A Little Glue Makes the Difference

SUMMARY: Using the same material, a spider can spin strands of silk that exhibit different properties. The secret behind the strands' varied degree of elasticity is a thin natural glue, creating both rigidity and flexibility in a single web. Scientists studying spider silk's qualities are hopeful about applications, given progress in genetic engineering.

PHOTOS BY FRITZ VOLLRATH

Radial threads are stiff, spiral threads stretchy.

Stretched between knotty tree trunks or wind-bent weeds, between sharp-edged rocks or fallen leaves, a spider's sticky web hangs taut, while the spider, cloistered within it, spins more silk and waits for dinner.

On the web also hangs each spider's survival. The web is a trap for catching food. It must be durable and resilient, recyclable, stiff enough not to sag, flexible enough not to snap against the strains of struggling prey, yet delicate enough to be nearly invisible.

To satisfy all of those requirements, the spider must be at once architect, engineer and manufacturer. The web must not only be carefully designed; the material with which it is made, an elastic thread, must be extraordinarily strong and light.

Spiders, of course, are not the only creatures working within such constraints. But their innate ability to meet specifications that human designers have yet to achieve has begun to attract the interest of scientists. According to two British researchers who have been studying the physical characteristics of spider webs, the silk used for their construction exhibits some "incredible properties."

"When it is wet, for example," says Fritz Vollrath, a research associate in the department of zoology at Oxford University, "it becomes exceptionally elastic. You can stretch it about 10 times its original length, and it will not lose its strength."

Consider, for a moment, what a bumblebee flying into a web looks like from a spider's point of view. "It's like a missile," says Vollrath. "It's an enormous, weighty mass moving at a very high velocity. In order to catch that missile, the spider's web must be able to absorb an awful lot of energy without snapping or falling apart. In fact it is often the case that only a few strands of silk have to absorb and dissipate all of the bee's energy of motion, bringing it from a high speed to a dead stop in a very short distance. The only way to do that is to use a thread that not only stretches very easily but also maintains its strength even when fully expanded."

To achieve this effect, nature has provided the spider with a clever trick, says Vollrath. "It wets down certain strands of its web with a watery glue, which not only makes the web very sticky but also makes it highly elastic."

The common garden spider, for instance, spins what is called an orb web, with the classic spiral pattern. This web contains two distinct types of silk fibers, each made of the same basic material but with very different physical characteristics. Stiff, dry radial threads emanate from the center of the web and provide the basic frame and structural support, like spokes in a bicycle wheel. On that frame lies a wet, sticky, stretchy silk that the spider lays down from the web's outer edge to its center, in a spiral pattern. It is the gooey so-called capture silk that traps prey, which the spider then eats along with the web itself.

Although the two types of fiber have entirely different properties, Donald T. Edmonds, a lecturer in the department of physics at Oxford University's Clarendon Laboratory, notes that the material is the same. "The difference is in the coating. The spider is able to modulate the springiness of the silk thread by the amount of watery glue it uses to coat the silk fibers. Somehow this wet coating is able to induce an incredible change of physical properties in one basic type of material."

Testing the silk's elasticity by stretching individual strands and then allowing them to contract, Vollrath and Edmonds found that the dry radial threads sagged when their fully stretched length was reduced by as little as 10 percent. In contrast, though, the wet capture threads could shrink by as much as 95 percent of their fully stretched length before they began to sag.

"The incorporation of the mechanical properties of the two types of silk (elastic and inelastic) into one web has obvious advantages," observe Vollrath and Edmonds in a recent report in the scientific journal Nature. "The tightly strung and stiff radial threads provide support for spider and prey, and transmit informative vibrations. On the other hand, the ability to maintain tension when hugely stretched and relaxed in rapid succession is essential to the coated capture threads, because it prevents single strands from touching and agglutinating when the web is buffeted and distorted by the wind. Moreover, it is important for the capture of prey that the capture threads can absorb the high kinetic energy of the insect's impact, and then entangle without offering any purchase which might aid a struggle to escape."

What especially intrigues Vollrath about these findings is that spider silk may turn out to be a material with a wide variety of applications, if it can be synthesized. "In terms of strength, it is similar to Kevlar, which is one of the strongest synthetic materials ever invented. However, if someone can find a way to produce silk the way a spider does, the process will probably be much less expensive than the one used to make Kevlar. The reason is that the spider produces silk very quickly using a small-scale cold process. It doesn't need much machinery."

During World War II, before synthetic

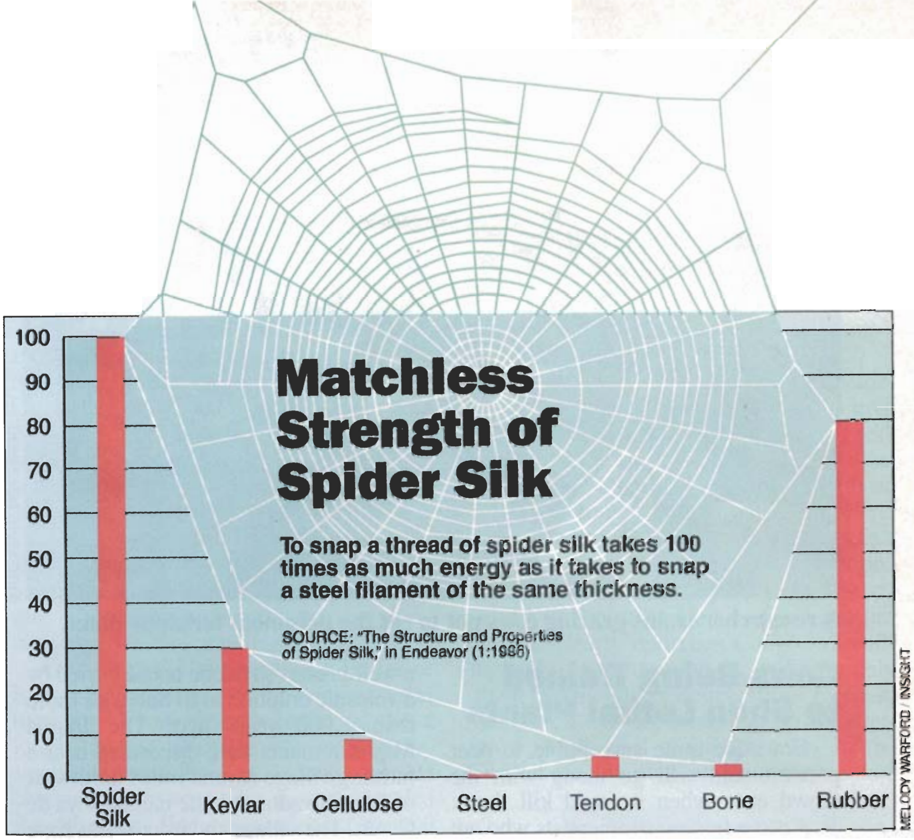
cloth came into wide use, fabric manufacturers had great interest in silk, as did scientists and military engineers, who saw it as the ideal fiber for making parachutes and the cross hairs in gun sights, owing to its fineness and lightness.

However, with the invention and large-scale production of synthetic fibers such as nylon and rayon, research into the uses and properties of silk decreased rapidly. For a time, the National Aeronautics and Space Administration showed an interest in spider silk as a material for making garments for space travel. But man-made threads won out, largely because of lower costs of production.

Today, though, with the rise of genetic engineering techniques, as well as an increasing demand for light, durable organic fibers, Vollrath sees a resurgence of interest in spider silk, both from a scientific and a commercial point of view.

One drawback of working with spider silk, says Edward Tillinghast, professor of zoology at the University of New Hampshire in Durham, is that a spider produces relatively small amounts of it during its lifetime. "Last year, for instance, I spent an entire summer collecting 500 milligrams of silk from several spiders. That's the same amount one silkworm produces in a day. In the near future, though, I suspect recombinant DNA technology will change these numbers. If someone can find a way to insert a spider's silk genes into bacteria, then the bacteria could churn out the stuff in rather high volumes."

Vollrath agrees. "Through genetic engineering," he says, "it may soon be possible to synthesize spider silk in big vats and produce it commercially. Some people are already working on this problem and are close to obtaining patents. The potential for applications is really quite enormous. Spider silk is much stronger than silkworm silk, the type used today. It is also stronger than nylon, rubber and even high-tensile steel, in terms of the energy necessary to break equivalent strands.



"Because steel is brittle it snaps fairly easily, whereas spider silk gives way," Vollrath adds. "Ounce for ounce, spider silk is much stronger than steel because of its light weight and flexibility. It takes 100 times more energy to break strands of spider silk than it does to snap steel threads."

Returning to the experience of a spider trying to catch a bumblebee in its web, Edmonds says that on a human scale it "would be something like trying to catch a jumbo jet with a large net just as it lands on a runway. Assuming that the plane is traveling about 100 miles per hour and the net is 100 yards in diameter, if we were to make a weblike net of spider silk, the radial support ropes would only have to be one inch in diameter, and the spiral capture ropes would only have to be one-half inch in diameter — that's how much energy spider silk can absorb. It really is quite amazing."

The spider's technique of wetting down part of its web demonstrates "a fascinating evolutionary adaptation," says Vollrath. "The fact that its silk becomes soft when wet could be a disadvantage. But instead, the spider turns it to his advantage.

"To an evolutionary biologist," he adds, "this adaptation demonstrates a very clever tinkering of nature."

— Richard Lipkin

The web's sag depends on the elasticity of its strands; those with a gluelike coating have more give and are less likely to sag.