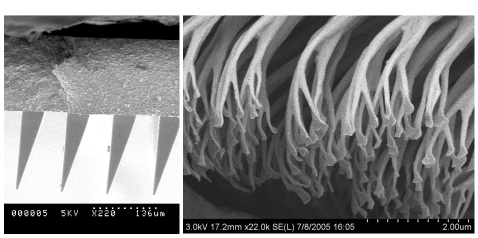


Figure 2: Frictional Adhesion Testing with Tokay Gecko. From previous work demonstrating frictional adhesion in gecko toes.



Microwedge Tokay Gecko Spatulae

Figure 3: Comparison of Microwedge and Tokay Gecko Spatula. Note that both surfaces have a small area of contact until loaded and deformed.

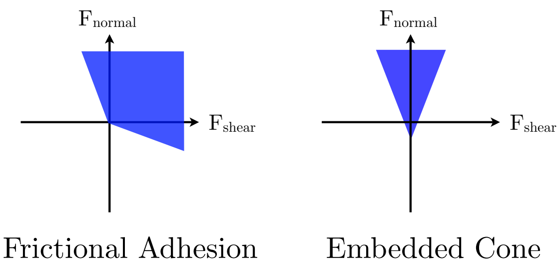


Figure 4: Comparison of Frictional Adhesion and Embedded Cone models. The frictional adhesion model is unique as increasing the shear on the adhesive generates more adhesion. Another unique feature is that the adhesion vanishes when the shear is removed.

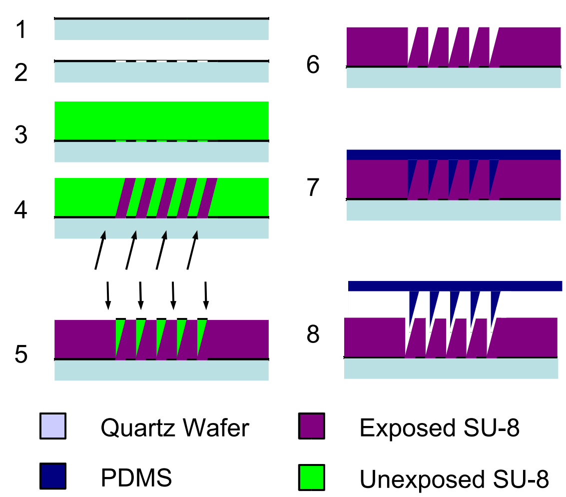


Figure 5: Fabrication Sequence 1) Deposit Aluminum 2) Pattern Aluminum 3) Deposit SU-8 4) Angled Self Aligned Exposure 5) Align Mask and Expose 6) Develop 7) Cast PDMS 8) Peel out cast

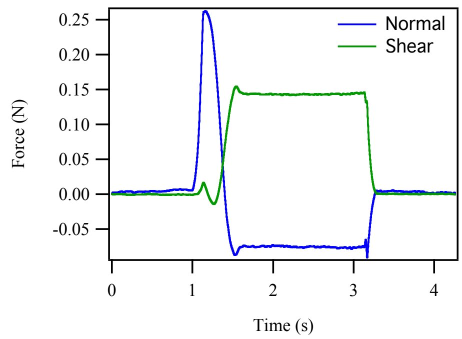


Figure 6: Microwedge Force Trace. The normal trace shows the initial compression phase followed by a region of adhesion during the parallel drag. In the shear trace, we see that there is a shear force created by the adhesive at the same time as the normal adhesion force.

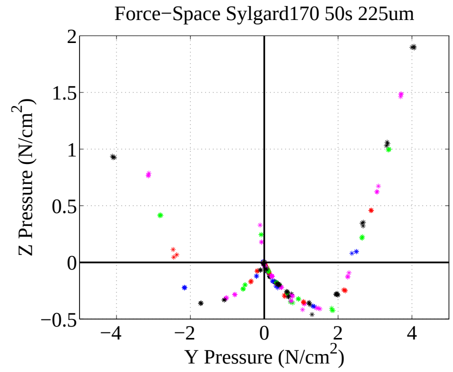


Figure 9: Frictional Adhesion Plot for 50 μm Diameter Microwedges. We see that the adhesion is increased as the shear increases. Also, if the shear is decreased to zero, the adhesion vanishes and the adhesive can be removed with no force.

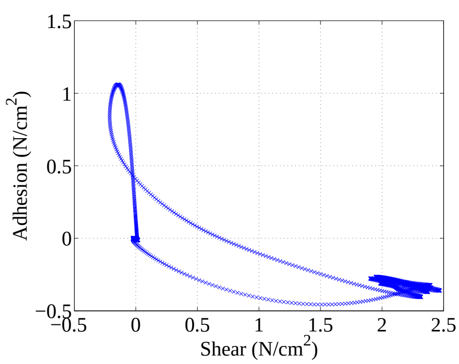


Figure 7: Microwedge Force Space. This plot represents data similar to that shown in Figure 6 but as a parametric plot. The plot begins at the origin and moves up the y-axis during the preload phase. As the sample is dragged the line moves into the fourth quadrant and lingers before returning to the origin.

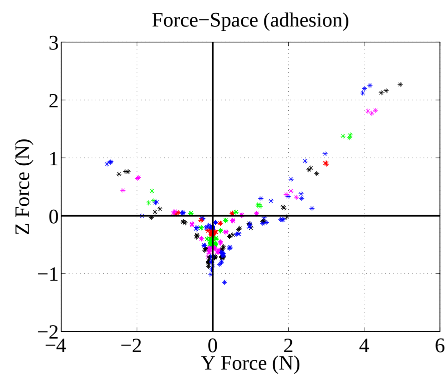


Figure 10: Frictional Adhesion Plot for Sylgard170 Flat Control Sample. The limit surface does not intersect the origin and increasing shear leads to diminished adhesive capability.

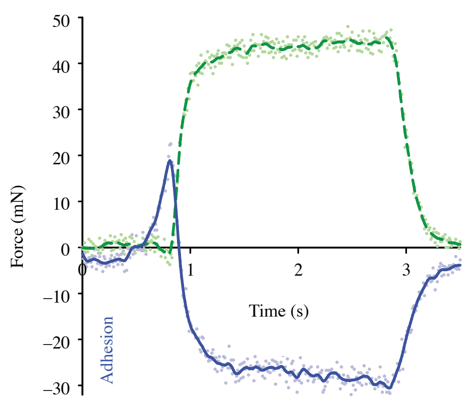


Figure 8: Gecko Force Trace. This trace shows the preload, drag, and generation of adhesion during the load-drag-pull test of a single gecko hair.

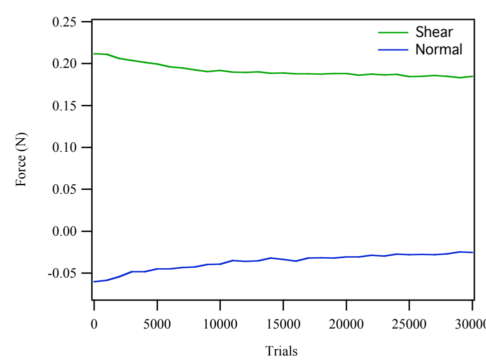


Figure 11: Lifetime Test of Microwedge Adhesive. 30,000 trials performed of 10mm drag. Adhesion fell to 50% of initial and shear fell to 86% of initial during test. This longevity is superior to other pressure sensitive adhesives.