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P3_6 Using Gecko Tape to Enable a Human to Climb

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Abstract
The adhesive material 'gecko tape' is introduced and its origins explained. An estimate of the capillary force is calculated. The amount of gecko tape required to support a human is considered and it is concluded that gecko tape could be used to enable a human to climb nearly any surface.

Introduction

'Gecko tape' is a new material, first synthesised in 2003, which uses a densely packed array of flexible plastic pillars to create an adhesive force [1]. It is called gecko tape because it mimics the feet of a gecko which are covered in micrometre sized hairs to create a force perpendicular to the surface, which allows a gecko to climb on nearly any surface, including glass. It may be possible to utilise enough gecko tape to enable a human to climb like a gecko.

Adhesion Mechanism

The adhesion is due to a van der Waals force between the tip of the pillar and the touching surface. Each hair/pillar produces a small adhesive force in the order of nN, so a large density is required. A hydrophilic material will often have a layer of water dissolved on its surface and the Gecko's hair interacts with the water via the capillary force [2], to create an additional adhesion. A Gecko's hair is approximately 0.5μm in diameter, and the van der Waals and capillary force are approximately equal.

Gecko tape is fabricated from plastic pillars of pyromellitic dianhydride-oxydianiline polyimide on a silicon wafer before being transferred onto a soft, flexible substrate. The soft substrate allows a lot of the polymers to make contact with a surface, giving optimum adhesion [1]. A strip of gecko tape (0.5cm^2), with a height of 2μm, a diameter of 0.5μm and a spacing of 1.6μm give a total adhesive force of 3N (each hair produces ~70nN of adhesive force) when placed onto SiO_2 a hydrophobic material. This is just for the van de Waals force; capillary force on hydrophilic materials can increase the adhesive force by a factor of 3 [1].

It is possible to estimate the adhesion caused by the capillary force, when a 'capillary bridge' between a gecko tape pillar and a surface is formed [2]. Due to the surface tension of water, between a pillar and a surface a curved meniscus will form between the two materials as the surface energy of the water is minimised. When a capillary bridge is formed there is a drop in the vapour pressure across the bridge. This is the adhesive force and the change in pressure is given by the Young-Laplace equation [4]

$$\Delta p = -\gamma \nabla . \hat{\text{n}}, \qquad (1)$$

where γ is the surface tension and $\hat{\text{n}}$ is the unit normal pointing out of the surface. The surface tension of water at room temperature at 1 atmosphere of pressure is 0.078Nm^{-1}[4] Assuming that the polyimide pillars have a hemispherical tip and the contact surface is completely flat with zero thickness eq (1) has a solution in the form

$$\Delta p = -\gamma H, \qquad (2)$$

where H is the mean radius of curvature. For a spherical meniscus [4]

$$H = \frac{1}{r}, \qquad (3)$$

where r is the radius of the meniscus, or 0.25μm for one of the pillars. Using eq (2) and (3) the change in pressure is $5.82 \times 10^5 Nm^{-2}$. Since pressure, P, is given by

$$P = \frac{F}{A}, \quad (4)$$

where F is the force and A is the area, the adhesive force can be calculated. For hemispherical pillar with surface area $2\pi r^2$, the adhesion force is 228nN, approximately three times greater than the van der Waals force. This estimate is for completely hydrophilic material that is fully saturated and is an overestimate because the surface will not be completely flat, and the pillar will not be a perfect hemisphere.

Currently gecko tape can only be made in small quantities, though it may be possible to make self-assembling pillars due to the electrical instability of polymers [3].

Application for a Human

For gecko tape to be used safely to enable a human to climb a wall or a ceiling, it needs to be able to support the weight of a human and extra for safety. The pillars can coil up on themselves or bunch together reducing adhesion, so there is an additional weight requirement. Also it should be able to hold a human on a completely hydrophobic surface, so if the climber transferred from a hydrophilic to a hydrophobic surface, they would not immediately fall. So only gecko tape with van der Waals adhesion will be considered.

Assuming that the average human weighs 75kg, with an additional 15 kg for safety, the force due to the Earth's gravity is given by

$$F = mg, \quad (5)$$

where m is the mass and g is the gravitational constant, taken to be $9.81 ms^{-2}$. Eq (4) gives a force of approximately 883N. If $0.5 cm^2$ can support 3N then $147 cm^2$ would be required to support a human.

Assuming that the surface of a human hand can be modelled as a rectangular palm, with fingers, when closed together make a scalene triangle, the surface area can be estimated. Using measurements from the author's hand yields a rectangle of dimensions 8.3cm by 9cm and hence area of $74.7 cm^2$. As well as triangle with a base of 7.6cm with sides 9.7cm and 9.3cm gives an area of $33 cm^2$ for a total area of $107.7 cm^2$. If multiple pads of gecko tape were used then it would be enough force to enable a human to climb a surface.

Conclusion

Gecko tape could be used to enable a human to safely climb like a gecko by having multiple pads. For example two gloves with gecko tape on the surface and two pads of gecko tape on a person's feet, would allow them to climb safely, as long as at least two pads were in contact with the surface at all times. This would also be advantageous as just one pad, say on the palm of a hand, could put a lot of force on the climber's wrist and may not be safe.

References

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