Journal of Fiber Bioengineering and Informatics 10:3 (2017) 163–172
doi:10.3993/jfbim00270

Comparative Study of the Silk Fiber Structure and Properties before and after the Tensional Twisting Treatment ⋆

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Abstract

The production of the silk textile products with super softness and high suspension has become one of the hot and difficult topics in textile researches. To endow the silk fiber with improved softness, tensional drawing under different conditions was used to regulate the fiber structure and reduce the fiber initial modulus. The silk fiber structural and mechanical properties were tested before and after the tensional twisting treatments under wet and dry conditions respectively. The results showed that unlike the dry drafted twisting treatment, the pre-wet tensional twisting treatment induced more uniform helical structural formation with lower crystal destruction and molecule rupture than the dry one; though the breaking force decreased, the silk softness and breaking elongation were both improved after the pre-wet twisting treatment.

Keywords: Pre-wet Drawing; twisting; Silk Fiber; Structural Readjustment; Mechanical Properties

1 Introduction

In nature, spiders and several worms including mites, butterflies and moths, can produce silks. Among the glands of these organisms, there are some special epithelial cells that can synthesize synthetic fibrin, and these fibrins eventually become silk [1]. Silk fibers produced by silkworm Bombyx mori mainly composed of sericin and fibroin proteins and also contains a small amount of other amino acids and residues of various impurities: wax, fat, dyes and mineral salts [2-3]. According to the degumming treatment, the weight loss of the raw silk is treated as a sericin dissolved in the hot alkaline solution. The results showed that the fibroin content was ranged from 66.5% to 73.5% and the sericin content was 26.5% to 33.5% [4]. When Silkworms Bombyx mori produce their cocoon silk from two modified salivary glands, the sericin

⋆Project supported by National Natural Science Foundation of China (No. 51403161) and the Technology Innovation Major Project of Hubei Province (No. 2166AAA024).

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Sep. 2017

wraps the fibroin fibers with successive sticky layers that help to form the cocoon. Simultaneously, sericin glues silk threads together to ensure the cocoon cohesion. Sericin molecules with many hydrophilic groups are spherical. The small forces between sericin molecules encourage the silk sericin dissolving easily in water; the solubility increased dramatically as the water temperature increased. Therefore textile silk fibers can be obtained after the cocoon degumming in water [5-6]. Regarded as the queen of textiles, silk fibers are fine, long, elastic, renewable, biodegradable [7]. In addition to the conventional textile application, silk fibroin has been used to manufacture medical materials and food additives [8-10] due to its good biodegradability and biocompatibility [11], beauty products due to its unique physical properties, high resistance chemical properties [12]. Unlike the most advanced synthetic polymers, silk fiber production does not require harsh processing conditions [13]. Therefore, scientists from textile engineers, polymer chemists and biomedical researchers have paid great attention to silk. In recent years, silk fibroin has been widely used in the preparation of artificial skin, blood vessels, bone tissue, tendon [14]; it has also been applied to make the covering materials, controlled drug release carrier, tissue engineering scaffold and other biological materials [15-19].

Aforementioned silk appealing characteristics are closely related to the silk fiber internal structure and composition. Therefore, structural investigations were conducted on the silk before various extensive applications. Pe'rez-Rigueiroa. J. et al [20-21] submerged silkworm silk fibers in liquid environments (water, acetone, ethanol and isopropanol), and then carried out the tensile tests on them. Through a series of experiments, they made the conclusion that the water will destroy the hydrogen bond before the amorphous phase is present, while other solvents help to form new hydrogen bonds in the silk amorphous phase. They also performed mechanical tests on single brins of Bombyx mori silk and drew a conclusion that the sericin present in silk facilitated the fiber cross-sectional structure integrity with no contribution to the resistance of fiber tensile deformation. Chaoyang Jiang et al [22] investigated the mechanical properties of robust ultrathin silk fibroin films; the results indicted the methanol treatment could optimize the structure of thin silk film, achieving a high elastic modulus of 6.5 GPa and ultimate strength reaching 100 MPa for the slik film. The structural optimization mechanism was regarded as the formation of a reinforced microstructure with crystalline b-sheets serving as the reinforcing fillers and physical crosslink sites similar to bulk silk materials.

Under the pressure of the silk advantage features and wide biomedical applications, the silk should be employed to produce high qualified textile products with super softness and high suspension during the conventional textile application. To complete this task, the silk fiber softness required a primary improvement. We predicted pre-wet tensional twisting could reset the fiber internal molecular structure, reduce initial modulus and then improve flexibility. Thus the aim of the present study was to regulate the structure of molecular chains in the silk fiber and to endow helical conformation characteristics by using pre-wet tensional twisting. Then the silk fiber softness, stability and flexibility got improved. To accomplish this goal, the precious silk was selected to conduct the tensional twisting treatment under dry and wet conditions. The mechanical properties were tested for all the silk fibers before and after the corresponding treatments on a single fiber tensile strength tester. Moreover, the surface and inner structures were examined for all the silk fibers before and after the corresponding treatments by scanning electron microscopy and fourier transform infrared spectrometer.