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Directly obtaining pristine magnetic silk fibers from silkworm

Jun-Ting Wang, Lu-Lu Li, Lei Feng, Jin-Fan Li, Lin-Hai Jiang, Qing Shen*

State Key Laboratory for Modification of Chemical Fiber and Polymer, and Polymer Department of Donghua University, 2999N. Renmin Rd., Songjiang, 201620 Shanghai, PR China

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ABSTRACT

By feeding the silkworms with the nano Fe_3O_4 powder together with mulberry leaves, we directly obtained silkworm spun pristine magnetic silk fiber, MSF. To compare with the normal SF found that this MSF not only has expected magnetic properties, but also has enhanced thermal stability and mechanical properties, e.g. stress and strain.

1. Introduction

Bombyx mori silk fiber, SF, is a semicrystalline biopolymer with 80–85% of glycine, alanine and serine and has been long time applied in textile, biotechnological and biomedical fields due to its high strength, rupture elongation, environmentally stable and biocompatible properties [1–4]. In order to fit various application cases, the functional SF is required. Currently the functional SF is fabricated by reconstructing the normal SF with some functional materials using artificial methods, e.g. spinning [1–5], and such functional SFs have been found with optical and electronic components thus capable to apply for some applications, e.g. diagnostic and therapeutic devices [5]. Observe that Chang et al. have introduced a method to produce magnetic SF, MSF, by applying $ZnSe:Mn^{2+}$ quantum dots to coat on the surface of SF under radiation condition [6].

Magnetic responsive materials are the topic of intense research due to their potential breakthrough applications in the biomedical, coatings, microfluidics and microelectronics fields. By merging magnetic and polymer materials one can obtain composites with exceptional magnetic responsive features. Magnetic actuation provides unique capabilities as it can be spatially and temporally controlled, and can additionally be operated externally to the system, providing a non-invasive approach to remote control [7–9]. Magnetic materials can be applied to the security paper, health-care products, magnetic filters, and electromagnetic shielding [7–11].

Among various magnetic materials, the magnetic biomaterials are preferred because they have some novel application in medicine areas [7–11]. As has been known, the SF with magnetic properties has been developed and reported by some researchers by taking the magnetic nanoparticle, Fe_3O_4, to coat the SF surface to form MSF [12]. Additionally, the magnetic cellulose fibers, MSF, have been produced by using magnetite to coat [8,13], lumen loading [14–17], in situ synthesis within cellulose matrix [18], dispersion in cellulose solutions [19], and embedded using ionic liquids [20,21].

The aim of this work is to introduce a simple method to obtain pristine MSF as compared with reported case [6]. Experimentally, we applied magnetic nanoparticles to feed silkworm together with the mulberry leaves then directly obtained MSF. The obtained MSF was compared with the normal SF both parallel fed in our lab. Additionally, the values of MSF obtained in this case were also compared with literature reported values [6].

2. Materials and methods

2.1. Materials

In this work, ten *B. mori* larval silkworms were reared on an artificial diet at our laboratory. Two kinds of mulberry leaves, MLs, were prepared to feed to silkworms, one is the inartificial MLs, and another is the MLs spread with Fe_3O_4 powder to form the MMLs. After one month feeding, 10 silkworm cocoons were obtained.

In this case, the used Fe_3O_4 powder is a commercial sample obtained from Guangzhou Jiechuang Trading Co., Ltd. China. According to this company, the size of these Fe_3O_4 powders is about 100 nm and a purity of about 99.8%.

* Corresponding author. Tel.: +86 21 62822096; fax: +86 21 62822096.
E-mail address: sqing@dhu.edu.cn (Q. Shen).

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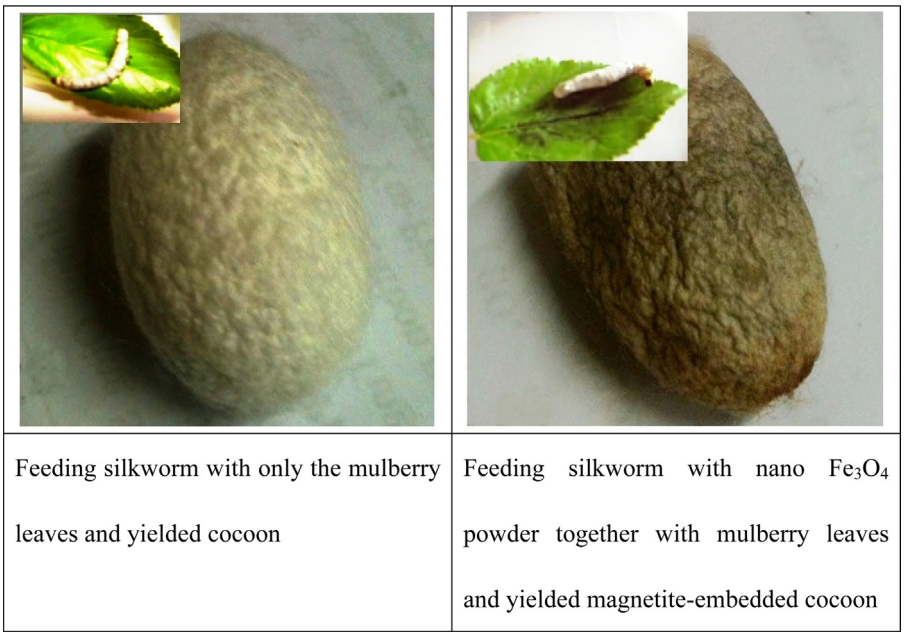

Feeding silkworm with only the mulberry leaves and yielded cocoon	Feeding silkworm with nano Fe_3O_4 powder together with mulberry leaves and yielded magnetite-embedded cocoon

Fig. 1. The macroscopical images of the normal feeding of silkworm with only mulberry leaves and the yielded cocoon (left) and the feeding of nano Fe_3O_4 powders together with the mulberry leaves and the yielded magnetite-embedded cocoon (right).

Table 1
Degree of crystallinity, DC, and degree of orientation, DO, of the normal silk fiber, SF, and magnetic silk fiber, MSF.

Silk fibers	Crystallinity (%)	Orientation (%)
SF	24.7	93.6
MSF	18.8	93.8

The MSF and normal SF were collected by immersing the silkworm cocoons in warm water (about 80–90 °C) with a pH about 9–10 for about 1–3 h then hand taken to wind in a glass bottle surface. Each SF was collected and prepared at about 10 m in length for analysis. Before measurement, the obtained SFs were oven dried at 90 °C for 24 h and the moisture was measured in a range of 3–5%.

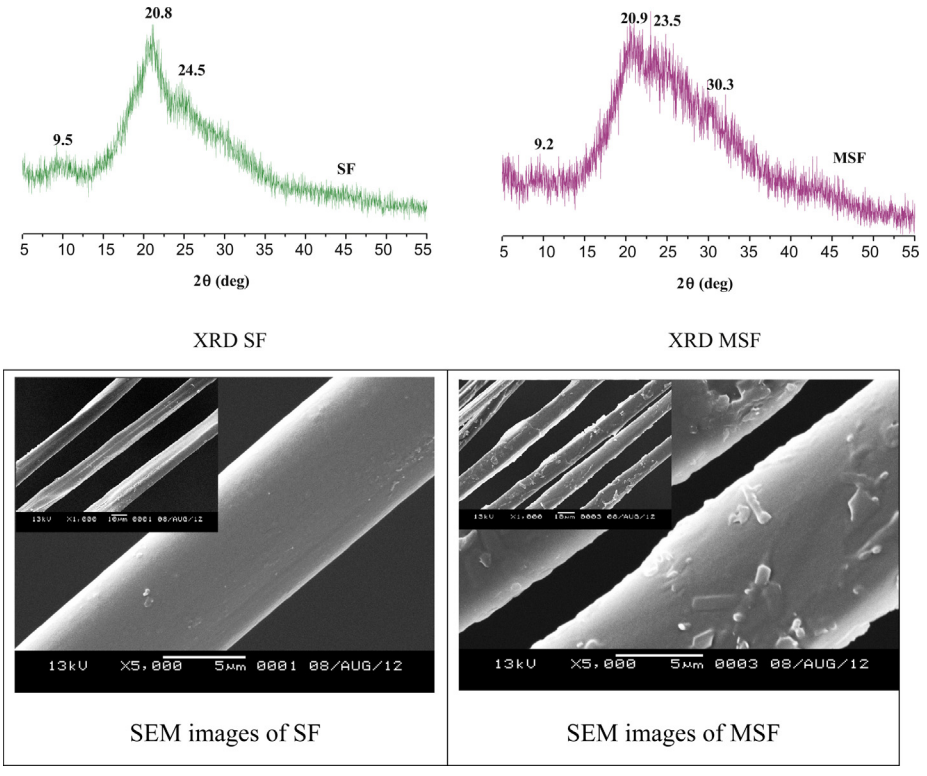

Fig. 2. XRD patterns and SEM images of the normal silk fiber, SF (left), and magnetic silk fiber, MSF (right).