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Research Article

Preliminary In Vivo Experiments on Adhesion of Geckos

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We performed preliminary experiments on the adhesion of a Tokay gecko on surfaces with different roughness, with or without particles with significant different granulometry, before/after or during the moult. The results were analyzed using the Weibull statistics.

1. INTRODUCTION

The Tokay gecko (*Gekko Gecko*) ability to climb or hang upside down to relatively smooth surfaces (Figure 1) is well-known since the past [1]. With a weight up to 300 g these animals exhibit a versatile and effective dry adhesion. Many hypotheses were formulated to explain this peculiarity [2–18]. Electron microscopy showed that the toes of this animal are covered by hierarchically organized microscopic hairs, further characterized by sub-nanohairs. The application of a similar principle to different fields, for the development of superadhesive smart materials, is nowadays of great interest [19–21].

The aim of this paper is to describe a preliminary series of experiments performed in vivo on a Tokay gecko. We recorded the gecko adhesive times on two surfaces characterized by significantly different roughness with or without particles with significant different granulometry, before/after or during the moult. We analyzed the adhesive times using classical Weibull statistics.

2. MATERIAL AND METHOD

The adhesion capability of a 50 g female Tokay gecko of approximately 20 cm in length was tested gently segregating the animal in a ($50 \times 50 \times 50\,\text{cm}^3$) box provided with several air inlets. One wall of the box was made of glass and the rest were made of plexiglass. Experiments were performed at room temperature (~24°C). All the tests were performed under the supervision of a certified veterinarian. The animal did not show any particular discomfort being manipulated or segregated in the box, except its well-known aggressiveness.

2.1. Characterization of the surface

The roughness of the materials used to build each face of the box was accurately characterized using a three-dimensional (3D) optical profilometer, Talysurf CLI 1000 (Taylor Hobson) with the CLA Confocal Gauge 300 HE (300 μm range and 10 nm vertical resolution). A surface area of 0.1 mm × 0.1 mm of each material was evaluated at 50 μm/s and 100 Hz sampling rate. The final resolution was 201 points/profile and all parameters of interest were referred to a 25 μm cutoff. The measured roughness parameters were the standard amplitude parameters Sa, Sq, Sp, Sv, Ssk, Sz, and the hybrid parameters Ssk and Sdr. Sa represents the surface arithmetical average roughness; Sq is the mean square roughness and represents the mean square deviation of profile from the middle line; Sp and Sv are, respectively, the height of the highest peak and the deepness of the deepest valley (absolute value); Sz is the average distance between the five highest peaks and the five deepest valleys detected in the analyzed area; the parameter Ssk describes the surface skewness; Sdr is equal to the ratio between effective and nominal surface areas minus one.

FIGURE 1: Gecko natural downwards position on a plexiglass surface.

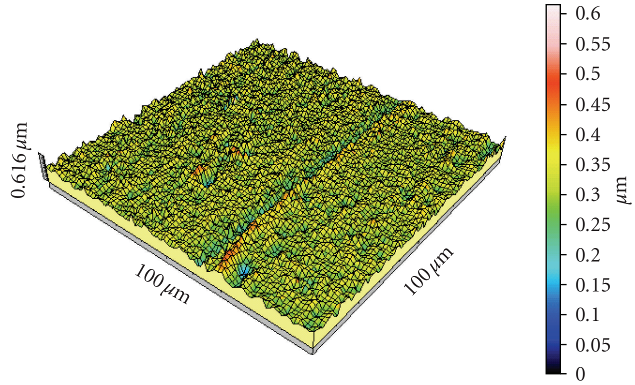

FIGURE 2: Glass: surface of glass without any superficial treatment.

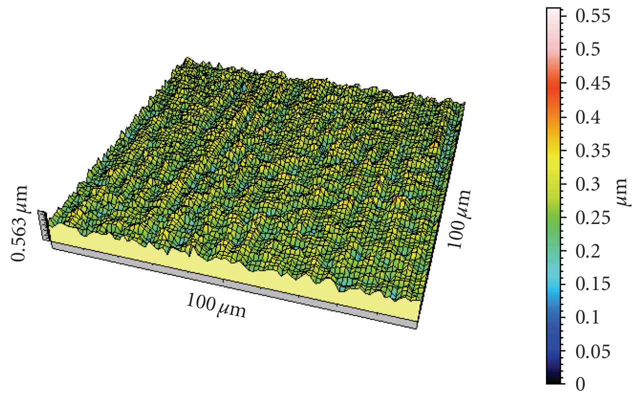

FIGURE 3: Plexiglass: surface of plexiglass without any superficial treatment.

2.2. Characterization of the toe

Four frozen and formaldehyde fixed samples of foots retrieved from two geckos died naturally were unfrozen at room temperature and scanned with a LEICA CLS 150 XE stereoscope and pictures of fields of interest recorded. A LEICA STEREOSCAN 430i electron microscope was used to measure the size of the setae.

The sequence of movements performed by the gecko during adhesion was recorded by gr-dx77u JVC digital video camera. The video camera was located axial to the gecko forearm and perpendicular to the ceiling surface of the box, approximately 25 cm far from the animal body. Single frames were then extracted using Nero Vision software.

2.3. Characterization of the particles

The adhesion test consisted in the progressive rotation of the box up to 180° with respect to its original position and in the description of the effect of the granulometries of different particles on the gecko adhesion ability. Calcium carbonate particles (50 g) and 2.5 mm diameter plastic spheres (100 g) were used to test two significant different granulometries. In order to test the long-term effect of small granulometry particles, the test using calcium carbonate was repeated also deeply cleaning the box but leaving dirt the animal feet. Plastic spheres were tested both lying freely on the bottom of the box or fixed, in order to form a restrained layer.

2.4. Adhesion experiments and Weibull statistics

A standard timer was used to measure the gecko failure times, defined as the number of seconds the animal was able to keep the upside down position before moving into another position (e.g., falling down). Tests were performed during the moult period and during the non-moult period.

The Weibull statistics, widely used for describing the strength and fatigue life in solids, was used to analyze the gecko adhesion ability. Thus, the loss of adhesion was treated as an interfacial failure.

TABLE 1: Superficial roughness parameters of plexiglass and glass.

	Plexiglass	Glass
Sa (μm)	0.033	0.031
Sq (μm)	0.042	0.041
Sp (μm)	0.252	0.366
Sv (μm)	0.277	0.434
Ssk	−0.122	−0.381
Sz (μm)	0.432	0.609
Sdr (%)	0.490	0.574

3. RESULTS

3.1. Characterization of the surface

Surface profiles of glass (Figure 2) and plexiglass (Figure 3) showed two homogeneous surfaces without significant 3D alterations, apart from small isolate bubbles on the glass surface derived from the fabrication process (melting). Table 1 summarizes averaged roughness parameters for the materials of interest. The surface of glass had a larger number of plateaus and several deep thin valleys in comparison to plexiglass.

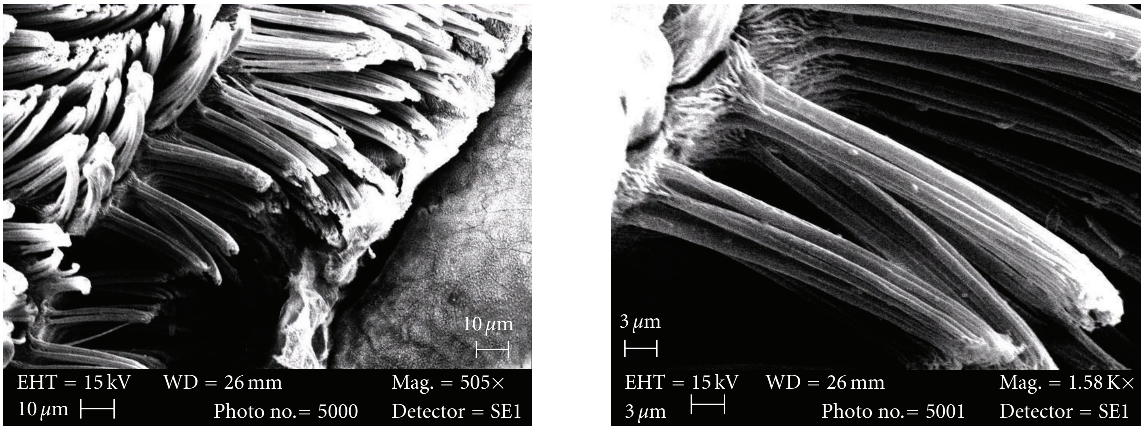

FIGURE 4: Scanning electron microscopy of the hierarchical structures of a gecko foot. Each toe contains hundreds of thousands of setae and each seta contains hundreds of spatulae.

3.2. Characterization of the toe

Multiscale observations confirmed classical observations [22–31]: the foot of Tokay gecko is characterized by a hierarchical structure starting with macroscopic lamellae, composed by setae, each of them containing different spatulae, representing the terminal contact units (Figure 4). The typical hyperextension of the toes has been clearly observed.

FIGURE 5: A gecko's dirty foot after treatment: the macroscopic aspect of lamellae is as a compact covered lamella, where the calcium carbonate fills all the empty free spaces between the setae.

3.3. Characterization of the particles

Small granulometry

Immediately after feet soiling with calcium carbonate (Figure 5) the ability of gecko to adhere to the surfaces vanished. Repeating the test one hour later no improvement in the adhesive ability of gecko has been observed. Self-cleaning was not observed. The gecko did not try to clean licking or moving quickly its feet and it seemed to be less aggressive, because of its perceived difficulty.

Large granulometry

The unconstrained spheres shifted away under the feet, thus capable of adhering to the underlying surfaces (plexiglass or glass). On the constrained layer made by the same spheres gecko exhibits its typical adhesive properties up to 180 deg rotation (Figure 6), making use also of its claws (Figure 7).

FIGURE 6: Adhesion on a layer of fixed spheres (2.5 mm in diameter).

3.4. Adhesion experiments and Weibull statistics

The measured times to failure were treated with Weibull Statistics. Accordingly, the distribution of failure (F) is given by:

$$F(t;m;t_0) = 1 - e^{-(t/t_0)^m}, \tag{1}$$

where t is the measured adhesion time, m is the shape parameter, and t_0 is the scale parameter of the distribution of failure (F). The cumulative probability $F_i(t)$ can be obtained experimentally as

$$F_i(t_i) = \frac{i - 1/2}{N}, \tag{2}$$

where N is the total number of performed tests and the measured times of failure, $t_i, \ldots, t_N$, are ranked in an ascending order. The Weibull statistics was found to be appropriate for describing the adhesion times on different surfaces. For example, the first series on plexiglass during the non moult period (measurements are reported in Table 2, Test 1) showed a Weibull modulus ~1.3 with a correlation

Figure 7: The nails on the tip of each toe.

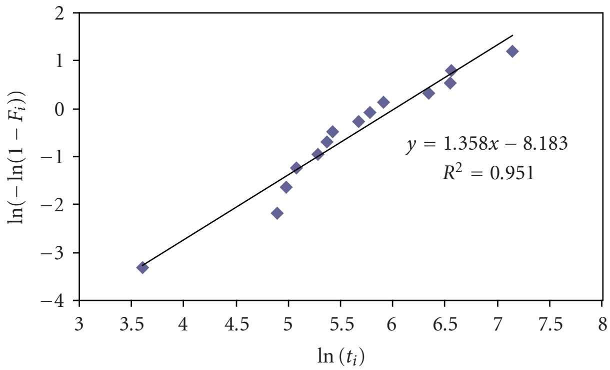

Figure 8: First set of measurements: Weibull statistics of gecko's time adhesion before the moult (Table 2, Test 1).

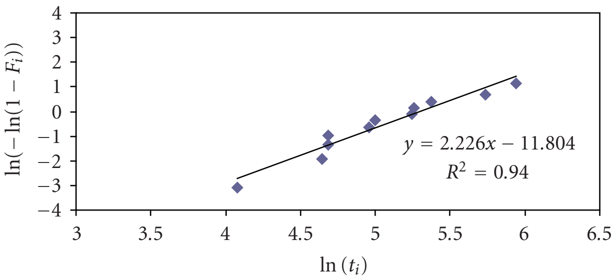

Figure 9: Second set of measurements: Weibull statistics of gecko's time adhesion during the moult (Table 2, Test 2).

coefficient of $R^2 = 0.95$, see Figure 8. The scale parameter t_0 was 413.86 seconds, approximately corresponding to 6 minutes and 53 seconds. The time measurements during the moult period (Table 2, Test 2), showed a decrease in the adhesion ability. The scale parameter t_0 was 200.79 seconds, approximately corresponding to 3 minutes and 20 seconds. The Weibull modulus during the moult increased up to ~2.2, with a correlation $R^2 = 0.94$, see Figure 9.

We have also observed an extraordinary increase in adhesion's time during the phase just following the moult, corresponding to adhesion times of the order of 2-3 hours, both on plexiglass and on glass.

The adhesive ability of gecko drastically decreases when the gecko moults. In the first series of measurements of gecko's time adhesion, the values are strongly variable by spanning between two orders of magnitude, in the range 37−1268 seconds, while the values of the second series obtained from the same gecko but during its moult are much less dispersed, from 59 to 380 seconds. The more variable the failure time, the lower the parameter m. Note that the shape parameter m of the first series ($m = 1.36$) is lower than in the second case ($m = 2.23$). As the failure shape parameter suggests, the failure during the moult becomes an almost deterministic process.

Table 2: Measurement results of gecko's time adhesion on plexiglass surface: first set before the moult; second set during the moult.

No.	Test 1 Time(s)	Test 2 Time(s)
1	37	59
2	134	104
3	145	108
4	160	108
5	197	142
6	215	148
7	228	190
8	292	192
9	323	216
10	369	310
11	568	380
12	700	
13	707	
14	1268	

4. CONCLUSIONS

We have showed that the gecko adhesive ability is drastically reduced when particles characterized by a "small" granulometry are interposed between toe and surface. Large particles can be controlled during adhesion, similarly to the surface roughness. The Weibull Statistics is found to be appropriate to describe the adhesion times of geckos. As the parameter m decreases, the failure time becomes more variable, describing a more stochastic and less deterministic process. This suggests that adhesion becomes a more deterministic process during the moult.

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