

SYNTHETIC GECKO

Gecko (lizard) foot/toe hairs (*Hemidactylus frenatus*). A lizard's foot has at least a half a million microscopic hairs – one-tenth the thickness of a human hair. The end of each hair is split into smaller hairs. At the frayed ends, these smaller hairs have spatula-shaped structures – about a billion per gecko. This spatula-shaped tip can flatten over rough or smooth surfaces and increases the area with which the hair can make contact. The gecko's attachment is accomplished by rolling and un-rolling these hairs onto the surface. © Dennis Kunkel Microscopy

NEW ADHESIVES BASED ON GECKO FOOT GEOMETRY OFFER SUBSTANTIAL BENEFITS IN A HUGE VARIETY OF APPLICATIONS

Although geckos run effortlessly across ceilings or along walls, our attempts to copy their unique adhesion capabilities have rarely been effective. However, a better understanding of the mechanisms involved, coupled with printed circuit processes, is bringing the adhesive technology close to commercial application. Fabian Acker talked to members of a UK research team who are helping to achieve this breakthrough.

The requirement for materials with the adhesion properties of a gecko's foot is driven by the aeronautic and defence industries. Many research institutes are involved in studying the adhesive properties of geckos' feet such as the BAE Systems's Advanced Technology Centre at Filton, where a variety of materials based on this adhesion technology – called 'Synthetic Gecko' – have already been manufactured.

Adapting existing clean-room technology with integrated circuit printing process, Filton's research team, led by doctors Sajad Haq and

Jeffrey Sargent, have modified a number of materials to exhibit gecko-foot adhesion for a portfolio of short-, medium- and long-term applications. Some of these are expected to become available for active use in the near future (although commercial confidentiality precludes listing these in detail).

They told *Ingenia* that prototype re-usable 'sticky' tapes, similar to double-sided Sellotape and 'patches' with adhesive on one side, have been manufactured successfully.

GECKO ADHESION

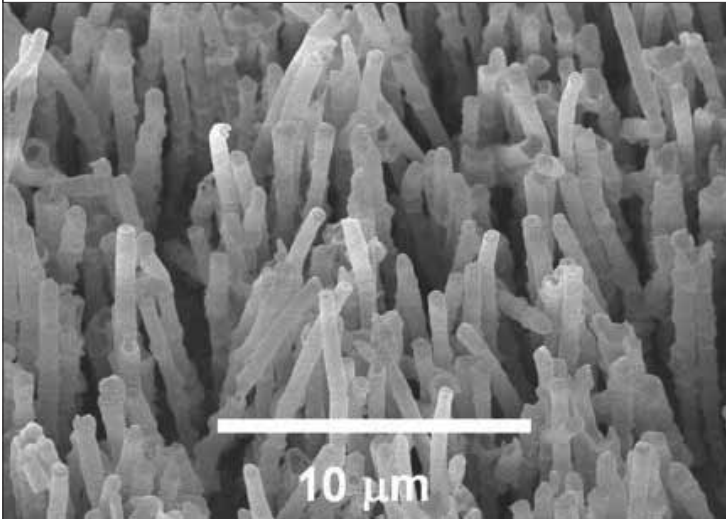
Separate research at Manchester University had already shown that a 1cm² prototype patch developed under controlled conditions can support about 3kg suspended from a horizontal plane. The university researchers claim that this is about one third of the capability of a gecko's foot.

Reproducing the adhesive force of a gecko's foot means reproducing its complex geometry. A gecko's foot consists of five components ranging from the macro, such as the foot and toes, down to the micro, such as the millions of

hairs at a density of about 5300/mm² on the toes, and then to the nano level with the tips of these hairs (about 5 microns in diameter) being split into hundreds of smaller hairs each about 200 nanometres in diameter.

Owing to their size and flexibility, the gecko is able to make close contact with almost any surface. The smallest hairs can enter the minute crevices and interstices known collectively as '*asperities*' that are present on most surfaces at a molecular level. The ability of these hairs and their tips to form intimate contacts with the host material is known as

Figure 1. Scanning electron micrograph of an array of 20 μm long, 0.6 μm diameter polymer fibres. Scale represents 10 μm
© The Fearing Group, Berkeley (UC)



'compliance,' in a similar way that a brush with many fine hairs can make close contact with a surface to be painted or cleaned.

STICKING TOGETHER

This degree of intimate contact exhibited by the hairs on the gecko's foot allows a normally weak force, the van der Waal's force (see box alongside), to become active. This provides one possible explanation as to the way in which the gecko's feet gain their adhesive power. It is not the only force operating – capillary forces also seem to have an effect, and there is some evidence that an increase in relative humidity improves adhesion. It is likely that both forces, and maybe others not yet discovered, may be involved.

VAN DER WAAL'S FORCE

This force is an electrical attraction between molecules; not the electrical forces within the molecules, but the sum of these forces on the molecules' surfaces. In a normal state, molecules are electrically neutral, but because of electron activity they acquire a temporary change in dipole moment when the electron forces are momentarily additive. The forces are only transient; the nature of a molecule is such that the electrical forces within it are, taken over a time average, in equilibrium. It can be visualised as a bar magnet or dipole during the brief times when it becomes polarised.

If the molecules on one surface can be brought into intimate contact with molecules

on a second, they will become attracted to each other when their polarities are opposite. The two mating surfaces will then adhere because the magnetic polarities of one set of molecules complements the polarities of the other. When this effect is multiplied a million or more times, the normally weak forces combine to provide powerful ones. Doctors Haq and Jeffrey caution that "it is by no means certain that the van der Waal's effect is the only mechanism at work with geckos. It is still an area of active research."

While research continues into more comprehensive explanations than that offered by van der Waals and capillary effects, the result can be reproduced artificially by

mimicking the structure of the gecko's foot. To do this, the research workers used micro-engineering clean-room facilities to find ways of replicating the compliant and nano elements of the gecko's foot. This involved working at micro and nano levels where the processes are similar to printing integrated circuits using photolithography and associated techniques.

Essentially, integrated circuits are considered as being two dimensional but at the nano level there are trenches, valleys and peaks. Using the masking and etching processes for patterning thin film already in-house, they were able to develop the procedures further, opening the way to large scale and inexpensive manufacturing.

POSSIBLE APPLICATIONS

The Filton team confirms that it has developed the technology to allow materials to be manufactured in quantity and at low unit cost. Commercial applications will now depend in part on bringing laboratory techniques into a routine production process, and in part on patenting and administrative procedures. A number of practical applications have already been demonstrated in the laboratory.

Meanwhile at Manchester University a team under Professor A Geim has developed a surface mimicking the gecko foot geometry using polyamide film (see Figure 1). The hairs are 2 μm long, with a diameter of around 0.5 μm and a periodicity of 1.6 μm . The Fearing Group at Berkeley (University of California), has also manufactured arrays of simulated gecko hairs 20 μm long, 0.6 μm diameter.

INITIAL USES

First applications of the technology from BAE Systems will be directed to the aeronautical and defence industries, and these are likely to fall into two categories – emergency repairs and assembly procedures. To grasp the potential for these likely uses, it is helpful to consider the analogy of Velcro – the principles are quite different, but some effects are similar, with the proviso that only one of the two surfaces has to exhibit gecko foot technology. Like a Velcro patch it is reusable, no fluids or gels are involved, and it can be applied rapidly.

The rapidity of application, with little or no preparation needed, makes it ideal for the first category (emergency use). This would be for repairing damage to aircraft fuselage or components caused by natural phenomena or by hostile action. Fuel tanks, hydraulic lines, windscreens, helmets, and instrument casings are a few of

the components whose loss or damage could jeopardise safety and would therefore be prime candidates for emergency repairs.

Further applications could encompass repairs to ships at sea, road vehicles and industrial machinery, all of which can be damaged by natural phenomena or enemy action. The adhesive power of Synthetic Gecko is so powerful that some repairs could become permanent, but straightforward mechanical removal or 'peeling' can detach the repair.

SHIPSHAPE

Repairs of hull damage on ships are highly labour intensive, can take many hours and may require the ship's speed to be reduced. Depending on the cargo or the sea-state, metal patches are sometimes attached by welding. Alternatively they may be bolted in place or secured with adhesives, which in themselves can pose dangers of toxic fumes in enclosed areas.

Attaching patches or panels with gecko foot technology would overcome all these disadvantages and offer no danger to flammable cargos – it can also be done quickly. Possibly the patch could be made of a non-metallic material, equally robust however more flexible, allowing it to follow hull contours.

On production lines, screwed, bolted or welded components and protective or decorative panels, could be attached by the new adhesive with the advantages of equally rapid removal and replacement. An instrument panel for example, could be firmly attached yet easily removed for adjustment or repair to the components behind it.

A CLEAN BOND

Two other properties of the gecko-foot geometry will prove of commercial value. One is that when the adhering element, such as a patch or tape, is removed, there is no residue



Geckos' adhesive microstructure requires little attachment force, leaves no residue, is directional, detaches without noticeable forces, is self-cleaning, and works underwater, in a vacuum, and on nearly every surface material and profile. Here above, the gecko is on glass which it can adhere to relatively easily © BAE Systems

remaining. The other is that simple changes in the geometry of the hair structure will change its property from adhesion to friction.

The first property opens up a range of medical uses wherever high adhesion and low contamination is needed. Research workers at Berkeley, suggest using it on the skin surface to repair lesions, and internally to repair or patch damaged organs.

GRIPPING MATERIAL

The friction property can be exploited industrially for items such as brake linings, vehicle and aircraft tyres (particularly valuable when landing on aircraft carrier decks), tank tracks, and drive belts; because a wide range of materials can be engineered to mimic the gecko-foot geometry on one or more surfaces, it may be that rubber tyres, used for their flexibility and frictional properties, could be replaced with other, modified, materials with greater resistance to degradation, but exhibiting better friction with the same or better flexibility.

Most of the advances promised by the 'Synthetic Gecko' technology do not depend principally on developing new materials, but by modifying existing ones. In addition, the production processes needed are broadly based on refining the existing ones. The prospect of adding new and useful properties to existing materials and machinery is only a matter of time.

POTENTIAL APPLICATIONS – LARGE AND SMALL



Top image The Advanced Concept Team at European Space Agency is looking at ways of holding spacecraft to asteroids such as Ida, the second of the two asteroids which the Galileo spacecraft encountered en route to Jupiter, partly by the use of dry adhesion based on gecko foot technology. Use of robots (so-called Waalbots) for repairing vehicles in space are also under consideration by a number of researchers using gecko foot adhesion technology © NASA

Bottom image A potential use for a gecko patch. Here a crude temporary repair, in which a roughly shaped piece of wood is hammered into the hull of a vessel to plug a leak. At sea, the repair would be adequate only for a limited time, and would not completely stop the ingress of water © MAIB

BIOGRAPHY – Fabian Acker

Fabian Acker, a marine and an electrical engineer, is the former editor of *The Motor Ship* and is consultant editor for the magazine *Hydropower & Dams*.