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How does ‘Gecko tape’ work?

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ABSTRACT

Human-made adhesives lose their tack rapidly after first use, while animals such as geckos can reuse their adhesive feet for a lifetime. Nature’s use of fibrillar structures as strong, renewable and self-cleaning adhesives has inspired the development of synthetic adhesives with similarly structured surfaces. More than a decade of research and engineering has culminated in ‘gecko tape’: a re-useable adhesive that has a structured surface similar to that of geckos and that outperforms the usual sticky tape. We report experiments that show that, despite its name, a commercial gecko tape shares few adhesive principles with its eponym. In particular, we find no evidence that the micrometric features that are present on the surface of the gecko tape play a role in its adhesive strength. In addition, we find that contrary to the gecko, the tape leaves behind a layer of adhesive after removal from the surface. The fact that the gecko tape outperforms a conventional adhesive tape is due to the fact that the softness of the backing of the gecko tape allows to create a much larger contact area for a given normal force. The conclusion is that surface features are not necessary to create a superb adhesive; tuning the backing layer elasticity may be enough.

1. Introduction

Animals can climb many surfaces due to the high friction that their feet experience. A large part of the friction is adhesive; the exceptional adhesive abilities found in the animal kingdom [1], have inspired material scientists for years to develop biomimetic adhesives [2,3]. The poster boy for these so-called ‘dry adhesives’ is the gecko, an animal that can climb onto almost any surface due to the sophisticated adhesive fibrillar structures found on its feet [4]. The soft fibrils that contact a countersurface ensure that the gecko can make a large contact area with almost any surface whether rough or smooth. In this way, geckos can stick due to the weakest and most generic of intermolecular interactions, the Van der Waals force [4]. However, the exact mechanisms of gecko adhesion are complex [5,6]: gecko feet have fibrillar features on a hierarchy of length scales, and the attachment and detachment processes depend sensitively on the angle the gecko makes with the substrate [7].

To reduce this complexity, researchers started making artificial structured adhesives from soft rubbers, with a surface covered with pillars [2,8,9]. This has allowed systematic study of structural parameters such as pillar shape [10] and orientation [11], pillar ordering [12] and backing layer stiffness [13]. This last factor has emerged to be a defining factor for adhesive strength, even for smooth, unstructured surfaces [14]. A combination of a stiff backing layer, providing an even

stress distribution, and a soft interface, providing a large contact area, seems to be a universal design motif, whether the adhesive surface is structured or not [15,16]. In fact, the gecko also uses this strategy, as its largest surface structures are most stiff, and the smallest features most compliant [16,17].

The prospect of being able to create an all-purpose reusable adhesive has led to the commercialisation of the gecko adhesion mechanisms into a product marketed as ‘gecko tape’ (Fig. 1A). Among different manufacturers, it is sold as a few millimetres thick double-sided tape, that is reusable and washable. The question arises, however, whether this tape really employs the same adhesive principles as its eponym, the gecko. In this paper, we investigate the physics of commercial ‘gecko tape’ adhesion by using mechanical testing, microscopy and Raman spectroscopy.

2. Experiments

The first question that arises is what the gecko tape surface looks like at micrometric scales. An optical profilometer (Keyence-VX100, 404 nm laser, 5× objective) is used to characterise the surface profile. The gecko tape surface profile shows a dilute ($\sim 10^2 \text{mm}^{-2}$), disordered array of pillars (Fig. 2A). This is intriguing, since research has shown that both disorder [12] and a low coverage of pillars [19] annul the effect of

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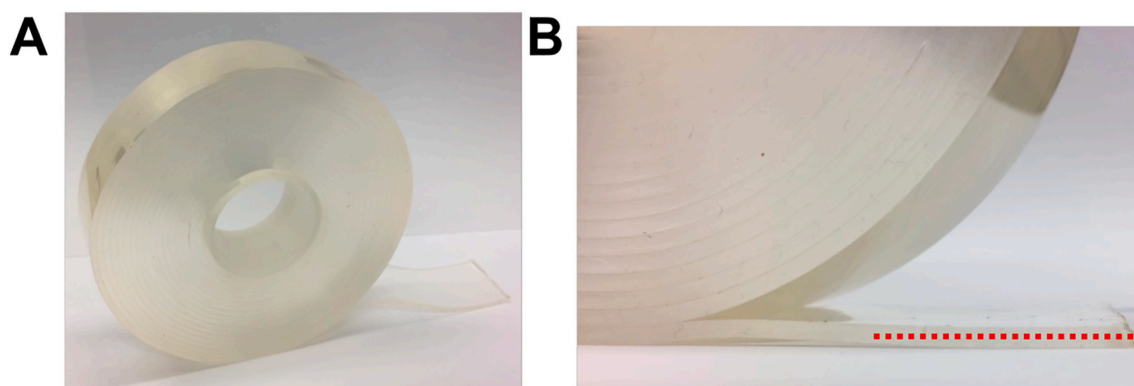


Fig. 1. Pictures of gecko tape. **A** A roll of gecko tape from Stickie [18] ($l = 3$ m, $w = 2.9$ cm, $h = 2$ mm). **B** To remove the fibrillar surface structures, the gecko tape is cut parallel to the adhesive surface.

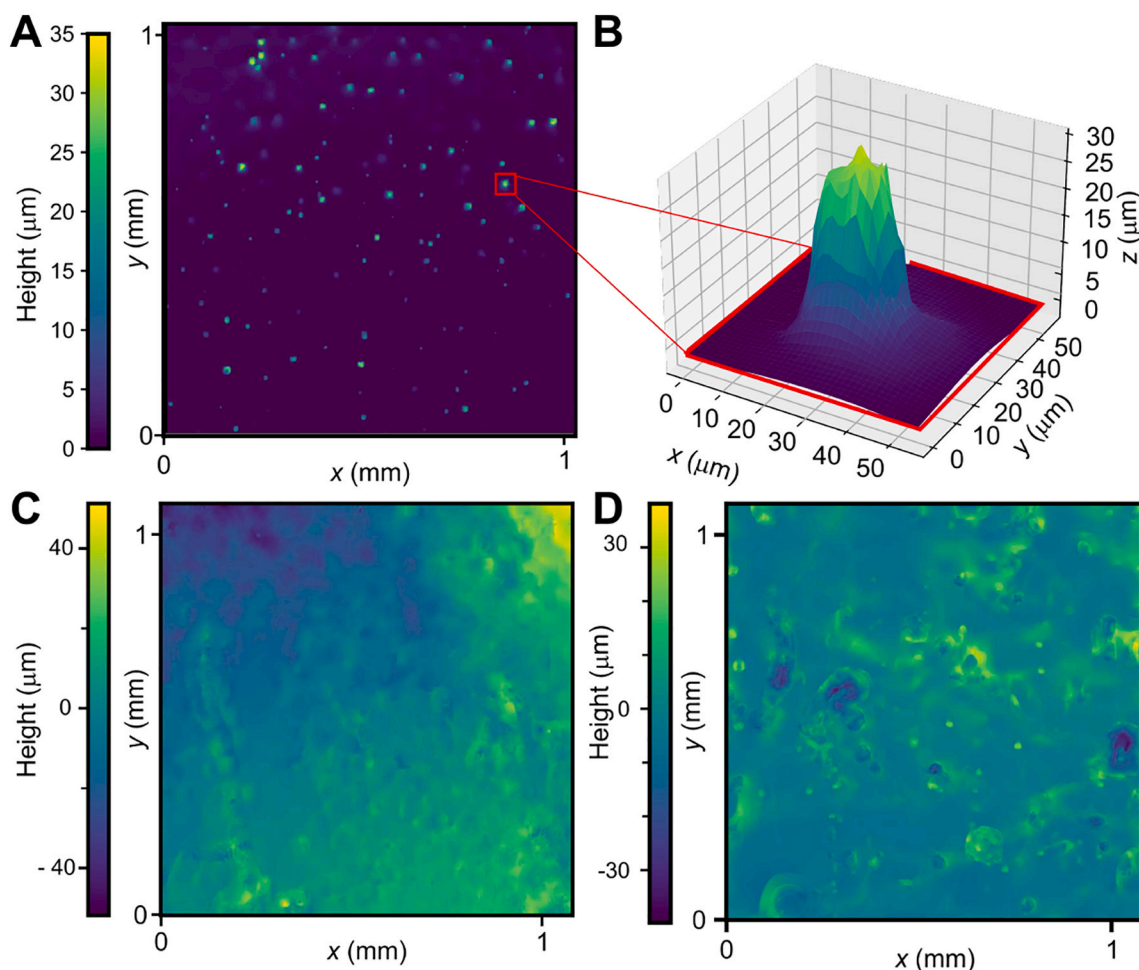


Fig. 2. **A** Optical profilometry image of a millimetric piece of tape shows clearly the distribution of pillars, **B** which are tens of micrometers high and wide. **C** Height profile of cut gecko surface, which is unstructured. **D** Height profile of conventional tape.

surface structure, leading to an adhesion that is the same as a flat surface. The pillars are tens of micrometers high and wide (Fig. 2B).

To simultaneously measure adhesion forces and image the contact area, we use a home-built mechanical set up on top of an inverted microscope (Zeiss Axiovert 200 M, $2.5\times$ objective), shown in Fig. 3. Millimetric circles of tape are glued to a screw connected a force sensor (Zemic, 5KG) that is mounted on a vertical translation stage. The countersurface is a glass microscopy slide (VWR, $h = 1$ mm) thoroughly cleaned with Hellmanex and ethanol. This set up allows us to accurately

measure the normal force F as a function of the vertical displacement d .

To disentangle the effects of surface structure and bulk material properties, adhesion tests are performed with three surfaces: the original gecko tape surface featuring the pillars, the surface of a piece of gecko tape from which the pillars have been removed (Fig. 1B), and conventional adhesive tape (Tesa Double-Sided Tape Universal, $w = 5.0$ cm, $h = 90\mu\text{m}$). To remove the pillars, $\sim 25\%$ of the original thickness of the gecko tape is cut away with a scalpel. The profile of the cut gecko tape shows an unstructured surface (Fig. 2C), similar to the profile of the

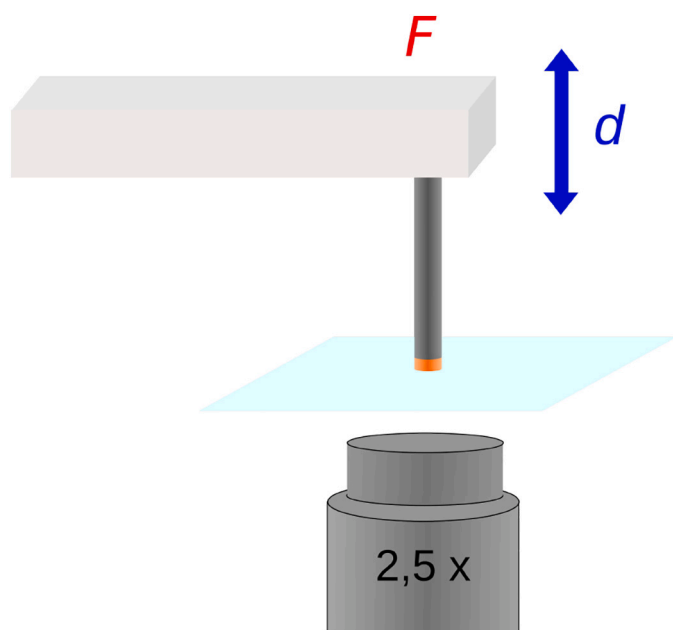


Fig. 3. The tape (orange) is connected to a force sensor which measures the force F under an imposed vertical displacement d . The tape-glass interface is imaged using a microscope.

conventional tape (Fig. 2D). Adhesion experiments are performed by separating a pre-loaded tape-glass contact ($v_{\text{load}} = 20 \mu\text{m} \cdot \text{s}^{-1}$) with a constant retraction velocity $v_{\text{retract}} = 10 \mu\text{m} \cdot \text{s}^{-1}$.

Fig. 4A shows typical force-distance curve for each of the three studied tapes. We define $d = 0$ as the point where the probe and the countersurface start to touch. We quantify the stiffness k by linearly fitting $F = kd$ to the compressive part of the force-distance curve (Fig. S2). We find $k_{\text{gecko}} = 9.26 \pm 0.05 \cdot 10^2 \text{N} \cdot \text{m}^{-1}$ and $k_{\text{conventional}} = 1.48 \pm 0.03 \cdot 10^4 \text{N} \cdot \text{m}^{-1}$. The cut gecko tape does not have a unique stiffness (the force-distance relation is non-linear, Fig. S2), but its stiffness is of the same order of magnitude as that of the original gecko tape.

When the maximum compressive force is reached, we image the tape-glass interface (Fig. 4B). Qualitatively, we can see that the gecko tape forms a continuous contact with the glass countersurface. This means that it does not touch the glass at discrete points with its pillars. It appears that because of the softness of the tape material, the pillars are strongly deformed upon contacting the countersurface, and continuous contact develops. Images made at higher resolution (Fig. S3) confirm these observations.

Quantitatively, the gecko tape generates a significantly larger contact area at a certain compressive force than the conventional tape (Fig. 4C, details about contact area measurement are in Supplementary Information). This difference can be attributed to the order-of-magnitude lower stiffness of the gecko tape compared to the conventional tape, which allows the gecko tape to deform much more upon contacting the glass slide.

The adhesion mechanics of gecko tape and the conventional tape are

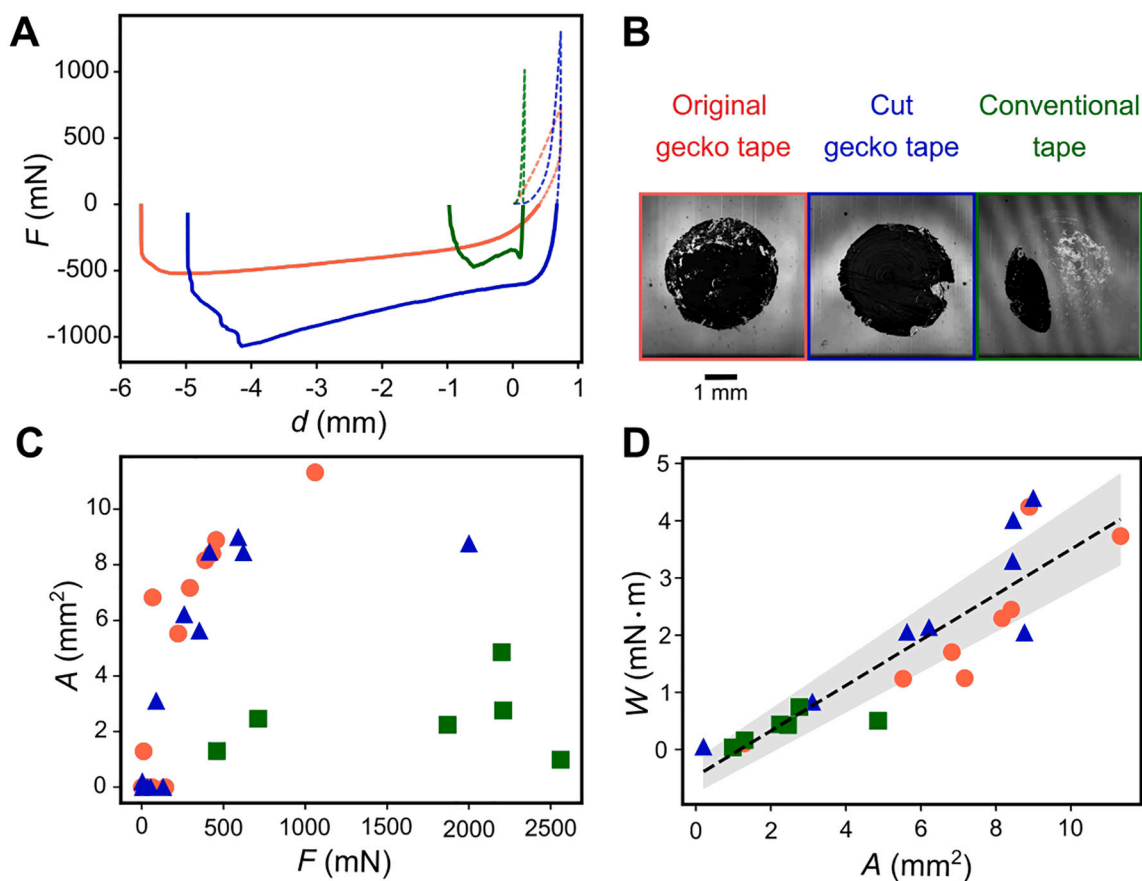


Fig. 4. A Typical force-distance curves. Positive d indicates compression of the surfaces, positive F a compressive force. Vice versa, negative d indicates separation of the surfaces, where F is tensile. B Microscopy images of tape-glass interface immediately before start of retraction. Black areas indicate tape-glass contact. Striped patterns are due to interference with glass and probe. C Contact mechanics: contact area A versus normal force F for original gecko tape ●, cut gecko surface ▲ and conventional tape ■ D Work of adhesion W versus contact area A . The dotted line and the grey shadow indicate the linear fit with the error interval, used to extract the surface energy W/A .

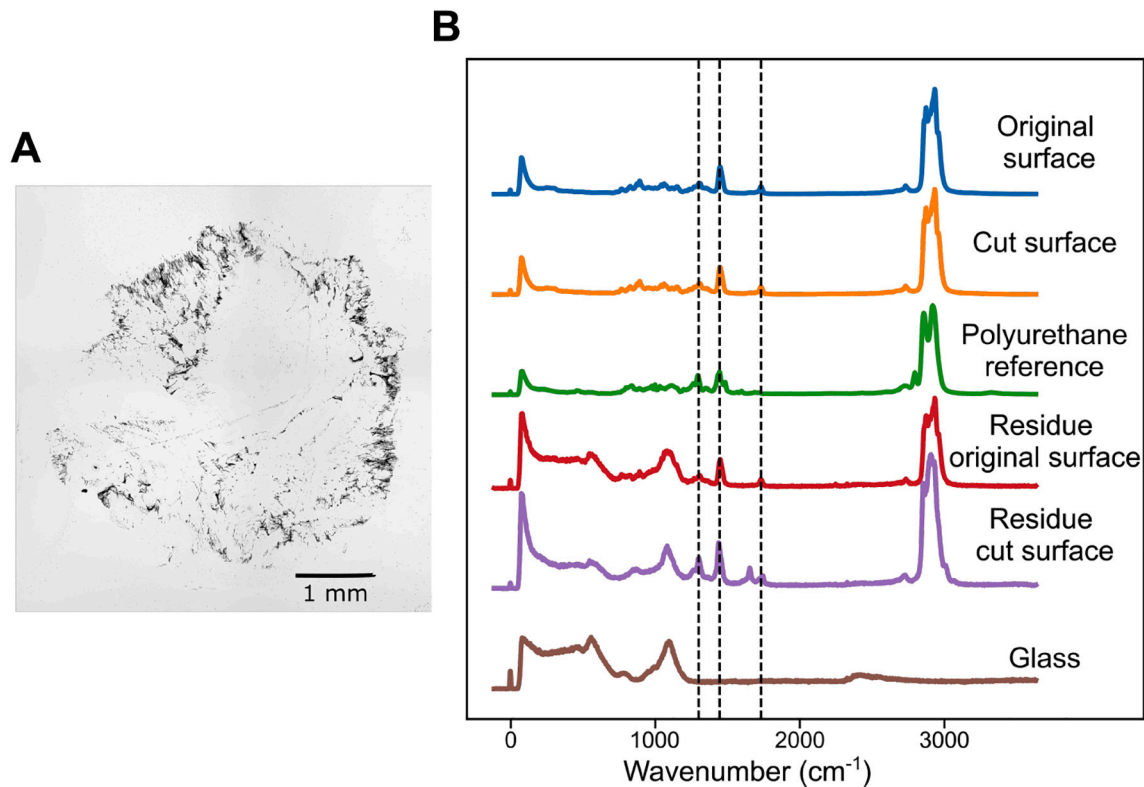


Fig. 5. A Residual layer on glass after contact with the gecko tape. B Raman spectrum of different gecko tape surfaces and residual layers. Polyurethane and glass data are shown for reference. Characteristic polyurethane peaks at 1732, 1445 and 1300 cm^{-1} are indicated with dotted lines.

very different (Fig. 4A). The conventional tape is around ten times thinner than the gecko tape ($h_{\text{conventional}} = 90 \mu\text{m}$, $h_{\text{gecko}} = 1 \text{mm}$) and cannot sustain an adhesive force over such a long distance as the gecko tape. We quantify adhesive strength with the work of adhesion: $W = -\int_{-\infty}^{d^*} F_{\text{retract}} \delta d$. d^* is the distance at which the force starts to be negative (tensile) during retraction.

When looking at the work of adhesion W as a function of contact area A (Fig. 4C), it is remarkable that all the measurements of work of adhesion W as a function of the contact area A follow a straight line that goes through the origin (dotted line in Fig. 4D). This means the effective adhesive surface energy is constant, and can be estimated from the fit to be $W/A = 4.0 \pm 0.5 \cdot 10^2 \text{N} \cdot \text{m}^{-1}$.

Apparently, the pillars on the original gecko tape do not change the surface energy as compared to an unstructured surface or one covered with adhesive.

It is also important to note that, in the adhesion experiments, the gecko tape does not really qualify as a ‘dry adhesive’: a residual layer of material of around 10 μm thick remains at the glass countersurface after contact (Fig. 5A). To understand what this layer is made of, we perform Raman spectroscopy (WITec UHTS 300, 532 nm excitation laser) on the original tape surface, the cut surface and the residual layers on glass as resulting from contact with the original surface or the cut surface (Fig. 5A). The peaks at 1732, 1445 and 1300 cm^{-1} are characteristic for polyurethane [20]: they are indeed also present in the spectrum of a polyurethane reference (Selectophore™, Merck). Thus, we can confirm the gecko tape is made of polyurethane (as indicated by the manufacturer). The 1732 cm^{-1} peak originates from a carbonyl group, which can be either part of the polyurethane amide group, or the isocyanate group of a precursor. Since this peak is present in the gecko tape and its residue, but not in the polyurethane reference, this suggests that the gecko tape contains unreacted precursor molecules. When this precursor is a polymer, it probably acts as glue.

3. Discussion and Conclusion

The surface of commercial gecko tape is covered with micrometric pillars, suggesting its structured surface contributes to generating strong adhesion, just like for the gecko. However, the observed density of the pillars is very low, 10^2 times lower than gecko *setae* density [4]. Adhesion experiments show that the presence of the pillars does not increase gecko tape adhesion; adhesion strength of the original gecko tape is very similar to that of gecko tape from which the pillars have been removed. In addition, in microscopy images of gecko tape-glass interfaces, no discrete contact of only the pillars was observed. In all cases, a continuous contact area can be seen, which implies the pillars play little role in the contact mechanics.

Nevertheless, a piece of gecko tape features a much higher work of adhesion than a piece of conventional adhesive tape of similar size. This is because it can generate a much larger contact area under the same normal force. In this way, it does resemble the gecko, which generates a large contact area with its soft fibrils.

The work of adhesion per unit area, an effective ‘surface energy’, of the gecko tape is remarkably similar to that of the conventional tape, which has a surface covered with glue. Furthermore, the gecko tape leaves a residual layer after contacting a countersurface, so we can conclude that the gecko tape also uses glue to stick instead of mere Van der Waals interactions between dry surfaces as the gecko does. Raman measurements leave the possibility open that the glue is made up of unreticulated polyurethane polymers.

To conclude, gecko tape is not very gecko-like; its pillars do not play any significant role in its adhesion strength and it uses a kind of glue to bond to a countersurface. Only the use of a soft surface to generate a large contact area is a principle that it shares with the gecko. A recommendation we can extend to gecko tape manufacturers is to spare the effort of creating micrometric structures, and focus on finding the optimal stiffness and chemistry for creating durable, reusable and strong adhesive contact.

Author Contributions

H.T.-D. conducted the profilometer, adhesion and microscopy experiments. H.T.-D. and S.L. conducted the Raman experiments. H.T.-D., M.G., S.L. and D.B. interpreted the data and wrote the manuscript.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biotri.2021.100179>.

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