Mimicry of Biological Adhesion Through Fabrication of Fibrillar Surfaces

CNF Project # 1225-04
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Abstract

The remarkably good ability for adhesion in geckos is because of the fibrillar structure found on their feet. This project aims to fabricate artificial mimics of these structures to make dry adhesives. The adhesive properties in these natural interfaces are due to their highly compliant geometry, so that they can make very good contact with all kinds of surfaces and hence weak surface interactions like van der Waals forces can be sufficient for good adhesion. We have made adhesive surfaces using the polymer poly(dimethylsiloxane) (PDMS). Our samples have thin pillars (fibrils) standing on the PDMS base and are topped by a thin roof of PDMS. We made different samples with varying fibril to fibril spacing and pillar/fibril heights. An indentation test was used on the samples to measure their adhesive properties such as work of adhesion, pull-off force and compliance.

Sample Fabrication

Samples with thin pillars/fibrils are made by molding polydimethylsiloxane (PDMS, Sylgard 184, Dow Corning) in silicon molds. Silicon (Si) molds are made using standard photolithography and deep ion etch techniques. The depth of the holes is estimated by the duration of etch, and that decides the height of the pillars in the samples. After the holes of desired depth and with desired pattern are made on the Si wafer, a self-assembled monolayer (SAM) of the molecule n-hexadecyltrichlorosilane is deposited on the wafer to reduce its surface energy. The polymer is poured in the Si mold and sandwiched between a glass slide (having SAM on it) and the mold. It is then cured in an oven at 80°C for 2 hours and then kept in dry ice for around 6 hours. In dry ice, the PDMS shrinks more than silicon, making it easier to remove it from the mold. The final step of affixing a thin terminal plate of PDMS on the pillars is accomplished by spin-coating a SAM-coated Si wafer with PDMS, and then placing the samples on this wafer with pillars in contact with liquid polymer. The assembly is then cured at 80°C for an hour in the oven. Glass coverslips are attached to the back of the samples while they are still on the wafer using O₂ plasma to activate adhesion between the two. Once the samples have the additional backing of a coverslip, they are carefully pulled off the wafer. Figure 1 shows a typical sample.

Indentation Experiments

Indentation experiments were carried out in a custom apparatus built on an inverted optical microscope. Typical experimental force and displacement data from a fibrillar surface and a flat control surface are shown in Figure 2. In either case, in the first cycle the sample was indented to the same depth but retracted to different depths, then cycled to the maximum depth ten times, and finally retracted completely out of contact. Note the markedly different behavior of a fibrillar surface and flat control surface. First, the fibrillar surface is much more compliant than the flat surface. Second, the fibrillar surface requires a greater pull-off force. Third, the fibrillar surface requires a greater amount of work to separate the indenter from the sample. Fourth, the fibrillar sample shows greater hysteresis in an indentation cycle. Contact micrographs are shown in Figure 2 for when the indenter is at a depth of 0 µm (a,e), 15 µm (b,d), and 30 µm (c) for both indentation and retraction. Figure 2 shows that the evolution of contact of the flat control surface is approximately symmetric about maximum indentation. This is not the case for the fibrillar samples. In fact, the contact area on the fibrillar surface remains pinned when the indenter retracts from 30 µm to 15 µm. This fact leads to energy dissipation and enhanced adhesion.
This work has been reported in the following journal publications:


Figure 1: Scanning electron micrograph of a synthetic fibrillar array with a terminal thin film. Fibril height is about 67 µm and spacing is 62 µm. Each fibril is square in cross-section with sides nominally 14 µm wide. The terminal film is about 4 µm thick.

Figure 2: Typical force vs. indenter depth of a fibrillar surface and a flat surface. The micrographs show the contact area corresponding to various points on the graph.