Low Spinnability of Sericin Dominates the Forcibly Spinning Speed

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Abstract

Forcibly spinning was applied to fully grown larvae of domestic Bombyx mori silkworm and the tensile properties of as-spun fibers were investigated. Tensile strength could be gained by elevating the spinning speed. However, it could not reach the level of naturally spun one. Forcibly spinning may be convenient to produce a finer filament. However, its applicability is limited due to the low spinnability of non-liquid crystalline sericin.

Key Words: Silkworm, Forcibly reeling, Sericin, Spinnability, Liquid crystalline property

1. Introduction

When the naturally spinning speeds are compared between spiders and silkworms, e.g. European garden spider (A. disdematus) discharges a web filament at 1.7 mm/sec (10°C)~6.0 mm/sec (30°C), i.e. walking speeds during radius construction of a web [1], while domestic silkworm (Bombyx mori) seemingly discharges at 3.1 mm/sec (20°C)~8.4 mm/sec (30°C) [2]. It seems that the naturally spinning speed of silkworms is a little greater than spiders.

The liquid silk making dragline discharged out from the spinneret of spider could be spun mechanically, i.e. so-called “forcibly spinning” could enhance the tensile strength of the dragline silk filament by 10 % in a case of European garden spider by elevating a forcibly spinning speed up to 100 mm/sec much higher than the naturally spinning [1]. Then, optimal forcibly spinning conditions were investigated and as a result the effectiveness of forcibly spinning was confirmed [3,4].

Further, the forcibly spinning method could show a potential to gain the tensile strength of Bombyx mori silkworm fibers to the level of spider dragline silk [5]. Then, investigations were made intensively to find out the optimal conditions [6-8]. However, in order to secure the stable forced reeling of liquid silk out from the spinneret of Bombyx mori silkworm and to obtain a continuous filament longer than 500 meter at least, stopping the movement of silkworm head in arcs has become critical. For this purpose, paralytic peptide has been custom synthesized [8]. Unfortunately, the tensile strength for the forcibly spun fibers obtained using paralyzed silkworms resulted in approximately one half of the naturally spun fibers although the enhancement could be confirmed in a case of spider silk spinning.

In this paper, tensile properties of forcibly spun Bombyx mori silkworm fibers were investigated, and discussions were made about the spinnability of Bombyx mori sericin.

2. Experimental

2.1 Silkworms

Fully grown larvae of domestic Bombyx mori silkworm, a single cross breed Gunma×200, were kindly supplied from Gunma Sericultural Technology Center.

2.2 Forcibly spinning

Fig. 1 shows the typical forcibly spinning experimental conditions.
conditions. For a short time spinning, usually a silkworm is grasped with fingers. The winding speed of the roller can be controlled up to 50 mm/sec by the electric motor device. A weak following wind at a speed of less than 0.3 m/sec can be blown along the spinning line by an electric fan located behind the silkworm. For comparison, the forcibly spinning was also attempted without drying air circulation.

2.3 Measurements

The tensile properties were measured with a crosshead speed of 20.4 mm/min at room temperature. Gauge length was set 7.0 mm. Tensile strength was determined by averaging the maximum strength of six measurements.

Samples were coated with gold and observed using a scanning electron microscope (SEM, S-3000N, HITACHI, Japan).

3. Results and Discussions

Figs. 2 and 3 show the aspects of as-forcibly spun fibers. When the forcibly spinning was made without drying air circulation, irregular deposition of isotropic sericin fraction occasionally occurred (see Figs. 2(a) and 3(a)). Such unregulated deposition of sericin could be fairly suppressed by a weak following drying air circulation (see Figs. 2(b) and 3(b)). The spinning system of silkworms can be classified into a kind of industrial dry spinning systems [9]. Thus, it is necessary to vaporize the solvent water for the formation of fiber structure. The water content of the liquid silk gel in the silk gland was estimated to be no less than 70 % [10,11].

The tensile strengths of as-forcibly spun filaments are listed in Table 1. Higher spinning condition seems to be effective to gain the tensile strength of as-spun filament. However, the tensile strengths obtained could reach neither the range of forcibly spun spider dragline silk nor the naturally spun Bombyx mori fibers of 4 gf/d [14], which corresponds to 484 MPa when converted using the density of 1.373 g/cm$^3$ of raw silk filament containing 25 % sericin [15]. Another peculiar phenomenon observed at tensile tests was the generation of definite yield point on the stress-strain curve although yielding behavior of naturally spun Bombyx mori filaments is ambiguous [8]. Fig. 4 depicts SEM image of the forcibly spun filament obtained just after the yielding. The generation of cruck in the sericin layer could be recognized. The molecular orientation in sericin layer seems to be not so well developed, and therefore the contribution of sericin layer to the tensile strength of filament is less expectable.

In a case of Nephila spider, the liquid silk making up dragline silk also shows a core-shell type morphology with the interface between core main proteins called spidroin I, II, and outer coat protein. They are synthesized in the major ampullate gland and can form liquid crystalline structures [16]. Thus, momentary large deformation can
be applied to the liquid silk of Nephila spider. On the contrary, the liquid crystalline properties have never been confirmed in Bombyx mori sericin. Thus, cohesive failure will occur in the sericin layer of Bombyx mori filament when large deformation applied suddenly, which dominates the forcibly spinning speed. Therefore, a remarkable difference in the spinnability between Nephila spider silk and Bombyx mori silkworm silk could be observed.

In the previous works, Bombyx mori sericin was considered as a water-absorbing resin that removes water from fibroin and increases the local concentration of fibroin making conditions suitable for the formation of the precursor for silk 1 structure [17], or as an accelerator for the beta-sheet conformation of fibroin [18]. Recently, the functionality of each sericin fraction, i.e. P, M, A, in relation to the fiber formation was investigated. The sericin M fraction will work as a crystallization inhibitor against silk 2 crystal modification of fibroin, and the preferential silk 2 crystal modification of fibroin H-chains at room temperature is considered to be guided by sericin P fraction like a nucleation agent. The detail has been reported elsewhere [19].

4. Conclusions

Forcibly spinning was applied to fully grown larvae of domestic Bombyx mori silkworm and the tensile properties of as-spun fibers were investigated. Tensile strength could be gained by elevating the spinning speed. However, it could not reach naturally spun one. Every forcibly spun filament showed a yield point at tensile tests. The generation of cruck in the sericin layer could be recognized just after the yield phenomenon, suggesting lower molecular orientation in sericin covering the as-spun filament. Forcibly spinning may be convenient to produce a finer filament. However, its applicability is limited due to the low spinnability of non-liquid crystalline sericin.

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