

Spider Silk: Structure and application

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DOI: 10.29322/IJSRP.10.04.2020.p10055

<http://dx.doi.org/10.29322/IJSRP.10.04.2020.p10055>

Abstract- the nature is full of mysteries and engages the full minded persons and scholars to itself throughout the world, the nature presents these mysteries on a wide variety of events and inside the complex world of different creatures. There are millions of creatures that have individually strange characteristics and life condition. There are things that are in-depth scientific and debate-raising facts with these creatures which most of them are hidden and need to be discovered. Spider silk and webs are one of this mysteries. Due to low rate of degradability, toughness, elasticity and biosynthetic characteristics, the spider silk evaluated to have many scientific uses and application. Hence here in this paper, I a bit more want to discuss on spider silk uses and application on some of life-related matters. And a bit on its structure and specifications.

Index Terms- Amino acids, Fiber, Mystery, Nature, Spider, Spider web, Web

I. INTRODUCTION

Spider is an incredible and extraordinary creature, and can be found almost everywhere in the world, such as industrial and residential areas, gardens, jungles and so on. Apparently for most of the people it looks creepy and horrific. But may be a hidden hope and a breakthrough for many science fields including medicine and environment. According to the scientist there are around 40000 species of spiders consisting a couple of groups and families. This creature has proved to be an excellent silk producer among other silk-produced insects. Inside a spider's body,

thread is stored as a highly concentrated liquid. It transforms to a solid thread when it leaves the body [2]. This silk is made of a fiber protein called fibroin, this protein is full of Amino acids of alanine $\text{CH}_3\text{CH}(\text{NH}_2)\text{COOH}$ and glycine which is produced by a special gland on its abdomen called spinneret. [5]

Spiders use many form of silks from an array of structures, which range from simple life lines to shelter for moulting, from egg sacs, webs and to ballooning. Orb-web spinning spiders produce different types of multifunctional and high performance fibers. This nature production has mechanical, biomechanical and biochemical properties which is unique in nature.

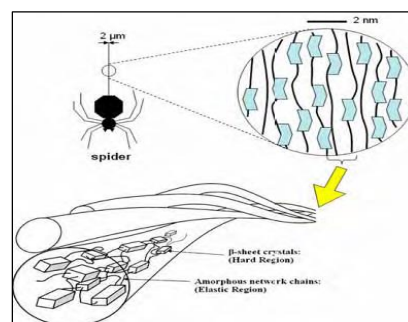


Fig. 1. Schematic representation of the hierarchical microstructure of spider silk (adapted from Elices [2]).

Biodiversity, elasticity, toughness, strength and flexibility in spider-produced silk has made it an important factor to open a new track for further development of technology in most fields of the applicable sciences.

Values for the stiffness, strength, extensibility and toughness of a two species spider silks, along with values

for other biomaterials and selected man-made materials, are presented in Table 1. [1]

II. USAGE AND APPLICATION

Let's talk about spider. To most people, they are creepy, they are gross, and they are... possibly a key to medical and industrial breakthroughs? Well not the spider themselves, but their silk! Spider silk has many potential applications in construction and medicine. It is stronger than steel and more elastic than a rubber band.

Spider silk has outstanding mechanical properties despite being spun at close to ambient temperatures and pressures using water as the solvent. The spider achieves this feat of processing by judiciously controlling the folding and crystallization of the main protein constituents, and by adding auxiliary compounds, to create a composite material of hierarchical structure [6].

A common garden spider can produce as many as seven types of silk, each made up of different sequence of proteins, in recent years scientists have suggested using spider silk to construct products as diverse as biodegradable water bottles, papers that cannot be torn, and even flexible bridge suspension cables! Think about that for a moment: the bridges of the future being suspended by the spider silk! Well, sort of. The spider silk would actually be mixed in with other materials to make something like an alloy. For example, researchers were able to meld spider silk and human skin in to Spiderman-like body armor. The hybrid skin was able to repel a slow-moving bullet fired from a 22-caliber rifle. If scaled up, spider-silk body armor could be three times stronger than Kevlar [2].

At one time, spider silk was commonly used as thread in optical devices such as telescopes, microscope and microscopic rifle sights. Some companies are trying to create airbags from spider silk composites. Instead of blasting you back in your seat, a spider silk airbag could envelope you, in the same way a web does, and the silk could absorb the force of impact. Virtually nobody has had a sufficient amount of spider-silk material to make a full-scale test of these product ideas. [2] Also it was reported that the web of *Nephila* was used by the

fisherman of the Indo-Pacific Ocean to catch small fish. [4]

Professor Gors Makenli and his colleagues inspiring from spiders silk was able to produce polymeric nano composites in Science Institute of Masachoset in 2007, which had a high elasticity and strength, these material are applicable in medical purposes and producing textile which easily cannot be torn [5].

We use spider silk also as additives in cosmetic products such as the shampoos, soaps, creams and nail varnish, enhancing the brightness, and or toughness of the products. Furthermore spider silk fibers could be applied in technical textiles (used, for example, in parachutes and bulletproof vests) which demand high toughness in combination with thinness [4]. And due to posing incredible specifications and characteristics, there are many other uses and application of spider silk. The following separately we will discuss the application of spider silk in the field of medical and environment.

1. Spider Silk and Medical Application

On the account of the combination of excellent mechanical properties, biocompatibility and slow biodegradability, and on the more medical side of things spider silk has found tremendous application in bio medical fields, such as tissue engineering and other medical fields. It can be used for growing artificial skin for burn victims. The silk's strength, flexibility, and slow biodegradability may make it an ideal material for growing skin and healing wounds [2]. Silk has been used most extensively as sutures for wound ligation and became the most common natural suture surpassing collagen (Catgut or Chromic Catgut TM, cross- linked collagen) used in the biomedical industry over the past 100 years.

In general, sutures should be strong, handle easily, and form secure knots. Sutures require the following characteristics for general surgical applications [3].

Spider silks have been used as bandages for centuries. Modern science has simply found ways to increase its efficiency, as well as discovered more of its amazing capabilities. In addition to providing a good scaffolding

on which to build skin, spider silk appears to aid in the regeneration of other parts of the body, such as neurons and blood vessels. Some types of spider silk may even have antimicrobial properties! Many surgeons use the thread from silk worms to stitch wounds back together, but spider threads are even thinner! That is important for eye and nerve surgery, where saving space is incredibly important. [2]

Several studies have shown that some of bisphosphonate peptides that have antibacterial activity could be found in the spider silk. Evaluated the antimicrobial activity of the silk of the spider *Pholcus phalangioides* against food born bacterial pathogens.

In addition, venoms of spider have been evaluated for the treatment of the cardiac arrhythmia, Alzheimer's disease, and erectile dysfunction. Carpathian mountain dwellers used the tube of silk produced by a spider species (*Athyus*) to cover their wounds and the silk reportedly facilitate the healing of the wounds because of its antiseptic properties. Also because the silk is rich in vitamin K, it's considered to be effective in blood clotting. [4] And still there are uses and practical application medical and biomedical fields need to be discussed in other science papers.

2. Spider Silk and Air Pollution

Combustion gases are much more harmful to people than pollutants deriving from the industry, because they spread in higher concentrations, on lower heights in the direct vicinity of people. Air pollution causes annually about 6% of all recorded fatal cases. The pollution coming from transport is responsible for half of them. [8]

The most dangerous are benzene, polycyclic aromatic hydrocarbons (PAH), dust and heavy metals. Dust is a serious threat. Coal particles have very high absorption capacity and therefore diverse toxic substances settle easily on their surface, including carcinogenic hydrocarbons and heavy metals. Dust participates in transporting them inside the human body. It irritates eyes, skin and respiratory tract (pneumoconiosis). Diesel engines are main source of dust emission [8].

As spider webs absorb air pollution from the environment, they can be useful indicators of air quality.

The advantages of application of spider webs are as follows: low cost of samples collection, availability of the research material, secluded location preventing their destruction by weather conditions (falls, wind, snow) and people, noninvasiveness of studies (no need of killing animals), easy collection of samples. Moreover, studies conducted so far show that cumulative ability of webs is an additional advantage. Such ability, being a consequence of its chemical structure, gives a unique opportunity to assess an air pollution level in a long-term period, contrary to the classic measurements which could only deliver information about the temporary state of the environment. Additionally, measurement of concentrations of pollutants is usually carried out with expensive and inconvenient equipment (large-sized and noisy apparatus).

On the opposite, webs collection from tunnel walls is fast and enables one to study a long-term influence of pollutants only by single examinations (e.g. 7 or 30 days).[8]

Zumudzki and Laskowski (2012) studied the biodiversity and future of spider communities along a metal pollution gradient as well, and concluded that spiders community may be attracted by the heavy metals not only directly but also by indirect effect of pollutants. The level of heavy metal in spider web can be used for both quality control and also for determination of environmental contamination or pollution. Spider web has been demonstrated as effective indicator of heavy metals attributed to particulate emission. Spider cobweb have also been used for the monitoring of pollution in industrial and residential areas. And spider have been used as bio control agent in reducing pollution of insect's pests on farmlands. (Hose et al 2002) in most developing countries, monitoring pollution may be too expensive because of the economic situation. If the instrument for monitoring is available, handling and maintenance may pose a problem. Because the maker may not take in to consideration the weather condition of the country, therefore there is a need to look for inexpensive ways of monitoring trace metals in our environment. [8]

Now for all scientist out there who are not too fond of insects at all, there is still hope! So the next time you are about to squish a spider, take a moment to appreciate

one of the nature’s most incredible creatures. And may be consider sparing its life; it might just save yours one day. [2] Some benefits and concerns of silk are detailed in Table 1 below.

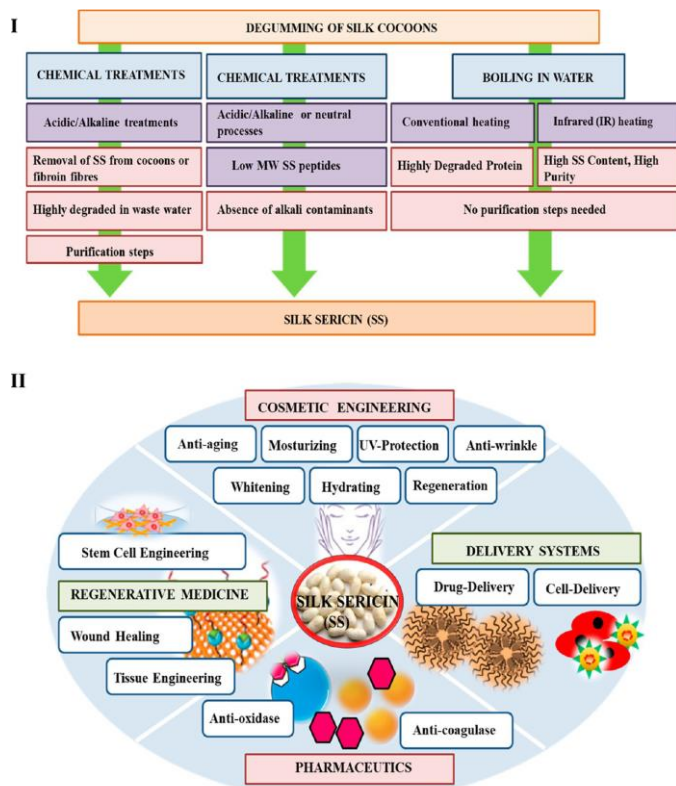


Figure 2. (I) Different methods of obtaining silk sericin from cocoons. (II) Biomedical applications of silk sericin.[9]

III. CONCLUSION

Spiders are incredible creatures, and all the issues related to the spiders silk are really amazing, the spider silk demonstrated to have strength, elasticity, toughness biochemical properties and slow biodegradability characteristic. The silk with all said properties have a full range and outstanding usage and application. It still is being analyzed and evaluated in more detailed, as a result there would be a lot of fields that the spider silk can elaborate theme.

Spider silk will make us able to have more sufficient and precise eye and nerve surgery; modern, strong and suspended bridges; micro scale and Nano scale machineries and robots to have a discovery path inside vessels and complicated structures of human body, for further exploration and analysis of our body. Taking advantages from spider silk, our environment will experience more freshness and would present a clean breath for everyone, since the determination and monitoring of air pollution would be easier and cost effective and many other potential application. In all these development and provocative approaches, spider silks would have been playing a key and remarkable role continually.

We speak about around 40000 of spider species composed of a variety of groups and families, each of which produces silk that poses their individual behavior, characteristics, synthesis and structures. Depending to these, a major prospection come to our mind for a vast field of researches and explorations in the coming future, which would have changed the track of our innovation. Then it is for us to consider a moment for appreciation of spiders. At the conclusion scientist, scholars and researchers should seek every available opportunities to find out, what else is behind the creating of this incredible and strange creature to be discovered and put to the service of humanity.

IV. APPENDIX

Table 1
 Benefits and concerns with the use of silks for biomedical applications [7]

Benefits

Novel mechanical properties of some silks that are superior to any other natural fiber and rival many high performance fibers

Natural fiber with a long standing history of use in clinical applications

The ability to process silks in aqueous solutions for subsequent formation of films and other material formats, with relatively simple insolubilization via exposure to alcohols and other environmental factors

Easily chemically modified with surface decorations, such as adhesion sites or cytokines, due to the availability of amine and acid side chains on some of the amino acids

Genetically tailorable composition and sequence to moderate specific features, such as molecular weight, crystallinity, solubility

Slow rates of degradation in vitro and in vivo, this is particularly useful in biodegradable scaffolds in which slow tissue ingrowth is desirable

No known risk of bioburden

Concerns

Adequate removal of contaminating sericin from silkworm silk to avoid biocompatibility problems

Slow degradation of crystalline (β-sheet) regions

Aborted proteolytic attack by macrophages and giant cells leading to encapsulation and the formation of a granuloma

Potential sensitization to silk fibroin resulting in an allergic response upon exposure to the biomaterial

Table 2.
 Tensile mechanical properties of spider silks and other materials
 (The Journal of Experimental Biology 202, 3295–3303)

Material	Stiffness, (GPa)	Strength (GPa)	Extensibility	Toughness (MJ m ⁻³)	Hysteresis (%)
Materials					
<i>Araneus MA silk</i>	10	1.1	0.27	160	65
<i>Araneus viscid silk</i>	0.003	0.5	2.7	150	65
<i>Bombyx mori cocoon silk</i>	7	0.6	0.18	70	
<i>Tendon collagen</i>	1.5	0.15	0.12	7.5	7
<i>Bone</i>	20	0.16	0.03	4	
<i>Wool, 100%RH</i>	0.5	0.2	0.5	60	
<i>Elastin</i>	0.001	0.002	1.5	2	10
<i>Resilin</i>	0.002	0.003	1.9	4	6
<i>Synthetic rubber</i>	0.001	0.05	8.5	100	
Nylone fibre	5	0.95	0.18	80	
Kevlar 49 fibre	130	3.6	0.027	50	
Carbon fibre	300	4	0.013	25	

High-tensile steel	200	1.5	0.008	6
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V. REFERENCES

- [1] J. M. Gosline, P. A. Guerette, C.S. Ortlepp and K. N. Savage, "The Mechanical Design of Spider Silks: From Fibroin Sequence to Mechanical Function" *The Journal of Experimental Biology* 202, 3295–3303 (1999)
- [2] Youtube/ Science Nature Page FB.com/ Sciencenaturepage
- [3] Gregory H. Altman, Frank Diaz, Caroline Jakuba, Tara Calabro, Rebecca L. Horan, Jingsong Chen, Helen Lu, John Richmond, David L. Kaplan, "Silk-based biomaterials" *Biomaterials* 24 (2003) 401–416
- [4] Agbaje Lateef, Sunday A. Ojo and Joseph A. Elegbede "The emerging roles of arthropods and their Metabolites in the green synthesis of metallic Nanoparticles DOI 10.1515/ntrev-2016-0049
- [5] Hamid Reza Tahib, Ali. Ebrahimi. "A Glance to Nano Technology". Art and Cultural Institute of Dibagaran. Tearan.
- [6] Fritz Vollrath & David P. Knight, "Liquid crystalline spinning of spider silk"
- [7] Gregory H. Altman, Frank Diaz, Caroline Jakuba, Tara Calabro, Rebecca L. Horan, Jingsong Chen, Helen Lu, John Richmond, David L. Kaplan, "Silk-based biomaterials" *Biomaterials* 24 (2003) 401–416
- [8] Justna Rybak, Izabela Sowka, Anna Zwozdziak, "Preliminary Assessment of Use of Spider Webs for the Indication of Air Contaminants". *Journal of Environment Protection Engineering*, (2012)
- [9] Shreya Mehrotra, Dimple Chouhan, Rocktotpal Konwarh, Manishekhar Kumar, Praveen Kumar Jadi, and Biman B. Mandal "Comprehensive Review on Silk at Nanoscale for Regenerative Medicine and Allied Applications" *pubs.acs.org/journal/abseba* (2019)

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