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.

Key word: Sodium alginate, Antarctic Krill protein, Wig fiber, Flame resistance

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[1,2,3] 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

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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 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 existing 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 $5 \times 10^6 \sim 6 \times 10^6$) 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 $4500\text{--}500\text{ cm}^{-1}$ with 64 scans at a resolution of 4 cm^{-1} . The dynamic mechanical properties of SA/AKP fiber was conducted on a dynamic mechanical analysis (DMA) (Q800, TA, USA), with frequency of 1 Hz, heating rate of $3\text{ }^{\circ}\text{C/min}$, and temperature scanning range of $25\text{--}200\text{ }^{\circ}\text{C}$. 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 K α over a 2θ range of $5\text{--}80^{\circ}$ with a step size of $4^{\circ}/\text{min}$. 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.

$$\delta = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \dots \dots \dots (2.1)$$

where: mean square error; : test value; : average; n: test times.

3. Results and discussion

The SA/AKP super-artificial hair fiber was prepared by wet spinning, the preparation process and forming mechanism are presented in Fig.2. The spinning dope containing Antarctic krill protein (AKP), sodium alginate (SA) and glutaraldehyde (GD) was injected into calcium chloride coagulation bath via spinneret. For the forming mechanism of SA/AKP super-artificial hair fiber, it was a dual diffusion effect between solvent and curing agent during the wet spinning process. SA formed “egg-box” via Ca^{2+} chelation, meanwhile, AKP began to separate out under the salt-out effect among the influence of calcium chloride coagulation bath. Homogeneous spinning dope formed filament in the coagulation bath with the above two effects. Afterwards, the filaments were stretched in water bath with certain temperature before entering the hot air dryer circulation. The macromolecular chains were oriented on the external stretching force field, and the crosslinking reaction between molecular chains generated cross-linked network structure during the process of hot air drying. The mechanical strength of SA/AKP fiber was enhanced from the inside and outside homogeneous crosslinking by adding GD into the spinning dope. Finally, optimal parameters of fiber molding process was obtained as follows: condition is 5 wt% CaCl_2 coagulation solution, coagulation time is 4.5 minutes, temperature is 30 °C. The SA/AKP fiber with excellent mechanical properties was successfully prepared

In order to make a high quality simulation with human hair, the acid black dye was added into spinning dope to achieve the uniform dye. Moreover, chemical bond combination between the dye molecules and protein by the pH value and temperature were controlled in the composite. The infrared spectra of the dyeing Antarctic krill protein are presented in Fig.3. The N-H stretching vibration is observed at 3364 cm^{-1} , the characteristic peak of C=O appears at 1648 cm^{-1} in AKP spectra. The new peaks at $1322\text{--}1537 \text{ cm}^{-1}$ and 1039 cm^{-1} are clearly observed in dyeing AKP spectra contrasting with the spectra of acid dye and AKP, while the original peak at 1230 cm^{-1} disappeared. All of the results manifest that the acid dye react with AKP molecules during the in situ dyeing process, which leads to much firmer combination between acid dye and AKP molecules. The combination of chemical bonds is superior to the blending with dyes and spinning solution because it is effective in reducing the migration of acid dyes. Furthermore, the chemical bond combination contribute to a strong color fastness and it is also uneasy to be rubbed off during the washing process. The chemical structure of SA/AKP wig fiber and human hair are investigated by FTIR analysis, and the corresponding spectra are presented in Fig. 4. For SA, the wide peak at 3375 cm^{-1} is attributed to the stack of N-H and O-H stretching vibration. For human hair, the N-H characteristic peak is observed at 3281 cm^{-1} and the corresponding peaks in AKP and human hair are also observed in the Fig.4(a). In addition, for more clear demonstration of the peaks within the wavelength range of $2000\text{--}500 \text{ cm}^{-1}$, Fig.4(a) was local-enlarged processed into Fig.4(b). For SA, some of the characteristic peaks are observed in the spectra: C=O stretching vibration at 1605 cm^{-1} , C-H in-plane flexural vibration at 1415 cm^{-1} , C-C stretching vibration at 1092 cm^{-1} and C-OH stretching vibration at 1035 cm^{-1} . Besides, the peaks at 1652 cm^{-1} and 1092 cm^{-1} are attributed to amide vibration absorption (C=O and N-H). The derivative spectra of SA, AKP and SA/AKP are presented to describe the attribution and revolution of the overlapped peaks

more clearly. By contrast, the absorption peak at 1652cm^{-1} is divided into two peaks which locates at 1643 cm^{-1} (C=N) and 1601 cm^{-1} (C=O), respectively. Meanwhile, N-H bending vibration at 1538 cm^{-1} is much weaker, and the C-O-C stretching vibration at 1108 cm^{-1} is getting significant. The results prove that glutaraldehyde (GD) reacts with the amino group of AKP and hydroxyl group of SA. Many other characterization about SA/AKP fiber were employed in our previous research work[30,31]. All of the test results prove that SA/AKP composite materials are successfully prepared.

The wide angle X-ray patterns of the SA/AKP fiber and human hair are shown in Fig.5. The SA/AKP wig fiber have similar crystal structure with human hair. The typical peaks of protein are observed at 22.6° , 29.5° , 36° , 39.5° , 43° , 47.6° and 57.7° , respectively. The amorphous diffraction peak around 23° was attributed to sodium alginate's amorphous structure in SA/AKPcrystallization curve contrasting with SA, and the same peak of protein appears obviously. These data prove that the crystallization of SA/AKP fiber structure is mainly from AKP, while SA exists in amorphous state as substrate materials. Compared with human hair, the crystallization degree of protein in SA/AKP fiber is lower. The phenomenon might be that there is a strong interaction between SA and AKP molecules, and strong hydrogen bonding interaction weakens the crystallization of AKP molecules.

The pictures of SA/AKP super-artificial hair fiber and human hair shown in Fig.6 (a & b). The SA/AKP super-artificial hair fiber has a bright color and excellent fleeciness feeling, and it also has a good vision simulation effect contrasting with human hair. The microstructure of human hair is exhibited in the Fig.6(c), there are numerous regular scales on the surface of human hair, and the diameter of the hair is about $76\text{ }\mu\text{m}$. By contrast, The SA/AKP super-artificial hair fiber has uneven groove structure along the axial, and the diameter of the fiber is about $80\text{ }\mu\text{m}$. It can be observed that there are plenty of groove structures on the surface of SA/AKP fiber. The formation of groove structure is a dual diffusion effect between solvents inside nascent fiber and coagulator in the bath. This formation mechanism will lead to an uneven shrinkage in the direction of fiber vertical axial, and molding groove structure on the fiber surface. The internal microstructure of SA/AKP and human hair are shown in Fig.6 (e & f). It can be observed in Fig.6 (e) that the cross section of SA/AKP wig fiber is irregularly rounded and there exists little cavities inside. The SA/AKP fiber might have worse mechanical properties due to the inner cavities in fiber which can result in stress concentration effect and break the fiber. The compact internal structure without cavities is the primary goal in spinning process because this microstructure can improve the fiber mechanical properties more significantly. Compared with SA/AKP fiber, the cross section of human hair is regularly oval, and there are also tiny cavities existed in internal fiber, but these cavities present in the continuous similar mesh structure. This specific structure greatly matches the corresponding mechanical test results of human hair.

The mechanical properties of SA/AKP super-artificial hair fiber are measured and the results are shown in Fig.7. The fracture strength of SA/AKP super-artificial hair fiber is higher than that of human hair, by 2.4 CN/dtex . The break elongation and young's modulus of SA/AKP fiber are markedly lower than that of the human hair. The elongation difference between SA/AKP fiber and human hair may be caused by the interior mesh structure of human hair. The flame resistance of human hair and SA/AKP super-artificial hair fiber are measured by vertical combustion, and the results are summarized in table 1. Flame retardant test data show that human hair is flammable with an LOI of 24.0. The combustion process was accompanied with burnt feathers smells,

without melt dripping, and the combustion product is ash carbide. Compared with the human hair, the SA/AKP super-artificial hair fiber exhibits more excellent flame retardant performance with the LOI of 39.0. It has burnt feathers smells during the process of combustion. While the oxygen concentration is lower, SA/AKP fiber show obvious self-extinguishing behavior; while the oxygen concentration is extremely higher, it is smoldering without melt dripping nor flame, and the burnt carbide was powdery. The phenomenon show that the SA/AKP fiber have higher fracture strength and excellent flame resistance. The flame resistance, air permeability, and hygroscopicity are superior to that of human hair. The as-prepared fiber do not only have similar microstructure but also have more excellent properties than human hair. In addition, SA/AKP fiber basing on biomass materials have perfect simulate effect with human hair.

The test condition of dynamic mechanical analysis (DMA) is similar to the actual application condition of the as-prepared fiber for real physical significance. The dynamic mechanical properties of human hair and SA/AKP super-artificial hair fiber are presented in Fig.8. The characteristic dynamic mechanical properties of human hair are exhibited in DMA curves, and the glass transition temperature (T_g) of protein molecules is about 65 °C. With the increase of temperature, the motion ability of macromolecules is enhanced significantly, the storage modulus first slightly decreases and then increases, but $\tan \delta$ decreases. This result indicates that the protein molecular chain has the molecular conformation transformed from α -keratin to β -keratin under the effect of alternating stress. The SA/AKP has a single T_g of 50 °C. It manifests that SA and AKP have good compatibility in the blends. As the temperature rises, the motion ability of molecules increases, and the loss modulus decreases drastically.

4. Conclusions

The SA/AKP super-artificial hair fiber was successfully prepared by wet spinning process. The raw materials was derived from natural marine organisms (Antarctic krill and seaweed), and the whole preparation process using water as solvent was pollution-free and non-toxic. In addition, the as-prepared fiber was biodegradable. Therefore, the as-prepared biomass fiber was a kind of real eco-friendly fiber for wig application. The super-artificial hair fiber exhibited excellent flame resistance and fine spinnability due to the incorporation of sodium alginate into the matrix. Groove structure formed upon the fiber surface during the preparation process, which provided good fleeciness and hygroscopicity, and eliminated the phenomenon of strong light reflection. Moreover, the hygroscopicity inhibited the electrostatic generation while worn. The excellent flame resistance prevented a secondary burn for skin while the as-prepared fiber was wearing as wig. Under the situation of oil shortage today, this kind of as-prepared biomass fiber for wig application would be an ideal replacement of regular chemical fiber, and it thus has a promising development prospect.

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6. References

- [1] L. Festa, Personal Effects: Wig and Possessive Individualism in the Long Eighteenth Century, *Eighteenth-Century Life*, 29 (2005) 47-90.
- [2] M. Kwass, Big Hair: a wig History of Consumption in Eighteenth Century, *American Historical Review*, 111(2006) 631-659.
- [3] J. McLaren, Legal Dress: A Brief History of Wigs in the Legal Profession, *International Journal of the Legal Profession*, 6(1999), 241-250.
- [4] V. Seigelshifer, T. Hartman, From Tichels to hair: Modern orthodox women and the practice of head covering, *Women's studies international forum*, 34(2011), 349-359.
- [5] J.T.Guthrie, A.Kazlauciuonas, L.Rongong, S. Rush, The Characterisation of Treated and Dyed Hair, *Dyes and pigments*, 29(1995), 23-44.
- [6] I. S. Kim, H. M. Cho, J. Koh, J. P. Kim, Low-Temperature Carrier Dyeing of Poly(vinyl chloride) Fibers with Disperse Dyes, *Journal of Applied Polymer Science*, 90(2003), 3896-3904.
- [7] H. C. Kim, D. H. Kim, J. Park, J. Ch. Lim, Y. W. Park, Miscibility of Flame Retardant Epoxy Resin with Poly(ethylene terephthalate), *Fibers and Polymers*, 10(2009), 594-600.
- [8] Y.j. Tao, Y. X. Pan, Z. Sh. Zhang, K. Ch. Mai, Non-isothermal crystallization, melting behaviour and polymorphism of polypropylene in 6-nucleated polypropylenen /recycled poly(ethylene terephthalate) blends, *European Polymer Journal*, 44(2008), 1165-1174.
- [9] X. M. Zeng, J. Hu, J. X. Zhao, Y. W. Zhang, D. Pan, Investigating the jet stretch in the wet spinning of PAN fiber, *J. App. PolymSci*, 106(2007), 2267-2273.
- [10] T. H. Ko, Ch. H. Lin, H. Y. Ting, Structural changes and molecular motion of polyacrylonitrilefibers during pyrolysis, *J. App. Polym. Sci*, 37(1989), 553-566.
- [11] F. K. Chen, Z. D. Zu, Ch. Chen, Protein composite fiber for wig and manufacturing method thereof., CN 102808237 A. 2012.
- [12] Y.J. Liu, H. C. Kim, Y. S. Chung, Basic Study on the Two-Tone Color Dyeing of PET and PVC Wig Fibers by Carrier Dyeing Method, *Fibers and Polymers*, 8(2007),363-371.
- [13] C.P. Papadopolou, N.K. Kalfoglou, Comparison of compatibilizer effectiveness for PET/PP blend: their mechanical, thermal and morphology characterization, *Polymer*, 41(2000), 2543-2555.
- [14] Y. W. Park, I. J. Song, H.Ch. Kim, Characterization of PET/PP Blend Fiber and it's Application to Wig,Fibers and Polymers, 15(2014), 1078-1083.
- [15] K. Badii, J. S. Church, G. Golkarnarenji, M. Naebe, H. Khayyam, Chemical structure based prediction of PAN and oxidized PAN fiber density through a non-linear mathematical model, *Polymer Degradation and Stability*, 131(2016), 53-61.
- [16] Y. Wang, W. Y. Yin, Chemical Modification for PAN Fibers during Heat-treatment Process, *Physics Procedia*, 18(2011), 202-205.
- [17] Zh. Zhou, S. Rajabzadeh, A. R.Shaikh, Y. Kakihana, W. Zh. Ma, H. Matsuyama, Effect of surface properties on antifouling performance of poly(vinyl chloride-co-poly(ethylene glycol)methyl ether methacrylate)/PVC blend membrane, *Journal of Membrane Science*, 514(2016), 537-546.
- [18] M. K. Cheung, D. Chan, Mechanical and rheological Properties of Polv(ethvlene terephthalate) /Polypropylene Blends, *Polymer International*, 43(1997), 281-287.
- [19] Y. Wang, W.Y. Yin. *Physics Procedia*, Chemical Modification for PAN fibers during Heat-treatment Process, 18 (2011), 202-205.
- [20] J Guo, X.C. Li, et al, The study of rheological and mechanical properties of the Antarctic krill protein/sodium alginate fibers , *Advanced Materials Research*,813 (2013), 377-381.

- [21] Xiaolin Zhang, Chen Huang, Xiangyu Jin, Influence of K^{+1} and Na^{+1} ions on the degradation of wet-spun alginate fibers for tissue engineering. *J. Appl. Polym. Sci.* 2017, 134, 44396-44404.
- [22] S. W. Qi, J. Guo, S. Y. Mu, et al. Modification and performance of polyacrylonitrile with maleic anhydride grafted krill protein. 29(2015), 686-692.
- [23] L. J. Yang, J. Guo, Y. Y. Q. D. An, L. Y. Wang, Sh. L. Li, X. L. Huang, S. Y. Mu, Sh. W. Qi, Hydrogen bonds of sodium alginate/Antarctic krill protein composite material, *Carbohydrate Polymers*, 142(2016), 275-281.
- [24] J. Ming, Zh. j. Jiang, P. Wang, Sh. y. Bie, B. q. Zuo, Silk fibroin/sodium alginate fibrous hydrogels regulated hydroxyapatite crystal growth, *Materials Science and Engineering*, 51(2015), 287-293.
- [25] H. Bokkhim, N. Bansal, L. Grndahl, B. Bhandari, Interactions between different forms of bovine lactoferrin and sodium alginate affect the properties of their mixtures, *Food Hydrocolloids*, 48 (2015), 38-46.
- [26] A. Sand, A. Vyas, A.K. Gupta, Graft copolymer based on (sodium alginate-g-acrylamide): Characterization and study of Water swelling capacity, metal ion sorption, flocculation and resistance to biodegradability, *International Journal of Biological Macromolecules*, 90 (2016), 37-43.
- [27] S. Thakur, S. Pandey, O. A. Arotiba, Development of a sodium alginate-based organic /inorganic superabsorbent composite hydrogel for adsorption of methylene blue, *Carbohydrate Polymers*, 153(2016), 34-46.
- [28] W. Zh. Jiang, L. Jinhyuk, S. Y. Xiu, A folding study of Antarctic krill (*Euphausia superba*) alkaline phosphatase using denaturants, *international journal of biological macromolecules*, 70(2014), 266-274.
- [29] L. Zh. Wang, Ch. H. Xue, Y. Xue, Y. M. Wang, Zh. J. Li, Optimization and evaluation of a novel technique for hydrolyzing Antarctic krill (*Euphausia superba*) proteins, *Food and Bioproducts Processing*, 94(2015), 629-636.
- [30] L.J. yang, J. Guo, et al, Rheological properties of sodium alginate/Antarctic krill protein composite materials and fiber preparation, *Polymeric materials science and engineering*, 31(2015), 146-153.
- [31] L.J. yang, J. Guo, et al, Preparation and characterization of high strength Antarctic krill protein/sodium alginate composite fiber, 33(2016), 1524-1530

Fig.1 The molecular structure of sodium alginate.

Fig.2 Preparation process and forming mechanism of SA/ AKP fiber.

Fig.3 Infrared spectra of the in situ dyeing Antarctic krill protein.

Fig.4 Infrared spectra of (a) SA/ACP fiber, SA and ACP, (b) Partial amplification figure of (a); (c) Derivative spectra of SA, ACP and SA/ACP fiber.

Fig.5 The crystallization properties of SA/AKP super fiber and human hair. SA sample was characterized with powder by disc technique. Others characterized with a bundle of fiber by tiled.

Fig.6 (a) Photographic pictures of human hair (b) SEM images of human hair surface and (c) SEM images of human hair cross-section (d) Photographic pictures of SA/AKP fiber (e) SEM images of SA/AKP fiber on surface and (f) Cross-section of SA/AKP fiber.

Fig.7 Mechanical comparison of SA/AKP fiber and human hair

Fig.8 Dynamic mechanical comparison analysis of SA/AKP fiber and human hair. (a) Dynamic mechanical of human hair (b) Dynamic mechanical of SA/AKP fiber. Both curve characterized as $\tan\delta$ in red line, loss modulus in blue line and storage modulus in black line.

Table 1 Flame resistance comparison of SA/AKP fiber and human hair

Sample	Combustion phenomenon description	N2 flow [m3/h]	O2 flow [m3/h]	LOI	standard deviation
Human hair	Have burnt feathers smells, smoldering last a period of times and then extinguish after leaving the fire source, Have carbide assembled, without the melt dripping.	0.9	0.25	21.7	24 1.41
	Have burnt feathers smells, smoldering last a period of times and then extinguish after leaving the fire source, Have carbide assembled, without the melt dripping.	0.9	0.28	23.7	
	Keep smoldering. Without the melt dripping, smells burnt feathers.	0.9	0.3	25	
	Self-extinguishing after leave fire source.	0.9	0.5	35.7	
SA/AKP fiber	Without the melt dripping, burnt feathers smells.	0.8	0.5	38.5	39 1.0
	Keep smoldering. Without the melt dripping, burnt feathers smells.	0.9	0.6	40	