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# Preparation and characterization of novel super-artificial hair fiber based on biomass materials

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ABSTRACT

A novel super-artificial hair fiber basing on sodium alginate (SA) and Antarctic Krill protein (AKP) was prepared by wet spinning successfully. Such SA/AKP fiber did not only have similar crystalline structure with human hair, but also had super flame resistance and mechanical performance. It should be noted that the whole preparation process was green without any incorporation of non-toxic solution. Moreover, comparing with human hair, the SA/AKP fiber had a lot of unique groove upon the fiber surface, which contributed a lot to excellent hygroscopicity. Meanwhile, the dyeing performance could be improved notably due to incorporation of protein into the matrix. Herein, the SA/AKP fiber with superior mechanical and functional performance had practical value for application in the field of synthetic wig.



## 1. Introduction

With the rapid economic development and great improvement of people's living standard, more and more people are getting to pursue more beautiful appearance, so wig fiber as emerging consumer products is widely loved and used [1–3]. In order to cater to the market demands, various kinds of wig products appear, correspondingly, naturally comfortable, high flame resistance, radiation protection, green, security, non-toxic, antibacterial and hygroscopicity properties are required by consumer [4,5]. Natural hair is the best materials to prepare wig, however the collection has become more and more difficult as civilization progress. Hence, the study on synthetic fiber to meet the functional and other differential requirement become quite important. Currently, the preparation materials of wig fiber are mainly derived from synthetic fiber including polyvinyl chloride (PVC) fiber [6], polyethylene terephthalate (PET) fiber [7,8], polyacrylonitrile (PAN) fiber [9,10] and protein fiber [11]. The PVC wig fibers have a good natural flame resistance and crimpness according to the previous research [6]. It is widely used during the preparation of long straight hair and big wave hair [12]. The PET wig fiber have high modulus, strength and excellent heat resistance. It has been developed as a new materials for wigs because of the better thermal properties [13,14]. The PAN wig fiber have a natural appearance and good flame resistance under modification, and it is often used to prepare high-grade wig products [15,16]. In conclusion, synthetic fiber have been extensively used to prepare wig products, and also exhibits good property in elasticity, softness and warmth. However, there are also a lot of problem, for instance, PVC fiber have disadvantage that the fluffy properties are so poor for wig application [17], pure PET fiber have poor flame retardant property [18]. Although PAN fiber have many excellent properties through modification, the market price is more expensive due to the higher production cost [19]. The most important defects are excessive chemical modifier, high pollution, complicated preparation technology and irreversible solvent recovery process in the process of preparation. And these synthetic fiber combustion would produce hot melt to cause skin burns, and they are prone to lead to itchy skin allergy due to static electricity to stimulate skin during wearing. Thus, the synthetic fiber have a series of unavoidable and undesirable problem.

The AKP/SA fiber prepared via wet spinning with $CaCl_2$ and PEG as coagulator had been researched by Guo, and the best forming mixing coagulation bath conditions was achieved [20]. However, the fiber break strength was lower to 1.51CN/dtex. Zhang obtained alginate fiber by wet spinning, researched the effect of $K^+$, $Na^+$ ion on the degradation performance of fiber, and applied the fiber into tissue engineering [21]. Qi prepared macromolecular monomer by reacting maleic anhydride with acrylonitrile, and the Antarctic krill protein was grafted on the macromolecular protein for electrostatic

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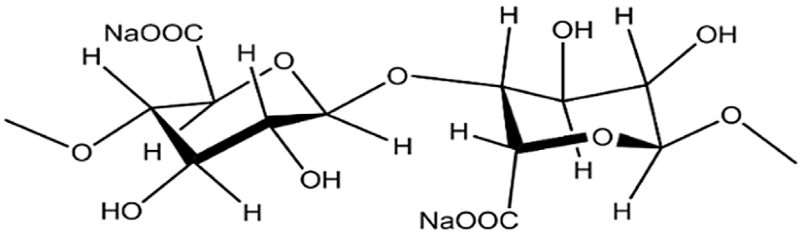


**Fig. 1.** The molecular structure of sodium alginate.

spinning process [22]. However, there is no corresponding reports on preparation for wig by using sodium alginate and Antarctic krill protein yet. Herein, in this paper, our research team put forward an approach to design and prepare wig fiber by blending sodium alginate with the Antarctic krill protein via wet spinning. In our research, the glutaraldehyde is selected to enhance the mechanical properties, and the break strength reached up to 2.4 CN/dtex, almost a 50% enhancement for 1.51 CN/dtex reported in the above literature. Furthermore, the preparation process of SA/AKP fiber is significantly simplified by using a single component coagulation bath. The whole preparation process is improved to be a real green process. Besides, the preparation is quite facile. This study also demonstrates that SA/AKP wig fiber have multiple advantages comparing with PET, PVC and PAN wig fiber, and such fiber is endowed with more excellent performance, such as higher flame resistance, better touch feeling, more excellent hygroscopicity properties, oxygen permeability and green non-toxicity without any additive.

Our design is inspired from natural flame resistance of sodium alginate, meanwhile, the incorporation of the Antarctic krill protein make the fiber have super-similar composition and microstructure. This kind of fiber based on biomass materials has irreplaceable advantages compared with current commercial wig products. Firstly, the raw materials resource is non-toxic and abundant with excellent nature performance. Secondly, the fiber preparation process is environmental friendly. Thirdly, SA and AKP have a good compatibility due to strong hydrogen bonds exiting in blends [23]. Sodium alginate is a linear polysaccharide polymer extracted with marine algae [24,25], and the chemical structure is shown in Fig. 1. A larger number of hydroxyl groups make the fiber have good hygroscopicity and excellent antistatic property, and extensively used in food, medicine, chemical industry, textile and other fields [26,27]. Antarctic krill protein was extracted from Antarctic krill in alkali solution, as previously described [28]. According to previous study, Antarctic krill biomass storage is nearly 6.5–10 billion tons and protein-rich [29]. The as-prepared SA/AKP fiber have more similar physical and chemical properties to human hair from the combination between Sodium alginate and Antarctic krill protein. In our study, the properties of SA/AKP fiber and human hair fiber are investigated systematically, including mechanical properties, crystallization properties and the characteristics of microstructure. The results indicate that the SA/AKP fiber had a similar crystal structure with human hair. Moreover, the other properties such as flame resistance are superior to that of human hair. As a kind of wig fiber based on biomass materials, SA/AKP fiber has a huge potential for development.

## 2. Materials and methods

### 2.1. Materials

Sodium alginate (molecular weight of $5 \times 10^6$–$6 \times 10^6$) was obtained from Qingdao Bright Moon Seaweed Group Co., Ltd, China. Antarctic krill protein was prepared in laboratory via extraction in alkali solution. Hydrochloric acid, glutaraldehyde, sodium hydroxide and calcium chloride (analytical grade) were purchased from Tianjin Ruimingte Chemicals Co., Ltd. All of the analytical pure were directly used without any further purification. Acid dyes (black) were obtained from Tianjin Xiangrui Dyes Co., Ltd. Human hair was collected from Asian person.

### 2.2. Preparation of SA/AKP super-artificial hair fiber

(1) SA/AKP spinning dope in situ dyeing: The AKP solution was prepared by adding AKP into 0.5% (w/w) sodium hydroxide solution with heating and stirring for 1 h, then the pH value of solution was adjusted and acid black dye for dyeing was added.
(2) Preparation of SA/AKP solution: The enhancer containing glutaraldehyde (GD) was added into dyeing AKP solution, and then SA was added with mechanical agitation. SA/AKP solution with the ratio of 10/2 (w/w) was prepared, afterward, air bubbles were eliminated under vacuum condition for 24 h. The SA/AKP super-artificial hair fiber was prepared via wet-spinning process in the 5% (w/w) calcium chloride coagulation bath.

### 2.3. Characterization of SA/AKP super-artificial hair fiber

The microstructure of the SA/AKP super-artificial hair fiber was observed by using a scanning electron microscope (SEM) (S-4800, HITACHI, Japan) with an accelerating voltage of 10 kv after sputter-coating with Au. The chemical structure of SA/AKP super-artificial hair fiber and in situ dyeing AKP were confirmed by a Nicolet 470 fourier-transformed infrared spectroscope (FTIR), The KBr pressed disc technique was used for SA/AKP sample preparation. The scanning range was 4500–500 $cm^{-1}$ with 64 scans at a resolution of 4 $cm^{-1}$. The dynamic mechanical properties of SA/AKP fiber were conducted on a dynamic mechanical analysis (DMA) (Q800, TA, USA), with frequency of 1 Hz, heating rate of 3 °C/min, and temperature scanning range of 25–200 °C. The mechanical properties of SA/AKP super-artificial hair fiber and human hair were measured using single fiber strength tester (LLY-06ED), and the fracture strength, break elongation and young's modulus were calculated by statistical method. The corresponding tests were executed with 10 times for each sample, respectively. The state of aggregation was determined using an X-ray diffractometer (XRD), (Diffractometer-6000, Rigaku, Japan) with Cu Kα over a 2θ range of 5–80° with a step size of 4°/min. Tube voltage was 2.5–40 kv, and Tube current was 80 mA. Flame resistance was evaluated using an SH5706 oxygen index apparatus, (Guangzhou xinhe electronic equipment Co., Ltd, China). 0.3 g fiber was taken to twist a bunch as a test sample. The test results was statistical data by averaging the 3 parallel tests for each sample. The correlated error was calculated from the formula (2.1). The test method for Limit Oxygen Index (LOI) refers to textile oxygen combustion performance test GB/T5454-1997.

$$\delta = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})}{n-1}} \tag{2.1}$$

where δ: mean square error; :$x_i$ test value; :$\bar{x}$average; n: test times.