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A1 4 Can Humans Climb Like Geckos?

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Abstract

Geckos possess an incredible ability to climb using a Van Der Waals mechanism, generating a force between the molecules in their feet and climbing surface. This paper explores the contact area a human would need to be able to climb like a Gecko. Using a plane-plane interaction, it is determined that an area of 7 cm^2 is needed to hold a climber to a glass surface.

Introduction

It is well known that geckos climb using the Van Der Waals (VDW) force [1]; this has led to speculation on whether humans could do the same given the right circumstances. The VDW force is caused by the random distribution of electrons around an atom or molecule. Due to this, atoms can have a skewed distribution with more electrons on one hemisphere than the other leading to a dipole across the atom. This dipole polarizes neighbouring atoms which couples them together through charge attraction [2]. Because of the statistical nature of the distributions, the VDW force does not last long. However, the large number of atoms allows the force to be constantly present.

Methodology

The system of interest is modelled as two rigid surfaces, being a hand and a glass wall, with a thin film of water in-between acting as a medium. The water represents beads of sweat on the hands of the climber. An additional assumption is that the surfaces are slow moving so that the system follows the boundary lubrication region of the Stribeck curve [3]. These assumptions make the maths simpler as the interaction of two non-rigid surfaces is beyond the scope of this paper. The force of the interaction is as follows:

$$F_{VDW} = -\frac{A_H A_a}{6\pi d^3}. \tag{1}$$

Where F_{VDW} is the VDW force in Newtons, A_H is the Hamaker constant for the skin/water/glass, A_a is the contact area and d is the separation of the surfaces in metres [4] estimated to be 0.3 nm [1]. The A_H term describes the strength of individual VDW forces and is dependent on the materials used. The A_H term in this system is non-standard and will need to be calculated using:

$$A_H \approx \frac{3kT}{4}\left(\frac{\epsilon_1-\epsilon_3}{\epsilon_1+\epsilon_3}\right)\left(\frac{\epsilon_2-\epsilon_3}{\epsilon_2+\epsilon_3}\right)+\frac{3h\nu_e}{8\sqrt{2}}C_1. \tag{2}$$

Where the term C_1 is:

$$C_1 = \frac{(n_1^2-n_3^2)(n_2^2-n_3^2)}{(n_1^2+n_3^2)^{\frac{1}{2}}(n_2^2+n_3^2)^{\frac{1}{2}}\{C_2\}}. \tag{3}$$

Where:

$$C_2 = (n_1^2+n_3^2)^{\frac{1}{2}}+(n_2^2+n_3^2)^{\frac{1}{2}}. \tag{4}$$

Where 1 = Skin, 2 = Glass, 3 = Water, ϵ is the dielectric constant of the material, n is the refractive index of the material, h is the Planks constant, and ν_e is the electron absorption frequency [5]. The equation assumes that ν_e is equal for all mediums which is taken to be $3 \times 10^{15}\,\mathrm{s}^{-1}$ [5]. The values for the dielectric constants and refractive indices are: $\epsilon_1 = 34.7$ at room temperature [6], $\epsilon_2 = 7.5$ [7], $\epsilon_3 = 80.1$ [8], $n_1 = 1.36$ [9], $n_2 = 1.52$ [10], and $n_3 = 1.33$ [10]. ϵ_3 ranges from 5 - 10 so the midpoint of the range has been taken as its value.

Equation (1) can be related to the vertical friction on the wall which acts in opposition to the weight of the climber.

$$F_{friction} = \mu(F_N + F_{VDW}). \tag{5}$$

Where μ is the coefficient of static friction and F_N is the normal force of the hand on the wall [11]. The coefficient of friction is 0.61 and the normal is 50 N [12]. This can be re-arranged to give an area.

$$A_a = \frac{6\pi d^3}{A_H}\left(\frac{mg}{\mu} - F_N\right). \tag{6}$$

A factor was added to (1) to account for phenomena not present in the equation. These are that the centre of mass for the weight shifts while climbing and that the asperities of the materials are the only points in true contact. The true contact area for a finger on a surface is found to be 54±7 % [13]. From these an additional factor of 40,000 will be multiplied to the force; 2 from the weight shift, 2 from the true contact area, and 10,000 to convert to cm^2.

Discussion

The model predicts that a human can climb like a gecko with a small contact area of $7\,\mathrm{cm}^2$. This is an underestimate, due to the model's simplicity some effects are not considered. One such effect is of a changing separation between the surfaces $[d_0 - h(x)]^3$. Taking into account a changing separation, with d_0 being the maximum separation and $h(x)$ being a change in separation, many of the points contributing to the VDW force would be further away leading to a greater area as $A_a \sim d^3$. Another factor that would increase the area is the speed of the climb. This would change the coefficient of friction as shown in the Stribeck curve [3] resulting in a larger area to compensate.

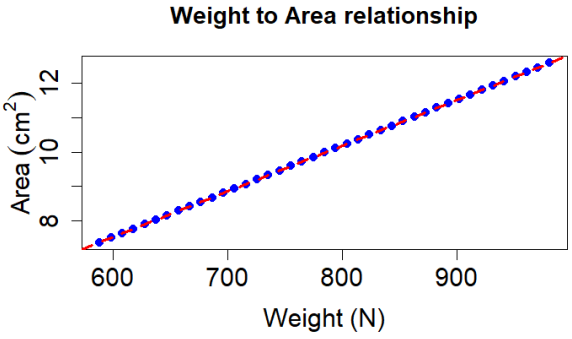


Figure 1: The weight is a range of $600 - 980\,\mathrm{N}$ with a gradient of $\frac{240{,}000\pi d^3}{A_H \mu}$. The data was obtained from the NHS [14].

Conclusions

In conclusion, a human could climb a wall like a gecko with an area as small as $5\,\mathrm{cm}^2$ for the weight range shown in Figure 1. However, the area predicted by the model is representative of what could be expected in idealised conditions but is an underestimation of what would be experienced in real scenarios.

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