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Silk Fiber: A Potential Fiber In Polymer Composite Material: A Brief Review

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Abstract

Silk is an ancient material used in textile industry as a lavish handloom. It has become a symbol of status in many developed countries. Due to the presence of various proteins and amino groups, its functionality in medical application such as suturing material, scaffolds, nerve generation, tissue engineering is highly praised. Besides, its importance in agriculture has been observed as a vital one. However, the strength of silk fiber has been commendable to reinforced it in polymer matrix for the development of strong composites. The journey of the present article starts with some basic information of silk containing its physical properties. Then, the types of silk cultivated were summarized. In the last section, the composites based on silk were discussed for physical, mechanical and wear behaviour.

Introduction

Composite materials are now a days greater in demand due to its high stiffness, low cost, manufacturing cost, and ease of availability. It is sustainable, hence preferred in most of the sectors to replace non-eco-friendly material [1, 2]. Composites are fabricated extensively with the help of carbon, kevlar or polymeric fiber and have been showing their worth in the last few decades with magnificent products ranging from aeroplane to sea ship. However, the environmental damages have reached at alarming state due to the carbon pollution taking place during the processing of these fibers. Various natural fibers have been utilized in place of synthetic fiber to lower down the environmental damages as caused by synthetic fibers [3]. But the resulted natural fiber composite could not match the mechanical properties of synthetic fiber polymer composites due to the inherent lower strength because of the lignocellulosic nature of natural fiber [4]. Here comes silk fiber in picture, one of the strongest natural fibers as strong as steel and is only natural fiber comes in single filament. Its bonding with synthetic and natural polymers has shown very much prominent results due to the formation of strong inter mechanical bond between the fiber and polymers [5]. It is widely considered as a suturing material in biomedical engineering due to its resorbability and bio degradability [6]. Its inclusion in polymer matrix made it strong as well as biodegradable that resulted in sustainable composite. The reinforcement of silk fiber in polymer is carried out in many ways such as short fiber, long fiber, in the form of mat and randomly oriented. It has been hybridized with many natural and synthetic fiber to achieve a strong bond among the fiber and matrix [7]. Structure of silk consists of outer layer of sericin which poses difficulties in making strong bond between Silk and matrix due to its slippery surface. This outer surface is required to be removed before reinforcing it to polymer [8] The above discussion regarding silk fiber is very helpful while fabricating a novel silk fiber reinforced polymer composite.

Types of Silk

Silk fiber is cultivated around the globe in different forms or types. One of the famous types of silk is bombyx mori Mulberry silk (figure 1(a)) which is mostly famous as a Chinese silk. Among the whole family of silk, Mulberry accounts for 90 % of stake. China, Japan and Korea are the major producer and exporter of this silk. For the preparation of mulberry silk, silkworm is killed to get the long fiber. It is highly soft and fine in texture. It is lustrous in appearance and required very intense preparation. An important type of silk known as wild silk also called Tasar silk. It is mainly cultivated in south east Asia mainly India, Sri Lanka, China and Japan. It is having colour ranging from light brown to lustrous brown. It is higher in modulus but weak in strength than Mulberry silk (figure 1 (b)). It possesses very high tenacity among all the silk fibers. The silkworm in India and Sri Lanka feeds Terminalia leaves whereas silkworm of China and Japan feeds nourished and Oak leaves that is why it is also named as Oak silk in some places

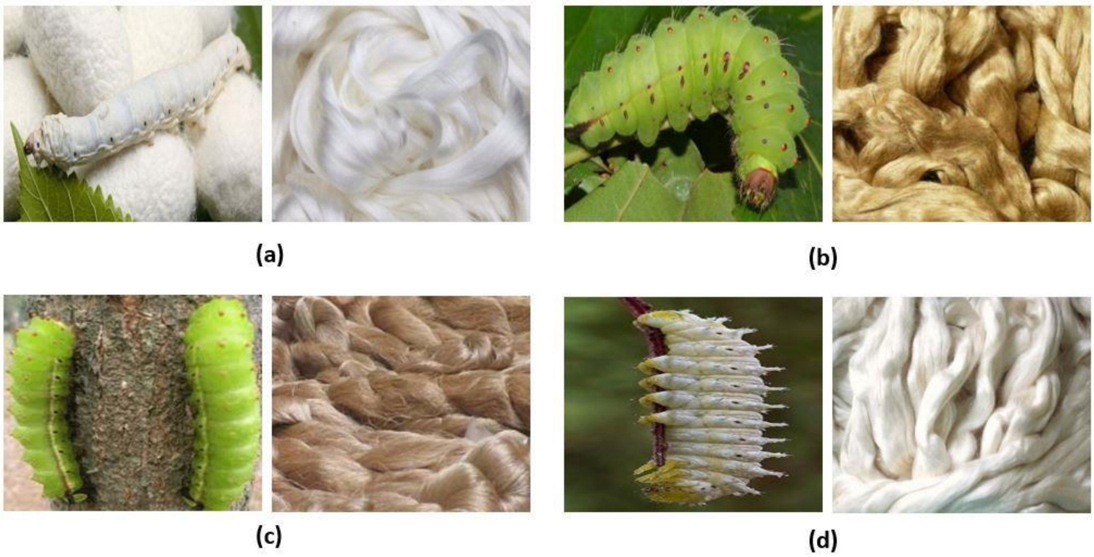

Figure 1. showing (a) Bombyx mori silkworm and its fiber, (b) Tasar silkworm and its fiber, (c) Muga silkworm and its fiber and (d) Eri silkworm and its fiber

The domestication of Antheraea assamensis is practiced in many places mainly in east Asia USA, South Africa and Europe for the cultivation of Muga silk. It is yellowish in colour with golden lining as shown in figure 1 (c). It is highly durable with fine texture and glossy looks. It is highly durable and has good longevity. The silk obtained by domesticating the Philosamia ricini silkworm is known as Eri silk as shown in figure 1 (d). In the process of development of Eri silk, the silkworm is not killed but kept alive to develop as a full moth so that it can live a complete life in the cocoon. The Eri silk is obtained by the destruction of fully developed moth in the cocoon.

Literature on silk based composites

Matrix	Reinforcement type	Manufacturing technique	Observations	Reference
PC	3 % Silk Waste, untreated 2.5 mm long	Double-screw extruder	Enhanced the modulus of elasticity, shore hardness, glass transition temperature and melt flow index but yield strength, tensile strength, impact strength and percentage elongation decreases Modulus of elasticity = 696.8 MPa, Yield Strength = 38.1 MPa, Tensile strength = 38.8 MPa, % elongation = 3.3 Hardness shore (D)= 79 Izod impact strength = 3.6 KJ/m^2, Melt flow Index = 41 g/10 min,	9
MPAHC	0.5 % Silk, 2 mm long soaked in nitric acid (1:10) solution for 2 hours.	Sol-gel followed by mechanical mixing	Splitting strength and Vickers hardness number increases Splitting strength = 14.9 MPa, Vickers hardness = 22.2 GPa	10
PLA	5 % Silk, oven dried 5 mm long	Hakke MiniLab twin-screw micro-extruder	Stiffness and ductility were enhanced and the faster rate of biodegradation was observed	11
PBS	30 % Silk, conventional oven dried 10 mm long	Mechanically mixed in kitchen mixer	Degradation rate slowed down by the inclusion of silk in the PBS. Initial storage modulus reduced by 20 % for 1000 hours of observation	12
Silk protein (fibroin)	Li-Br treated 25 % aligned Bombyx mori silk fiber	Solution casting process	Noteworthy enhancement in the breaking stress, elongation at break and compression modulus. Tensile modulus reduced by	13

			25%. Li-Br treatment of silk fiber greatly enhanced the fiber- matrix adhesion. Breaking stress= 151 MPa, % breaking elongation = 27.1, Tensile modulus = 2.8 GPa, Breaking energy= 23.2 KJ/m^2, Compression modulus= 1.1 GPa	
Cellulose- 12 % urea-7 % NaOH	5 % waste silk fiber of 1 mm length treated with 5 % NaOH solution	Matrix was prepared by mixing of cellulose in NaOH-Urea solution and then composite was prepared by casting method	Improvement in tensile and tensile modulus was observed whereas elongation at break reduced. Thermal analysis revealed that at temperature above 350^0 C, the weight percentage of silk fiber reduced in higher percentage as compared to cellulose matrix. Tensile strength = 59.1 MPa Tensile modulus= 5.2 GPa, % Elongation at break = 2.5	14
PLA	5 % short silk fiber of 5 mm length	Injection moulding	Young's modulus and flexural modulus enhances while tensile strength, flexural strength and strain at break decreases. Biodegradability suggested that inclusion of silk fiber accelerated the biodegradation rate of pure PLA. Youngs modulus = 4.08 GPa, Tensile strength = 70.6 MPa, Strain at break = 3.8 %, Flexural modulus = 4.06 GPa, Flexural strength = 97.41 MPa	15

PP	Untreated 20 % silk fiber mat	Compression moulding	Tensile strength, tensile modulus, bending strength, bending modulus, impact energy improves by the reinforcement of silk fiber however elongation at break decreased drastically. Gamma radiation at 5 Kilo Grays produced best mechanical properties. Tensile strength = 55.1 MPa, Tensile modulus = 0.78 GPa, Elongation at break = 18 %, Bending strength = 56.3 MPa, Bending modulus = 3.45 GPa, Impact strength = 17 KJ/m^2, Shore Hardness (D) = 97	16
gelatin	20 % silk fiber mat	Heat press	Mechanical properties increased except elongation at break. Composite degrades very rapidly and lost half of its initial weight within 24 hours of degradation test in soil. Tensile strength = 44.5 MPa, Tensile modulus = 0.65 GPa, % Elongation at break = 8.2 Bending strength = 63 MPa, Bending modulus = 3.7 GPa, Impact strength = 5.1 KJ/m^2, Hardness shore (A) = 96	17
PLA	5 % Silk	Melt extruder followed by injection moulding	Coefficient of linear expansion of the composite reduced by 28 % as compared to neat PLA. Degraded composite exhibited lower storage modulus and tan δ but higher glass transition temperature. Greater amount of crystallinity was observed for degraded composite. Composite was viewed as	18

			potential bone fixation biomaterial	
Wheat protei n isolate	5 % Silk fiber	Conventional casting	Mechanical properties were enhanced but elongation at break reduced. Potential material for packaging for medicine and food. Tensile strength = 28.4 MPa, Tensile modulus = 1.6 GPa, % Elongation at break = 3.4	19
Recycl ed Polya mide-6	3 % silk fiber	Extrusion followed by injection moulding	Modulus of elasticity = .69945 GPa, Yield strength = 63.28 MPa, Tensile strength = 64.38 MPa, % Elongation = 6.61, Hardness (D) = 71.75, Impact strength = 4.7 KJ/m^2, Melt flow index = 17.9 g/10 min	20
Epoxy	36.2 % non-woven silk fiber	Hot pressing and vacuum driven resin transfer moulding	Tensile strength = 60 MPa, Flexural strength = 143 MPa, Tensile strain = 1.3 % Flexural strain = 3.4 %, Interlaminar shear strength = 31 MPa, Impact strength = 16 KJ/m^2,	21
Epoxy	45.2 % plain woven silk fiber	Hot pressing and vacuum driven resin transfer moulding	Tensile strength = 111 MPa, Flexural strength = 250 MPa, Tensile strain = 5.2 % Flexural strain = 6.9 %, Interlaminar shear strength = 42.6 MPa, Impact strength = 115 KJ/m^2	21
Epoxy	Random oriented silk with jute fiber and grewia optiva	Compression moulding	Improvement in tensile, impact, flexural and hardness of the composite. resistance to wear enhances due to high tenacity of silk fiber. Strong inter mechanical bond was observed between the fiber and matrix. Surface treatment with NaOH greatly	22, 23, 24

			enhances the fiber characteristics leading to enhancement in tribological characterisics	

Conclusion

Silk is a animal fiber has a major component of amine, glycine and some percentage of protein. Its textile and medical applications are already soaring at a greater pace. The inclusion of silk in polymer matrix is gaining a decent pace due to its inherent characteristics of strong peptide bonds. The type of bonding it makes with synthetic as well as bio polymer is largely appreciated. Particularly, the mechanical properties of polymer are greatly enhanced by the addition of silk fiber. It is lighter in weight thus, have higher surface to volume ratio. A small amount of silk fiber (2 to 10 %) can increase the mechanical strength of polymer to significance level. The treatment of silk further enhances the bonding between the fiber and matrix. Silk as we know is no more a bio medical or textile material. Its inclusion in various bio polymer can lead to future sustainable biocomposite with exclusive mechanical and tribological properties.

Reference

1. Lalit, R., Mayank, P., & Ankur, K. (2018). Natural fibers and biopolymers characterization: a future potential composite material. Strojnícky časopis-Journal of Mechanical Engineering, 68(1), 33-50.
2. Ranakoti, L., Gangil, B., Mishra, S. K., Singh, T., Sharma, S., Ilyas, R. A., & El-Khatib, S. (2022). Critical Review on Polylactic Acid: Properties, Structure, Processing, Biocomposites, and Nanocomposites. Materials, 15(12), 4312.
3. Mahir, F. I., Keya, K. N., Sarker, B., Nahiun, K. M., & Khan, R. A. (2019). A brief review on natural fiber used as a replacement of synthetic fiber in polymer composites. Materials Engineering Research, 1(2), 86-97.
4. de Azevedo, A. R., Cruz, A. S., Marvila, M. T., de Oliveira, L. B., Monteiro, S. N., Vieira, C. M. F., ... & Daironas, M. (2021). Natural fibers as an alternative to synthetic fibers in reinforcement of geopolymer matrices: a comparative review. Polymers, 13(15), 2493.
5. Ranakoti, L., Gupta, M. K., & Rakesh, P. K. (2019). Silk and silk-based composites: opportunities and challenges. Processing of Green Composites, 91-106.
6. Holland, C., Numata, K., Rnjak-Kovacina, J., & Seib, F. P. (2019). The biomedical use of silk: past, present, future. Advanced healthcare materials, 8(1), 1800465.
7. Lv, L., Han, X., Wu, X., & Li, C. (2019). Peeling and Mesoscale Dissociation of Silk Fibers for Hybridization of Electrothermic Fibrous Composites. ACS Sustainable Chemistry & Engineering, 8(1), 248-255.

8. Qiu, W., Patil, A., Hu, F., & Liu, X. Y. (2019). Hierarchical structure of silk materials versus mechanical performance and mesoscopic engineering principles. Small, 15(51), 1903948.
9. Taşdemır, M., Koçak, D., Usta, I., Akalin, M., & Merdan, N. (2008). Properties of recycled polycarbonate/waste silk and cotton fiber polymer composites. International Journal of Polymeric Materials, 57(8), 797-805.
10. Li, S., Liu, B., Cheng, J., & Hu, J. (2008). Composite cement of magnesium-bearing phosphoaluminate–hydroxyapatite reinforced by treated raw silk fiber. Cement and Concrete Composites, 30(4), 347-352.
11. Cheung, H. Y., Lau, K. T., Pow, Y. F., Zhao, Y. Q., & Hui, D. (2010). Biodegradation of a silkworm silk/PLA composite. Composites Part B: Engineering, 41(3), 223-228.
12. Han, S. O., Ahn, H. J., & Cho, D. (2010). Hygrothermal effect on henequen or silk fiber reinforced poly (butylene succinate) biocomposites. Composites Part B: Engineering, 41(6), 491-497.
13. Yuan, Q., Yao, J., Chen, X., Huang, L., & Shao, Z. (2010). The preparation of high performance silk fiber/fibroin composite. Polymer, 51(21), 4843-4849.
14. Nadhan, A. V., Rajulu, A. V., Li, R., Cai, J., & Zhang, L. (2012). Properties of waste silk short fiber/cellulose green composite films. Journal of composite materials, 46(1), 123-127.
15. Ho, M. P., Lau, K. T., Wang, H., & Bhattacharyya, D. (2011). Characteristics of a silk fibre reinforced biodegradable plastic. Composites Part B: Engineering, 42(2), 117-122.
16. Shubhra, Q. T., & Alam, A. K. M. M. (2011). Effect of gamma radiation on the mechanical properties of natural silk fiber and synthetic E-glass fiber reinforced polypropylene composites: A comparative study. Radiation Physics and Chemistry, 80(11), 1228-1232.
17. Shubhra, Q. T., Alam, A. K. M. M., & Beg, M. D. H. (2011). Mechanical and degradation characteristics of natural silk fiber reinforced gelatin composites. Materials letters, 65(2), 333-336.
18. Ho, M. P., Wang, H., Lau, K. T., & Leng, J. (2013). Effect of silk fiber to the mechanical and thermal properties of its biodegradable composites. Journal of applied polymer science, 127(4), 2389-2396.
19. Veerapratap, S., Song, J. I., Luo, N., Zhang, J., Rajulu, A. V., & Rao, K. C. (2012). Tensile properties of short waste silk fibers/wheat protein isolate green composites. Materials Letters, 77, 86-88.
20. Taşdemir, M., Koçak, D., Merdan, N., İsmail, U. S. T. A., & AKALIN, M. (2013). Recycled polyamide-6/waste silk & cotton fibre polymer composites: Effect of fibre length. Marmara Fen Bilimleri Dergisi, 25(4), 157-166.
21. Shah, D. U., Porter, D., & Vollrath, F. (2014). Can silk become an effective reinforcing fibre? A property comparison with flax and glass reinforced composites. Composites Science and Technology, 101, 173-183.
22. Ranakoti, L., & Rakesh, P. K. (2020). Physio-mechanical characterization of tasar silk waste/jute fiber hybrid composite. Composites Communications, 22, 100526.

23. Ranakoti, L., Rakesh, P. K., & Gangil, B. (2021). Effect of Tasar Silk Waste on the Mechanical Properties of Jute/Grewia Optiva Fibers Reinforced Epoxy Laminates. Journal of Natural Fibers, 1-13.

24. Ranakoti, L., Gangil, B., Rajesh, P. K., Singh, T., Sharma, S., Li, C., ... & Mahmoud, O. (2022). Effect of surface treatment and fiber loading on the physical, mechanical, sliding wear, and morphological characteristics of tasar silk fiber waste-epoxy composites for multifaceted biomedical and engineering applications: fabrication and characterizations. Journal of Materials Research and Technology, 19, 2863-2876.