# Spider Silk – Properties and Uses

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## Introduction

Researchers are always looking for and trying to develop new materials that are stronger, or lighter, or tougher than materials currently in use. One such material has been found, not in the laboratory, but in nature. That material is spider silk obtained from spider. Spider silk is also known as gossamer. Spider silk is an extremely strong material and is on weight basis stronger than steel. It has been suggested that a pencil thick strand of silk could stop a Boeing 747 in flight.

The silk is used by the spider for a lot of different uses. Constructing their webs, the production of egg sacs, wrapping in their prey, as a life line when jumping, or dropping to escape, for transferring semen from the abdomen to the male palp, in drag lines marked with pheromones, as a shelter in which it can retreat.

Silk is for more than 50% a polymerized protein called fibroine with a molecular weight of 200.000 - 300.000. When looking at silk at a molecular scale one can see that the proteins strands are regularly orientated.

## Properties

### Physical properties

1. **Length:** Continuous
2. **Fineness:** It is finer than the human hair (most threads are a few microns in diameter)
3. **Strength:** Spider silk is incredibly tough and is stronger by weight than steel. Quantitatively, spider silk is five times stronger than steel of the same diameter. It has been suggested that a Boeing 747 could be stopped in flight by a single pencil-width strand and spider silk is almost as strong as Kevlar, the toughest man-made polymer. The strength of a biological material like spider silk lies in the specific geometric configuration of structural proteins, which have small clusters of weak hydrogen bonds that work cooperatively to resist force and dissipate energy, researchers in Civil and Environmental Engineering have revealed.
   This structure makes the lightweight natural material as strong as steel, even though the "glue" of hydrogen bonds that hold spider silk together at the molecular level is 100 to 1,000 times weaker than the powerful glue of steel's metallic bonds or even Kevlar's covalent bonds. It is simple to see why spider silk is of such interest to materials chemists since new ultra-strong fibers based on the silk could be developed.

## Thermal properties

Spider silk is able to keep its strength below -40°C. The toughest silk is the dragline silk from the Golden Orb-Weaving spider (Nephilia clavipes), so-called because it uses silk of a golden hue to make orb webs.

## Elastic properties

The material is elastic and only breaks at between 2 - 4 times its length. In the figure given: a strand of a social spider, stegodyphus sarasinorum, is shown as normal size, stretched 5 times and 20 times its original length.

Spider silk is also especially ductile, able to stretch up to 40% of its length without breaking. This gives it a very high toughness (or work to fracture), which "equals that of commercial polyaramid (aromatic nylon) filaments, which themselves are benchmarks of modern polymer fiber technology."

## Types of Spider Silk and its Uses

The different types of silk produced by spider, each for a different purpose:

- Dragline silk are used to connect the spider to the web, as safety lines in case a spider should fall and as the non-sticky spokes of the web. Dragline silk is the strongest kind of silk because it must support the weight of the spider.
- Capture-spiral silk: Used for the capturing lines of the web. Sticky, extremely stretchy and tough.
- Tubiliform silk: male spiders weave sperm webs on which they deposit sperm and subsequently transfer it to their front palps, ready for placing on a females genital organs. Some species make a web and coat it with sex pheromones to attract a mate. Used for protective egg sacs. Stiffest silk.
- Aciniform silk: Used to wrap and secure freshly captured prey. Two to three times as tough as the other silks, including dragline.
- Minor-ampullate silk: Used for temporary scaffolding during web construction
- Swathing silk for the wrapping and immobilisation of prey.
- Webs for catching prey using sticky silk - it is elastic to prevent the prey from rebounding off the web. Shelters such as burrows or nests.
- Parachuting or ballooning which is used to aid the dispersal of young and to find new areas as a food source. Silk is released and is caught by the wind to lift the spider up into the air - flying spiders.

## Applications of Spider Silk

Engineers have suggested the uses for the strands in bulletproof vests, parachutes and fishing nets, report the Independent; however its main benefits could be seen in medicine, where the strands could be used as biodegradable sutures for internal wounds.

- Used for making artificial tendons and ligaments for supporting weak blood vessels.
- Manufacturing rip-proof, and light weight clothing.
- Making biodegradable bottles.
- Can be used in ropes, seat belts, and parachutes due to its tensile strength
- For making rust-free panels on motor vehicles or boats.
- Making bandages and surgical threads.

**Spinning Spider Silk via Biomimicry**

The spinning process evolved in spiders is highly specialized and complex. Many scientists have tried to mimic this system with little success. In attempting to produce a non-biological spinneret prototype, Nexia and its partners have focused on achieving the correct level of shear forces that trigger spider silk proteins to nucleate and form a consistent fiber.

In general, the spin dope, which contains spider silk protein, is optimized in concentration and chemical composition. The spin dope is then placed in a chamber, similar to a syringe, to push (extrude) the protein through a very small aperture into a solution bath, which extracts the water from the protein solution stream, thus forming a continuous fiber. The fiber's β-pleated sheets will be roughly aligned at this point. Once extruded from the "spinneret" the fiber is stretched or drawn in the bath, which functions to align further the proteins.

**Artificial Spider Silk**

Spider silk's properties have made it the target of industrial research efforts. It is not generally considered possible to use spiders themselves to produce industrially useful quantities of spider silk, due to the difficulties of managing large quantities of small spiders (although it was tried with Nephila silk). Compared with silkworms, spiders are aggressive and will eat one another, making it inadvisable to keep many spiders together in the same space. Other efforts have involved extracting the spider silk gene and using other organisms to produce the required amount of spider silk. In 2000, Nexia, a Canadian biotechnology company, was successful in producing spider silk protein in transgenic goats. These goats carried the gene for spider silk protein, and the milk produced by the goats contained significant quantities of the protein (1-2 grams of silk proteins / liter of milk). Attempts to spin the protein into a fiber similar to natural spider silk (what would be the biosteel) resulted to fibers with tenacities of 2-3 grams/denierr. The spider's highly sophisticated spinneret is instrumental in organizing the silk proteins into strong domains. Specifically, the spinneret creates a gradient of protein concentration, pH, and pressure, which drive the protein solution through liquid crystalline phase transitions, ultimately generating the required silk structure (which is a mixture of crystalline and amorphous biopolymer regions). Replicating these complex conditions in lab environment has proved difficult. Nexia used wet spinning methodologies which implied "squeezing" the recombinant silk-protein solution (BIOSTEEL) through small extrusion holes in order to simulate the behavior of the spinneret, but this was insufficient to replicate the exact properties of the native spider silk. Ultimately, Nexia currently continues research and product development with BIOSTEEL by collaborating with academic labs and companies that are willing to work with BIOSTEEL. Extrusion of protein fibers in an aqueous environment is known as 'wet-spinning'. "This process has so far produced silk fibers of diameters ranging from 10-60 μm, compared to diameters of 2.5-4 μm seen in natural spider silk."

**Fascinating Spider Silk**

Fundamentally, the spinning of spider silk represents a phase change from a solution into a solid thread; but the exact details of this process are largely unknown. The silk used by orb weaver spiders to spin the edges and spokes of their webs and to rappel away in the face of danger is made of two different proteins. The Munich team has now successfully used genetic engineering to produce one of the spider silk proteins of the European garden spider (Araneus daidematus).

While purifying the protein by dialysis, the researchers observed the separation of two different fluid phases. Whereas one phase consisted of protein dimers, the second consisted of oligomers—multiple protein units linked together. After the addition of potassium phosphate, a natural initiator of silk aggregation, the liquid could be pulled into threads. "It is clearly not a structural change in the protein, but rather the degree of oligomerization that is crucial for thread formation," concludes Scheibel.

The silk solution in the spider's silk gland has a very high protein concentration. This solution also contains a high concentration of sodium chloride, which suppresses oligomer formation. If the sodium chloride is removed, the proteins aggregate into oligomers.

In addition, the pH value also plays a crucial role in web production: within the silk gland, the pH is relatively high, but within the spinning duct it drops to a slightly acidic level. No phase separation was observed for the synthetic spider protein when the pH was maintained at an alkaline level. At high pH, the normally uncharged tyrosine groups in the protein are deprotonated, which gives them a negative charge. This charge weakens the interactions between the hydrophobic, lipophilic regions of the proteins, which are necessary for oligomerization.

"Our insights form a foundation for the establishment of an effective spinning process for the production genetically engineered spider silk," hopes Scheibel.

**Method of Reinforcing a Fiber with Spider Silk**

The subject invention is a method of reinforcing a fiber utilizing *Nephila clavipes* spider silk. The method comprises the steps of suspending the fiber between the first support and the second support wherein the suspended fiber defines a central axis and positioning a silk line dispensing device near the fiber aligned with the central axis for attaching a silk line to the fiber. A *N. clavipes* spider is positioned directly onto the fiber, and, once the *N. clavipes* spider is agitated, it excretes large sticky discs or attachment discs from its pyriform gland to attach its silk line to the fiber. The method is characterized by rotating the fiber about the central axis to helically coat the fiber with the silk line for increasing the strength of the fiber. The fiber is wound around a spool and directly incorporated into a fabric.

**The Effect of Spinning Forces on Spider Silk Properties**

A new forced silking procedure has been developed that allows measurement of the low forces involved in the silking process and, subsequently, retrieval and tensile testing of the samples spun at the measured silking forces. A strong correlation between silking force and tensile behaviors of spider silk has been established. Fibres spun at high silking force-compared with the conventional yield stress-are stiff and show stress–strain curves previously found in forcibly sulked fibres. By contrast, fibres spun at low and very low silking forces are more compliant, and their tensile behaviors corresponds to that of fibres naturally spun by the spider or to fibres subjected to maximum super contraction, respectively. It has also been found that samples retrieved from processes with significant variations in the silking force are largely variable in terms of force–displacement curves, although reproducibility improves if force is re-scaled into stress. Fibres retrieved from processes with constant silking force show similar tensile properties both in terms of force–displacement and stress–strain curves.

**Conclusion**

The researchers and their companions are trying their level best to produce extemily advanced quality of synthetic spider silk. With all the work being done the silk synthetic spider could quite be possibly to produce in mass production in the near future for daily use. The synthetic spider silk would be used for the strands in bulletproof vests, parachutes and fishing nets, report the Independent; however its main benefits could be seen in medicine, where the strands could be used as biodegradable sutures for internal wounds.

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