materials update

Elastic character

With its unique combination of high strength and elasticity, spider silk outperforms almost every synthetic material that has ever been made. But despite many years of research, much remains unknown about its exact structure. By measuring and modelling the mechanical behaviour of spider silk at a molecular scale, researchers hope to understand more about this remarkable material.

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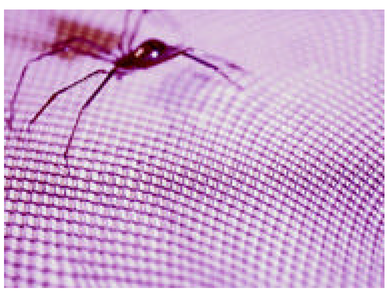

Spider silk is one of the most remarkable of all materials, natural or synthetic, ever made. Its strength is comparable to that of steel cable, and yet it can be stretched by up to to 1,000%. This combination of high strength and elasticity make it extremely attractive for use in applications ranging from artificial tendons and ligaments to bulletproof clothing. And yet there is still much that is unknown about how it achieves its impressive properties. In next month's *Nature Materials*, Nathan Becker and colleagues describe the use of atomic force microscopy to investigate the elastic properties of molecules of spider silk, and develop models to explain these properties on both a molecular and macroscopic level.

Many different types of spider silk have been identified, but researchers have primarily focused on just two, known as dragline and capture silk. Dragline silk is the stronger of the two, being several times stronger than steel cable, and is used to construct the frame and radial lines of an orb-weaving spider's web. Capture silk, on the other hand, although not as strong as dragline silk, is many times more elastic and is used to make the sticky spiral threads the

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Capture silk is made from an interconnected mesh of protein-based polymeric threads, which form tight coil-like structures when relaxed and extend into long chain-like structures when stretched. Although the basic sequence of amino acids that form these protein chains has been known for several years, because they have never been crystallized — vital to carrying out X-ray diffraction — their exact physical structure is not fully understood.

To investigate the molecular origin of capture silk's elastic properties, Becker et al. use a variation on an atomic force microscope (AFM) known as a molecular force probe (MFP), which, unlike a conventional AFM, is optimized to measure the forces involved in pulling molecules away from a surface rather than pushing them towards it. This instrument allows them to obtain details about the minute force variations that occur when threads of capture silk are stretched.

On stretching the threads, the authors observe a number of abrupt steps in the tensile force applied to these molecules as a function of distance, which they believe are caused by the rupture of sacrificial bonds within the molecules. When allowed to relax back to an unstretched state, however, they find that these bonds reform to regain the molecule's elasticity and prevent mechanical degradation.

More significantly, they find that on both a molecular level and at the macroscopic scale of an entire thread, the elastic force of spider capture silk increases exponentially over almost three orders of magnitude as a function of stretching distance. This is in contrast to the behaviour of a conventional spring whose force increases linearly with distance. One model the authors suggest to explain this behaviour is the presence of networks of many individual molecular springs connected in series and parallel. At low displacements, the elastic is dominated by long chains of these springs connected in series. As these stretch to their limit or break, at larger displacements the behaviour becomes controlled by the stiffer networks of springs connected in parallel. The authors hope that with further studies these models can be better tested and refined.

Scientists have already begun to produce small quantities of synthetic spider silk from the genetically modified epithelial cells of cows and hamsters, and hope soon to produce large quantities from the mammary glands of goats. The authors hope that by developing techniques to test and build models of these materials at the molecular level, their properties and eventual commercial production can be optimized.

nature materials article
Molecular nanosprings in spider capture-silk threads
Nathan Becker, Emin Oroudjev, Stephanie Mutz, Jason P. Cleveland, Paul K. Hansma, Cheryl Y. Hayashi, Makarov E. Dmitrii & Helen G. Hansma

Spider capture silk is a natural material that outperforms almost any synthetic material in its combination of strength and elasticity. The structure of this remarkable material is still largely unknown, because spider-silk proteins have not been crystallized. Capture silk is the sticky spiral in the webs of orb-weaving spiders. Here we are investigating specifically the capture spiral threads from *Araneus*, an ecribellate orbweaving spider. The major protein of these threads is flagelliform protein, a variety of silk fibroin. We present models for molecular and supramolecular structures of flagelliform protein, derived from amino acid sequences, force spectroscopy (molecular pulling) and stretching of bulk capture web. Pulling on molecules in capture-silk fibres from *Araneus* has revealed rupture peaks due to sacrificial bonds, characteristic of other self-healing biomaterials. The overall force changes are exponential for both capture-silk molecules and intact strands of capture silk.

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