Preparation and properties of antibacterial and mite-resistant TCM/PNA blend fiber

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Abstract. The acrylic fiber with antibacterial and mite-resistant function is prepared by wet spinning method by adding the extracts of LC with antibacterial function and the HX extract with the function of anti-mite to PAN (polyacrylonitrile) spinning liquid, and its morphological structure, basic properties of antibacterial and mite-resistant performance were tested. The results show that compared with pure PAN fiber, the fracture strength and elongation of the blend fiber of traditional Chinese medicine (TCM)/PAN decreased slightly with the addition of plant extract, and the thermal stability is improved. The inhibitory rate of the quantitative test is 93.83%; the removal rate of mites by TCM/PAN blend fiber non-woven fabrics is 83.21%, which had strong effect of preventing mites.

1. Introduction
The properties of polyacrylonitrile fiber are very similar to wool, which is called "synthetic wool". Therefore, acrylic thermal underwear and acrylic household carpet are well loved by consumers. However, some underwear and household textiles that are closely related to people's life can easily become the environment where bacteria, mold, mites and other microorganisms can survive. After contact with people, people will cause certain damage to human body, so people start to develop anti-bacterial and anti-insect fiber or textile [1-3]. As chemical antibacterial agents and anti-mite agents will produce certain side effects on human body, adding natural plant TCM antibacterial agents and textile materials of insect repellent, as a result of green environmental protection, safety and health and other advantages are gradually favored by consumers. Many Chinese herbal extracts themselves are natural antibacterial agents and anti-mite agents, which are mixed with PAN spinning liquid. The polyacrylonitrile fiber with anti-bacterial and anti-mite functions is obtained by the wet spinning method, satisfying people's pursuit of green and healthy living quality. In this paper, LC with antibacterial effect and HX extract with anti-mite effect were used to prepare antibacterial and anti-mite acrylic fiber, and its morphological structure, basic performance and anti-mite performance were tested.
2. Experimental

2.1 Materials

PAN powder, with a molecular weight of 80,000, purchased from Gong Guan Yu Ming plastic raw materials Co., Ltd.; Sulphuric acid, zinc sulfate, anhydrous sodium sulfate and dimethyl sulfoxide (DMSO) were purchased from Qingdao FuChi instrument Co., Ltd.; distilled water, LC extract and HX extract, with specifications purchased from Xi’an Helin Bio-technique Co., Ltd.; Staphylococcus aureus (ATCC 6538), Nutrient broth, nutrient AGAR, buffer, distilled water, dust mites, feed, saturated salt water, etc. All reagents are analytical pure.

2.2 Preparation of antibacterial and anti-mite PNA fiber

The concentration of the spinning solution was 16% prepared by using 80 thousand molecular weight PAN polymer and dimethyl sulfoxide (DMSO). By testing the properties of different solutions, the final solution for spinning has been optimized, that is, the addition amount of LC extract and HX extract respectively accounts for 6% and 6% of PAN mass in the spinning solution. According to the optimal proportion, the use of ABS 135-s precision electronic weighing scales LC extract and HX extract added to 100 ml of PAN spinning solution, after stirring evenly then into 60°C constant temperature water-bath water and stir with electric mixer on medium speed 2 h. When extract powder and mix the dope, let stand for a period of time, will blend spinning fluid by three filter cloth filter of 200 mesh (aperture size of 0.075 mm), remove the blend spinning there are still some particles and bubbles in liquid, to ensure that all material in the blend spinning fluid and large molecules can be smoothly through the spinneret, then wet spinning. The forming process of the fiber in the coagulation bath is the process of double diffusion and phase separation of solvent (DMSO) and non-solvent (H2O) into fibers [4, 5].

2.3 Characterization

2.3.1 Basic properties of fiber test

Nicolet5700 Fourier infrared spectrometer and ATR method were used to measure the information of sample structure characteristics, and the molecular structure was analyzed by reflecting signals on sample surface [6]. The prepared fiber was cut into thin slices by Y172 Haversian fiber slicer and put under jsm-6390 LV low-vacuum scanning electron microscopy to observe the longitudinal and transverse sectional shapes of the fibers. The mechanical properties of the fibers were tested under dry and wet conditions. The NETZSCH STA 409 PC type thermal analyzer, put a certain amount of fiber in nitrogen atmosphere, between 0°C to 700°C temperature under different temperature measuring the weight of the corresponding fibre weightless.

2.3.2 Antibacterial and Anti-mite test

According to the national standard evaluation of anti-bacterial properties of GBT 20944.3-2008, part 3: oscillation method, quantitative inhibition rate of staphylococcus aureus was tested.

The non-woven samples were tested for anti-mite in accordance with the repellent method in the national standard evaluation of anti-mite performance of GBT 24253-2009 textiles.

3. Results and discussion

3.1 Molecular structure

From Fig.1(a) can be seen the function of plant extracts from TCM/PAN blend fibers main groups
respectively corresponding to the absorption peak of 701.96 cm\(^{-1}\) (CH\(_2\) in-plane swing), 950.73 cm\(^{-1}\) (carboxylic acid in-plane bending), 1015.82 cm\(^{-1}\) (C-O stretching vibration), 1168.65 cm\(^{-1}\) (C-O-C antisymmetric contraction), 1436.22 cm\(^{-1}\) (C=C stretching vibration of benzene ring skeleton peak), 1657.51 cm\(^{-1}\) key (C = O stretching vibration characteristic peak of ketone substance), 1730.31 cm\(^{-1}\) (C=O bond stretching vibration), 2240.87 cm\(^{-1}\) (nitrile base characteristic absorption peak), 2916.80 cm\(^{-1}\) (C-H bond anti-stretching vibration) and the characteristic peak of O-H stretching vibration near 3400 cm\(^{-1}\). Function of plant extracts from TCM/PAN blend fibers with ordinary acrylic fiber are near 3400 cm\(^{-1}\) ~ 3500 cm\(^{-1}\) link appeared in the characterization of macromolecular hydrogen bond O-H stretching vibration characteristic peak, near 2240 cm\(^{-1}\) in characterization of nitrile characteristic peak, this shows that the function of TCM/PAN blend fibers to maintain the normal acrylic fiber original basic molecular structure. However, the characteristic peaks of benzodiazepine skeleton and ketone in the extract were found in the infrared spectrogram of the TCM/PAN blend fibers. In conclusion, the addition of LC extract and HX extract did not destroy the basic structure of the acrylic fiber, and introduced substances such as benzene ring and ketone for the blend functional fiber, making it have certain functions.

Figure1. (a) Infrared spectrogram of blend fibers. (b) Infrared spectrogram of ordinary fiber.

3.2 The surface morphology of the fibers

The fiber sections obtained by slicing method and brittle method were observed by scanning electron microscopy at low magnification. Fig.2 (a)-(b) are respectively cross-sectional images of the two fibers. Fig.2 (c)-(d) respectively show the longitudinal surface morphology of the two fibers. As shown in Fig.2 (a)-(b), the cross section of the TCM/PAN blend functional fiber and ordinary acrylic fiber is mostly round or oval. There is no obvious difference between the two kinds of fibers in the cross section shape at lower amplification and they are relatively flat. The cross-section of the fiber was observed under high magnification, and it was found that the TCM/PAN blend fiber had a more obvious circular section, and the mixed functional fiber formed more internal grooves during the solidification process. This may be because the addition of Chinese herbal extracts affects the solidification rate of the fibers. Another possible reason is that the fibers fall off during the brittle process. This phenomenon indicates that there are many active components of functional agents in the fiber. As shown in the longitudinal electron microscopy figures of Fig.2 (c)-(d), there are 1~2 axial grooves on the longitudinal surface of ordinary acrylic fiber and functional acrylic fiber. Compared with ordinary acrylic fiber, the surface grooves of blend functional fiber are deeper, but the whole is more flat. From electron microscope can also be seen in the figure, nanoscale plant fiber surface with the function of TCM extract ingredients, combined with Fig.2 (d) can show that the function of acrylic fiber inside, the surface has the existence of the active components of Chinese medicine extract.
3.3 Mechanical properties

The mechanical properties of the TCM/PAN blend fiber and ordinary acrylic fiber were shown in Table 1. According to the test data in Table 1, the fracture strength and elongation of the acrylic fiber with the addition of TCM are lower than that of ordinary acrylic fiber in both dry and wet state. This is because the addition of the TCM extracts causes the fiber to form more micropores than ordinary acrylic fiber in the spinning solidification process, which affects the mechanical properties of the fiber to some extent. In addition, the addition of plant the TCM extracts improves the problem of large reduction of mechanical property of acrylic fiber in wet state. This is because according to the test of swelling rate of blend film, both of the two plant TCM extracts added have certain hygroscopic property, and LC extract has greater hygroscopic property than HX extract. The two fibers tested in this study were primary fibers which were obtained by spinning sample mechanism.

| Fibers         | Breaking strength (cN/dtex) | Elongation at break (%) |
|----------------|----------------------------|-------------------------|
|                | dry | wet   | dry | wet   |
| Ordinary fiber | 2.05| 1.74  | 25.36| 18.86 |
| Blend fibers   | 1.62| 1.35  | 21.52| 17.29 |

3.4 Thermal stability

As shown in Fig.3, the mass decline trend of blended functional acrylic fiber and ordinary acrylic fiber is basically consistent, but the weight maintenance rate of ordinary acrylic fiber is only 33.77%, while the weight maintenance rate of the TCM/PAN blend functional fiber is 68.41%, which is 50.64% higher than that of ordinary acrylic fiber. The heat loss of primary fiber under nitrogen during the heating process is mainly reflected in the cyclization reaction during the heating process[7]. The cyclization reaction is due to the fact that PAN copolymer contains highly active -C dimethyl sulfoxide functional group. When dimethyl sulfoxide is thermally decomposed to reach the activation point, and the negative oxygen atoms on the sulfoxide functional group -S=O will attack carbon atoms on the -C congruent N, thus causing unsaturated triple bonds to open and cross-linking. In the process of wet spinning solidification forming, there are some residual DMSO solution and diffused water in the fiber. Therefore, in the process of thermal analysis of primary fiber, dimethylsulfoxide and water are also included in the thermal reaction besides PAN[8].
3.5 Antibacterial and Anti-mite

The bacteriostatic effect measured by concussion method is shown in Fig.4 (a)(b), and the size and bacteriostatic rate of the bacteriostatic belt are calculated. As can be seen from Fig.4 (a)(b), the bacteria colonies in the plates of the TCM/PAN blend fiber were far less than those in the plates of ordinary acrylic fiber by counting the number of colonies. The bacterial inhibition rate of the TCM/PAN blend fiber was 93.83%, which was much higher than the requirement of national standard that the bacterial inhibition rate was greater than or equal to 70%. This was consistent with the qualitative test results, indicating that the TCM/PAN blend fiber had good bacteriostatic effect.

Results such as Table 3, it can be seen from the test data in Table 3, by contrast, the number of mites survive is less than that of controls, function of the TCM/PAN blend fiber non-woven fabrics of mite displacement rate was 83.21%, indicating that HX extract as a function of anti mite agent played a good anti mite effect, income effect of fibre products with strong anti-mite.

![Figure 3](image)

**Figure 3.** Thermogravimetric analysis of two kinds of fibers in nitrogen atmosphere

![Figure 4](image)

**Figure 4.** (a) The bacteriostatic effect of ordinary acrylic fiber was measured by shock method. (b) The antibacterial effect of blending functional fibers was measured by shock method.

**Table 2.** Results of anti-mite test

| Sample                         | Action time (h) | Number of mites in petri dishes in control group | Number of mites in petri dishes in experimental group | Ward off rate (%) |
|--------------------------------|-----------------|---------------------------------------------------|-----------------------------------------------------|-------------------|
| Non-woven functional fiber of TCM/PAN blending | 24              | 137                                               | 23                                                  | 83.21             |
4. Conclusions
The cross-section of PAN fiber prepared by the addition of LC extract and HX extract of the plant TCM was mostly round and oval. The addition of extracts makes the fiber more grooves and holes. The basic mechanical properties were slightly lower than ordinary acrylic fiber. Through the infrared spectrum analysis of the extract and fiber, it was found that the functional fiber of the TCM /PAN blends retained the original basic molecular structure of ordinary acrylic fiber, and the characteristic peak of benzodiazepine skeleton and ketone in the extract, which played the anti-bacterial and anti-mite effect, was also found in the infrared spectrogram of the blend functional fiber. Through under nitrogen atmosphere thermal performance test of fiber blending function of acrylic fiber and ordinary acrylic fiber quality are almost consistent downward trend, but the weight of the ordinary acrylic fiber keeping rate of only 33.77%, and function of plant extracts from TCM/PAN blend fibers remain at a rate of 68.41%, the weight of the retention increased by 50.64% than ordinary acrylic fiber. In the quantitative antibacterial experiment, the antibacterial rate of the functional fiber blended by the plant TCM/PAN was 93.83%.The repellent rate of non-woven fabric of the TCM /PAN blend functional fiber was 83.21%.

Acknowledgements
This work was financially supported by Husheng Yu fund.

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