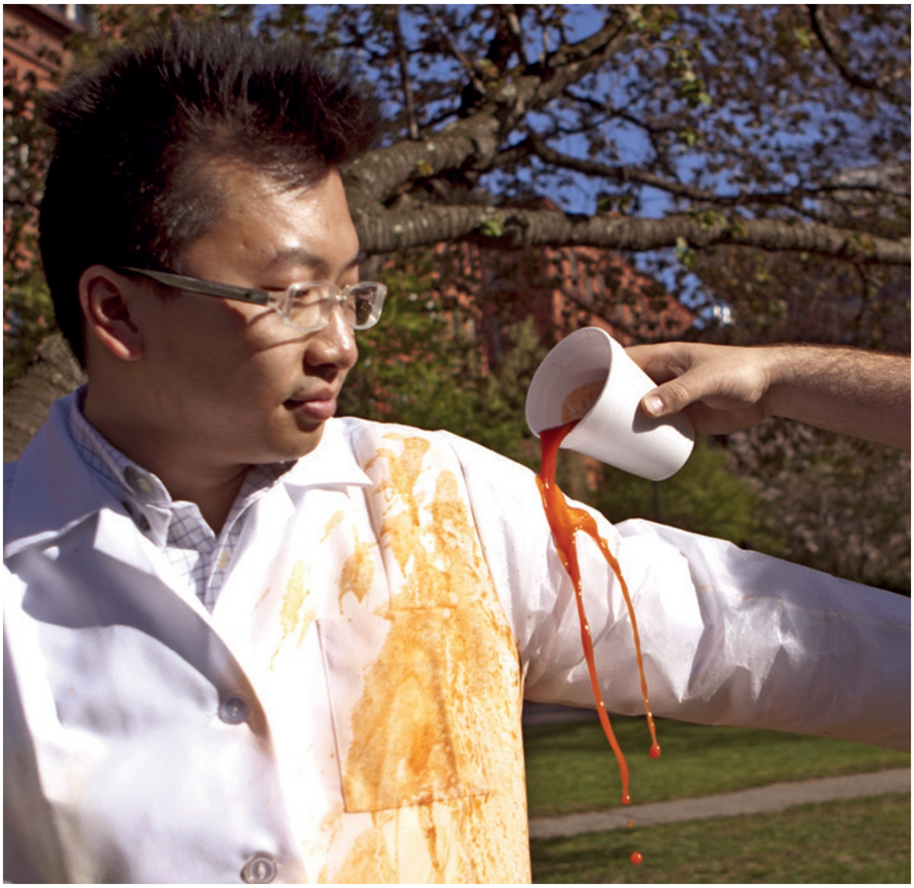


ELIZA R. GRINNELL, HARVARD SEAS

The water-repellent fabric used to make the sleeves of this lab coat was inspired by a carnivorous plant.

TEXTILES

Fabrics of life

Bioinspired fibres and coatings that can repel water, oil and other liquids form the basis of cutting-edge cloth.

BY ELIE DOLGIN

Philseok Kim fills a syringe full of reddish-brown oil and dribbles it onto a swatch of polyester cloth. The viscous fluid beads into a droplet and gradually slides into the bin below, leaving the fabric as clean and stain-free as the day it was milled. Kim then squirts on a splash of red-tinted water, a stand-in for human blood. "It just rolls off," he says.

Kim is a chemist and a founder of SLIPS Technologies, a company in Cambridge, Massachusetts, that derives its name from an innovative approach to creating super-slick coatings: 'slippery liquid-infused porous surfaces'. SLIPS can make a substrate friction-free, simply by locking a thin film of lubricating liquid onto any material. Modelled on the insect-trapping mechanism of the *Nepenthes* pitcher plant, SLIPS could one day become state-of-the-art in repellent surfaces — replacing designs now on the market that themselves were modelled on another plant, the *Nelumbo* lotus flower, the leaves of which wick away water.

According to Scott Healey, vice-president of business development at SLIPS Technologies, the company's platform has a range of potential applications in the energy, automotive, environmental and manufacturing sectors. But it is in cutting-edge textiles that the technology could be first put to use. "We have interest from several textile and apparel companies," says Healey. "The market is coming to us right now."

In October 2014, the company inked its first partnership, with BASF, a German chemical manufacturer headquartered in Ludwigshafen, to produce SLIPS-coated thermoplastics for footwear and other functions. Other companies have expressed interest in co-developing sportswear, specialized garments for construction, tactical suits for the military and medical gowns for hospitals — all enhanced with the SLIPS surfaces. "They have ideas, we have technology, and we're trying to blend those together," Healey says.

SLIPS Technologies, which Kim co-founded with Joanna Aizenberg, a materials scientist at the nearby Wyss Institute for Biologically Inspired Engineering at Harvard University, is part of a new wave of commercial and academic efforts to apply the lessons learned from nature to the textile industry. This strategy has a history dating back at least a century — from the production of rayon (then known as viscose) in the late nineteenth century and acrylic in the 1940s, developed as artificial mimics of silk and wool, to the invention of Velcro, which was modelled on the sticky fruit of the cocklebur plant.

But today the approach has moved well beyond synthetic fibres and fabric fasteners. From breathable clothes to camouflage systems, textile designers are taking inspiration from evolution to help them solve their problems. "People are borrowing and finding great ideas all over the place," says Matt Powell, a sportswear-industry analyst at NPD Group, a market-research firm based in Port Washington, New York. "The technology advances are just staggering."

CREATIVE COATING

Aizenberg and her colleagues first described SLIPS in 2011, showing that the bioinspired technology could repel blood, oil and other complex fluids under a range of harsh conditions and temperatures[1]. That study looked only at solid surfaces; the next challenge was to see how SLIPS fared on fabrics such as cotton and polyester.

Choosing which textiles to test required a unique kind of field research. Cicely Shillingford, one of the lead scientists on the project, sifted through the racks of brand-named athletics gear at a department store. She peered through a magnifying glass to find the densest weave of polyester, which helps to boost the repellency, and settled on a pair of Nike running shorts.

Shillingford and Noah MacCallum, who at the time were students visiting from the University of Waterloo in Ontario, Canada, put the SLIPS-treated running shorts and six other SLIPS-enabled fabrics through a battery of tests. They twisted and rubbed the samples to see how the coating would stand up to physical damage. They analysed the repellency using two assays defined by the American Association of Textile Chemists and Colorists, and they examined breathability using a standard water-vapour transmission test[2]. "Pretty much on every score, except for breathability, we had much better results than anything that other [repellent] fabrics would have," says Aizenberg.

Because SLIPS relies on impregnating materials with lubricant, "it's a direct trade-off between breathability and repellency", explains Shillingford. The technology could be used today in clothes for which breathability is not paramount, such as those worn by construction workers to protect them from exposure to dangerous chemicals. But for active wear in which moisture

MAIN IMAGE: IAN SHAW/ALAMY; INSET: PAUL D. STEWART/SPL

release is important, some scientists have turned to a different botanical artefact.

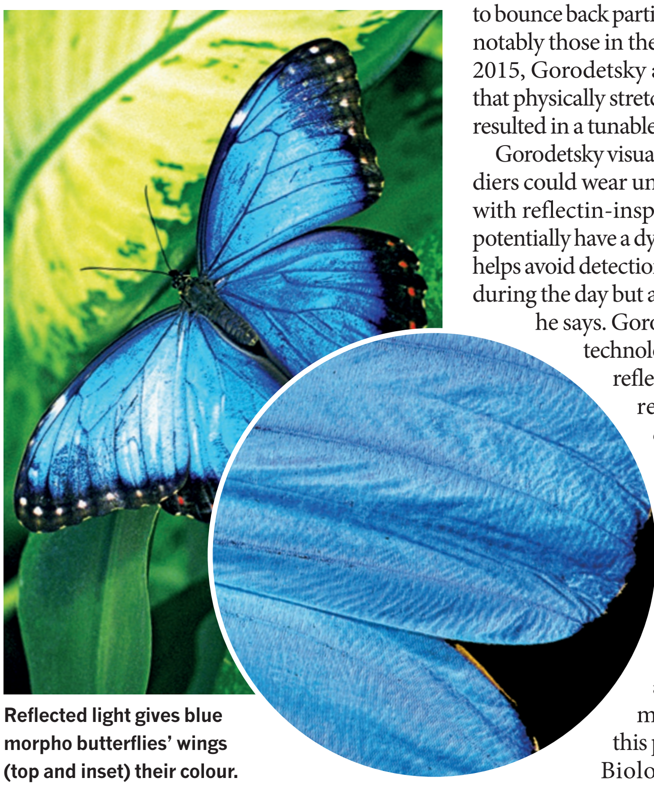
MMT Textiles was established in 2009 to commercialize a type of fabric that mimics the structure of pine cones by opening and closing depending on the humidity in the microclimate of the garment. Ordinarily, when a fabric gets wet, the fibres swell as they absorb moisture. London-based MMT Textiles' fibres behave differently: they incorporate two synthetic polymers that are stuck together in a single fibre. One polymer is hydrophobic, which means that it resists water, whereas the other is hygroscopic and absorbs moisture. The tension between these two layers causes the fabric to curl and shrink in response to water vapour — in the same way that a bimetallic strip bends in response to temperature changes. Under dry conditions, the MMT Textiles fabrics open up like a pine cone, which reduces airflow and increases the fabric's insulation properties. Under wet or sweaty ones, "the yarns become tighter, which improves the air permeability of the garment," explains Veronika Kapsali, a biomimetic-fashion researcher at Northumbria University in Newcastle, UK, and technical director of MMT Textiles.

Like SLIPS Technologies, MMT Textiles is partnering with several international apparel companies to develop sportswear, denim, bedding and other materials. Kapsali expects to have a product on the market by early 2016. Switzerland's Schoeller Textiles, based in Sevelen, also has a pine-cone-inspired technology, called c_change. This fabric opens and closes depending on temperature, and thus releases, when necessary, warm and moist air from the interior of the clothing. Several high-end lines of outerwear, including one tailored for professional yacht racing, already incorporate breathable c_change designs.

WHEN APPEARANCE IS DECEPTIVE

The responsive features of biomimetic textiles, such as those that improve repellency and breathability, might go unnoticed by the naked eye. But for other biologically inspired designs, changes in the appearance of the fabric are the desired goal.

Some companies have taken inspiration from the South American blue morpho butterfly (genus *Morpho*) and are creating structurally coloured fibres with no dyes or pigments. The butterfly's iridescent colouring is not from a pigment but is produced when tiny scales on its wings reflect the light. The companies mimic this effect by laminating dozens of ultra-thin layers of polyester or nylon, and the thickness of the layers, their patterning and the different refractive indices of the materials give rise to a variety of colours. The technology's proponents claim these colours will never fade, and that the manufacturing is environmentally friendly because no chemical colouring is involved. "The ability to colour things just by light refraction is going to be really cool," says Michael Ellison, a



Reflected light gives blue morpho butterflies' wings (top and inset) their colour.

polymer-fibre physicist who studies biomimetic materials at Clemson University, South Carolina.

The US military is also expressing a growing interest in colour-changing fabrics. These focus on cephalopods — marine invertebrates such as squid and octopus that naturally alter their skin patterns in response to different visual backgrounds — to develop more-effective camouflage techniques. In 2014, researchers at the University of Illinois at Urbana–Champaign, funded by the US Office of Naval Research, reported the construction of cephalopod-inspired flexible sheets that can 'read' surrounding patterns and adapt to match the environment[3]. The artificial skin emulates the mottled patterns of cuttlefish, with their small-scale light and dark patches. A combination of sensors and colour-changing materials enables the sheets to match the backdrop. The prototype is small and only works in black and white, but its designers say the material can be scaled up and adapted to encompass the full colour spectrum.

> *"You could have a dynamic camo patterning that helps avoid detection in visible light."*

The influence of cephalopods extends beyond the visible spectrum. Alon Gorodetsky, a materials scientist at the University of California, Irvine, is drawing inspiration from these animals to fabricate materials for infrared stealth applications. He is working with a protein called reflectin, which is normally found in the skin of squid. Using various chemical, mechanical and electrical stimuli, he has found a way to fine-tune the optical properties of coatings based on reflectin to bounce back particular wavelengths of light — notably those in the near infrared. In February 2015, Gorodetsky and his colleagues showed that physically stretching films of these proteins resulted in a tunable shift in reflectance[4].

Gorodetsky visualises a scenario in which soldiers could wear uniforms coated or patterned with reflectin-inspired materials. "You could potentially have a dynamic camo patterning that helps avoid detection not only in the visible light during the day but also in the infrared at night," he says. Gorodetsky is also adapting the technology to create fabrics that can reflect longer-wavelength infrared. "This thermocomfort cloth would let a person dynamically regulate how their body emits thermal radiation," he says. In December 2014, Gorodetsky received a US$2.4 million grant from the Advanced Research Projects Agency-Energy, an arm of the US Department of Energy, to explore this possibility.

Biologically inspired materials might also lead to swifter swimmers. Swimwear companies such as Speedo have claimed to make shark-skin-like fabrics, but George Lauder, an ichthyologist at Harvard University, has demonstrated that the Speedo suits that were banned after the 2008 Olympics do not contain the microscopic shark scales, called denticles, that reduce drag[5]. Using a three-dimensional (3D) printer, Lauder last year constructed true artificial skin of the shortfin mako shark (*Isurus oxyrinchus*) and showed that it not only limits drag but also increases thrust[6].

Unfortunately, current manufacturing limitations preclude the production of true shark-skin-like swimwear or dive suits. "You can't 3D print this at scale with the surface structure that we want," said Lauder from his Harvard office, with a sample of the flexible, scaly, artificial shark skin in his hand. So for now, the research continues. Lauder is even teaming up with Aizenberg, his Harvard colleague, to see whether SLIPS coatings applied to his artificial shark skin can create a superfast and water-repellent material. Pitcher plants and mako sharks might never meet in nature. But the insights they bring to the lab could inspire the next biomimetic fabric. ■

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