Spider webs rely on nonlinear material behavior and architecture

Perhaps no other natural structure better exemplifies a design that optimizes material function than the spider web. However, despite extensive theoretical and experimental investigations of the molecular design and mechanical properties of spider silk, the integrity and performance of the spider web has not yet been fully explained. Recently, M.J. Buehler from the Massachusetts Institute of Technology, N.M. Pugno of Politecnico di Torino, Italy, and their colleagues showed that the superior performance of spider webs can be attributed to a combination of the silk threads' nonlinear stiffening response to strain—which is a result of a unique molecular structure—and their discrete geometrical arrangement in a web, rather than their remarkable strength and toughness as had been previously assumed.

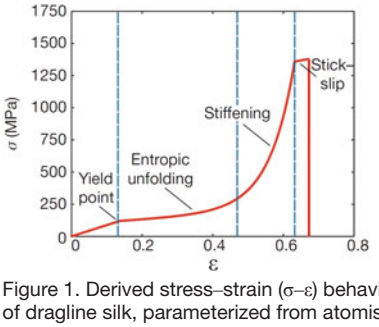

Figure 1. Derived stress–strain (σ–ε) behavior of dragline silk, parameterized from atomistic simulations and validated against experiments. Reproduced with permission from *Nature* **482** (7383) (2012), DOI: 10.1038/nature10739; p. 72. © 2012 Macmillan Publishers Ltd.

As reported in the February 2 issue of *Nature* (DOI: 10.1038/nature10739; p. 72), Buehler and co-researchers used results from atomistic simulations to parameterize the behavior of dragline silk from the species *Nephila clavipes* (see Figure 1). This silk model was used in conjunction with a web model containing spiral (sticky capture silk) and radial (strong dragline silk) threads, which are the primary components commonly found in orb webs. Thread removal (up to 10%) had relatively little impact on the web's response to a load. By comparing the loading of radial versus spiral threads, the researchers found that the force required to break radial threads is about 150% higher than for spiral threads, yet, in both cases, failure and resulting damage were limited and localized about the loaded thread.

In order to determine whether localized failure is due to the silk's materials properties or the web architecture, the researchers constructed and tested two additional web models using idealized engineered fibers exhibiting linear elastic or elastic–perfectly plastic behaviors. Both of these revealed increasingly non-localized damage (see Figure 2). The researchers incorporated their models' materials behaviors into quantized fracture mechanics, which can be used to describe the failure of discrete structures, to prove that the relative size of the damage zones is a function of the materials' stress–strain relationships. They also derived a scaling law that relates the undamaged fraction of the web to a parameter that defines the nonlinear nature of a material's stress–strain relationship. The nonlinear stiffening behavior ensures that a loaded thread becomes the sacrificial element, which can be repaired, while the large majority of the web remains intact.

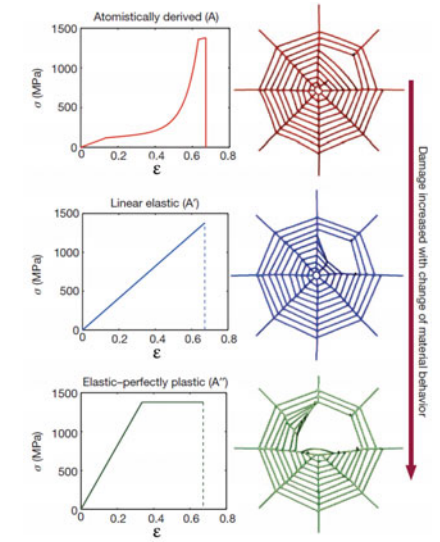

Figure 2. Web response for varied silk behavior under targeted (local) and distributed (global) loading. Reproduced with permission from *Nature* **482** (7383) (2012), DOI: 10.1038/nature10739; p. 72. © 2012 Macmillan Publishers Ltd.

The researchers said that whereas current engineering practices use sacrificial elements to dissipate energy (as in the response to seismic waves, for example), web-design principles should now be considered. They said, "Such an engineering design could ignore the requirements for the magnitude of a potential load and allow local failure to occur, a design stipulation that requires the consideration of both material behavior and structural architecture."

Steven Trohalaki

Bio Focus

Molecular self-assembly controlled by different pathways

Molecular self-assembly is the process through which molecular building blocks organize themselves into supramolecular structures. Controlling the principles of molecular self-assembly opens the door to new materials with special properties, for example, self-repairing coatings. The properties of these materials are strongly influenced by the way the building blocks are assembled; a small difference in their organization can lead to very different properties. Peter A. Korevaar and colleagues at Eindhoven University of Technology in The Netherlands have succeeded in monitoring and controlling a molecular self-assembly process through different pathways.

As reported in the January 18 advanced online issue of *Nature* (DOI: 10.1038/nature10720), the research team uses a molecular building block whose assembly can be studied with time using circular dichroism: *S*-chiral oligo(p-phenylenevinylene) or SOPV. Molecules of this kind are frequently used in organic electronic devices, in which small differences in the morphology of the material lead to large differences in their properties. At the start of

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