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Protein behavior might hold the key to synthetic silk

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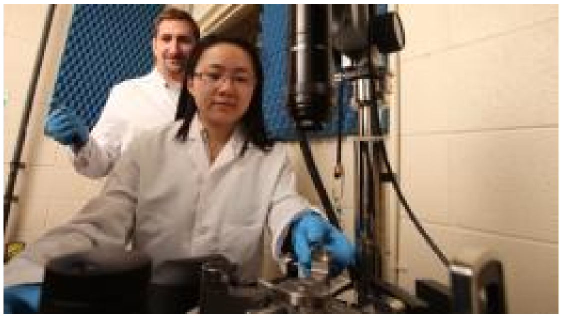

Graduate student Minzhen Cai loads a sample of silk dope into the atomic force microscope as Hannes Schniepp, assistant professor of applied science, looks on. The two William & Mary researchers are part of a collaborative that recently published a paper describing the structure and behavior of one of the main proteins in silk. Photo by Stephen Salpukas

The world may just have moved a step closer to the reality of comic books.

A trans-Atlantic collaboration of scientists has revealed the structure of a key protein of silk and discovered a previously unknown behavior of this protein: to self-organize into tiny fibrils a single molecule in diameter. This discovery sets the stage for the eventual creation of synthetic silk—not just the luxury fabric that's a product of silkworms, but also the manufacture of ultra-tough spider silk familiar to fans of the Marvel superhero Spider-Man.

Hannes Schniepp cautions that the world's textile mills aren't likely to start producing "spidey silk" in the near future, but says his work describing the structure of the silk protein and its self-organizing behavior is an important step in that direction. Schniepp is an assistant professor in the Department of Applied Science at the College of William & Mary. Along with graduate student Minzhen Cai and a set of collaborators at the University of Oxford in the United Kingdom, he has published a paper describing silk at the molecular level.

"Silk is a polymer," Schniepp explained. "It's not a synthetically-made polymer, but it's a polymer made out of proteins."

Synthetic plastics are polymers, but these macromolecules are common in the natural world, too. Schniepp pointed out that much of the human body—including DNA—is constructed of various polymers.

"What's so fascinating about silk is that in terms of its mechanical properties, silk is better than any polymer that we can make synthetically," he said. "Particularly, certain spider silks are even tougher than Kevlar, the best high-performance polymer we have."

You can't farm spiders

For millennia, people have been using the cocoons of silkworms to weave silk cloth. Humans have used spider silk to a much lesser degree, but spiders have proven to be impossible to cultivate: "They start eating each other," Schniepp says.

Figuring out a process to make synthetic silk has been a sort of Holy Grail of materials science for nearly as long as people have been making silk. After years of scientific study, the exact natures of both the biochemistry and the mechanics of silk creation by silkworms and spiders remain elusive.

"The big question really is how does the spider do it? How does the silkworm do it?," Schniepp says. "The problem is it's a tiny animal and it happens really in very small dimensions inside the animal, and it's really almost impossible to watch what's going on there."

He said that most of the scientific study on structure of silk has focused on examination of the product through microscopy and other analytical tools. The study has yielded a fair amount of understanding about the structural nature of silk, but scientists had no idea of what shape an individual silk protein had.

Schniepp and his team at William & Mary took a different approach than most materials scientists, sampling "silk dope," the gel-like material inside the silkworm that the worm exudes to spin its cocoon.

"A lot of these biomolecules, they're very sensitive to changes. So the closer you can be to the native state, the more valuable this information is that you get," he said.

Working with silk dope

Schniepp and his research group examined the silk dope in their McGlothlin-Street Hall laboratory, using an atomic force microscope (AFM), an instrument capable of looking at materials at the nanoscale. Before placing them in the AFM, they prepared their silk dope, diluting the samples with a bit of water, then spun the sample on a plate, so that the silk spread out on the surface.

"When you spin liquid on a plate like this, you shear it. And that does something to these proteins that's similar to the way that the animals do," he explained. "They have a gland that produces this material and at the end is something like a nozzle. So they squeeze this material out through the nozzle. To create a similar effect, you shear the solution. By spinning it very quickly, the liquid is forced away, and it is similar to what happens when the animal pushes the silk out."

A number of curious things happen when the material is sheared. For one thing, the water-soluble silk dope has been transformed into something waterproof. More importantly, the shearing somehow induces individual proteins to "find each other," as Schniepp describes, and to self-organize into fibrils. One molecule thick, the fibrils are the thinnest possible threads of silk and are precursors to silk fibers.

Seen through AFM magnification, each fibril shows where the individual proteins have conglomerated. The magnification resembles a string of pearls. It's the first time that the structure of the native silkworm protein has been imaged at such high resolution.

The work on silk is supported by the Jeffress Memorial Trust. Schniepp published his findings in a paper, "Shear-Induced Self-Assembly of Native Silk Proteins into Fibrils Studied by Atomic Force Microscopy" in the journal *Biomacromolecules*. Fritz Vollrath of Oxford University is a co-author, as is Cai. They are continuing their work on the structure of the material.

"We don't know what other secrets silk has hidden for us," Schniepp says.

Provided by The College of William & Mary

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