

Spider Silk Applications: A Comprehensive Review of Biomedical, Textile, And Emerging Functional Uses

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Abstract—Spider silk is an extraordinary natural protein fiber recognized for its unique combination of high tensile strength, elasticity, toughness, biocompatibility, and biodegradability, making it a highly promising material across multiple scientific and engineering domains. Historically used for rudimentary medical applications, recent advances in biotechnological production (e.g., recombinant proteins) and material design have expanded its potential. This review synthesizes current research on spider silk applications in biomedical engineering, textiles, materials science, and emerging technologies, explores production approaches, and highlights challenges and future directions.

Index Terms—Silk, Spider, Tensile Strength, Textile

I. INTRODUCTION

Spider silk is one of the most remarkable natural biomaterials known; attracting sustained scientific interest due to its exceptional mechanical, biological, and functional properties. Produced by specialized abdominal glands of spiders, silk is primarily composed of high-molecular-weight fibrous proteins known as spidroins, which are organized into hierarchically structured fibers. This unique molecular architecture endows spider silk with an extraordinary combination of high tensile strength, elasticity, toughness, and resilience, often surpassing many synthetic fibers such as nylon, Kevlar, and steel on a weight-to-strength basis. Unlike most biological materials, spider silk exhibits simultaneous strength and extensibility, allowing it to absorb large amounts of energy without breaking. Additionally, spider silk is biocompatible, biodegradable, non-toxic, and minimally immunogenic, making it particularly attractive for biomedical and biotechnological applications. Historically, natural spider webs were used for wound dressing and hemostasis in traditional

medicine, indicating early recognition of their medical potential. Modern research has expanded these traditional uses into advanced applications such as surgical sutures, tissue engineering scaffolds, drug delivery systems, and regenerative medicine.

Beyond biomedical uses, spider silk has gained prominence in materials science and engineering due to its lightweight nature and high durability. Its potential applications include high-performance textiles, protective clothing, aerospace composites, and environmentally sustainable alternatives to petroleum-based polymers. Moreover, recent studies have highlighted spider silk's responsiveness to environmental stimuli such as humidity and temperature, opening new avenues in smart materials, soft robotics, sensors, and actuators. Despite its outstanding properties, large-scale utilization of natural spider silk remains limited due to biological constraints, including spiders' territorial and cannibalistic behavior, which prevents mass rearing. Consequently, significant research efforts have been directed toward recombinant production of spider silk proteins using genetically engineered bacteria, yeast, plants, insects, and even transgenic animals. Advances in synthetic biology, protein engineering, and fiber-spinning technologies have brought spider silk-based materials closer to commercial viability. Given the rapid expansion of interdisciplinary research on spider silk, a comprehensive understanding of its properties, production strategies, and application potential is essential. This review aims to critically examine the diverse applications of spider silk, with particular emphasis on biomedical, textile, industrial, and emerging technological fields. Additionally, it highlights current challenges in production and processing, while discussing future prospects for

spider silk as a next-generation sustainable biomaterial.

II. PROPERTIES UNDERPINNING APPLICATIONS:

Spider silk's defining traits include:

- Exceptional tensile strength and toughness
- High elasticity
- Biocompatibility and biodegradability
- Processability into fibers, films, hydrogels, and composites

These properties arise from hierarchical protein structures of spidroins that can be tailored via recombinant expression or surface engineering.

III. BIOMEDICAL APPLICATIONS

Wound Healing and Sutures

Spider silk's biocompatibility and strength make it suitable for surgical sutures that reduce immune response and support rapid healing. Historically, spider webs were used for wound-care due to coagulant properties, and modern work builds on that concept with advanced biopolymer sutures.

Tissue Engineering and Regenerative Medicine

Silk matrices and scaffolds serve as structural support for cell growth and tissue regeneration. Applications include scaffolding for bone, cartilage, ligaments, nerve, and vascular tissues. Recombinant spider silk hydrogels and 3D constructs support cell adhesion and differentiation, making them promising for complex tissue engineering.

Drug Delivery Systems

Spider silk proteins can be processed into films, nanoparticles, and hydrogels with tunable release properties, enabling localized and controlled drug delivery with reduced side effects.

Customized Biofunctional Materials

Research shows that biochemical and surface structuring of spider silk coatings can promote cell-specific responses, which could be exploited for tailored implant surfaces or regenerative scaffolds.

IV. TEXTILE AND MATERIAL APPLICATIONS

High-Performance Fibers

Spider silk's high strength and lightweight nature make it an attractive material for performance apparel, protective clothing, and military uses (e.g., bullet-resistant vests) once scalable production is achieved.

Sustainable and Biodegradable Textiles

Bioengineered spider silk fabrics offer a biodegradable alternative to synthetic textiles like nylon and polyester, emphasising sustainability and low environmental footprint.

Composites and Structural Materials

Spider silk can reinforce biocomposites, improve lightweight structures, and potentially be used in automotive and aerospace components where high strength-to-weight ratios are critical.

V. EMERGING AND FUTURE APPLICATIONS

Actuators and Robotics

Spider silk's sensitivity to environmental humidity and its capability to contract and twist suggests potential use in humidity-driven actuators and robotic muscles, broadening its application in soft robotics and smart materials.

Biodegradable Plastics and Packaging

Due to biodegradability and strength, spider silk proteins could inform the design of environmentally friendly plastics and packaging materials, helping reduce reliance on petrochemicals.

Biosensing and Electronics

Ongoing research also explores applications in flexible sensors, bioelectronic devices, and energy storage components leveraging silk's mechanical and biological traits (e.g., bioactivity and processability).

Production Challenges and Outlook

Natural spider silk production is limited by spider biology, so researchers have turned to recombinant production in bacteria, yeast, goat milk, and engineered organisms to mass-produce spidroin proteins. Challenges remain in replicating the natural spinning process and achieving cost-effective manufacturing at industrial scales.

Emerging strategies like genetic engineering, synthetic biology, and advanced polymer processing promise to expand feasible applications further.

VI. CONCLUSIONS

Spider silk stands at the frontier of biomaterials and multifunctional materials research, with compelling applications spanning biomedical devices, high-performance textiles, sustainable materials, and smart systems. While production challenges remain, continued interdisciplinary innovation positions spider silk as a transformative material for future technology.

REFERENCES

- [1] M. Branković, F. Živić, N. Grujović, I. Stojadinović, S. Milenković, and N. Kotorčević, “Review of spider silk applications in biomedical and tissue engineering,” *Biomimetics*, vol. 9, no. 3, p. 169, 2024, doi: 10.3390/biomimetics9030169.
- [2] B. Bakhshandeh, S. S. Nateghi, M. M. Gazani, Z. Dehghani, and F. Mohammadzadeh, “A review on advances in the applications of spider silk in biomedical issues,” *International Journal of Biological Macromolecules*, vol. 192, pp. 258–271, Dec. 2021, doi: 10.1016/j.ijbiomac.2021.09.201.
- [3] V. Shravanilakshmi, A. S. Tejaswini, G. V. Shwetha, K. Aramani, G. S. Sindhu, and M. K. Veenita, “Spider silk as a next generation biomaterial: Advances in biomedical and tissue engineering applications,” *Archives of Current Research International*, vol. 25, no. 8, pp. 796–811, 2025, doi: 10.9734/acri/2025/v25i81460.
- [4] E. Kiseleva, P. Krivoshapkin, and E. Krivoshapkina, “Recent advances in development of functional spider silk-based hybrid materials,” *Materials Chemistry and Physics*, 2020.
- [5] J. M. Gosline, M. W. Denny, and M. E. DeMont, “Spider silks and their applications,” *Trends in Biotechnology*, vol. 26, no. 5, pp. 244–251, 2008, doi: 10.1016/j.tibtech.2008.02.006.