Surface structures and properties of rabbit hair fibers treated with cold gas plasma

Hou Dayin [1 *], Wei Qufu[2], Li Liangfei[1]

(1. Key Laboratory of Textile Materials of Anhui Colleges, Anhui Univ. of Tech. and Sci., Wuhu, Auhui 241000, China;
2. Key Laboratory of Eco-Textile (Ministry of Education), Southern Yangtze Univ., Wuxi, Jiangsu 214122, China)

Abstract: The cuticle scales grown smoothly and closely packed on the surface of rabbit hair fibers which resulted in low surface friction coefficient and poor dyeability of the materials. In this study, cold gas plasma was used to modify the rabbit hair fibers. The effects of plasma treatment on the surface morphology and contact angles were characterized using atomic force microscopy (AFM) and dynamic contact angle (DCA) measurments. The AFM observations showed that the cuticle layers of rabbit hairs were gradually removed and the etching effect was obviously revealed after plasma treatment. Plasma treatment significantly reduced both the advancing contact angles and receding contact angles of the rabbit hair fibers, as evaluated by DCA tests. The investigation also showed that plasma treatment led to improvement in fiber crimp and the dyeability of the rabbit hair fibers.

Key words: cold gas plasma; rabbit hairs; dynamic contact angles; dye uptake

0 Introduction

Rabbit hair, one of the animal protein fibers, enjoys a reputation as "green soft gold" due to its excellent properties such as softness and fluffy hand, smooth surface and good heat insulation. However, the very slight relief of the cuticle scales on the fiber surface causes its low friction coefficient, low bonding force between fibers and poor dyeability. Rabbit hair fabrics are easy to loss fibers, which have limited the development of rabbit hair products. Therefore, there is a growing demand for the modification of rabbit hair. In recent years, various techniques have been tried to modify rabbit hair fibers. Composite agents were used to modify rabbit hair for increasing surface friction and crimp in order to improve spinnability of the fibers[1]. The use of sericin to stick the rabbit hair fibers for controlling washing shrinkage was also tried[2] and the use of enzymes to solve hair loss problems was reported in the literature[3]. Natural polymers were used to modify rabbit hair for increasing breaking strength[4]. Whereas, all these methods can be used to modify rabbit hair in different ways, but they have such disadvantages as influencing on its bulk properties, environmental pollution and poor dyeability.

Plasma treatment is a kind of environmental-friendly surface modification technologies. It treatment is also a simple and short modification process without any pollution. Moreover, plasma modification only takes place on the upmost surface of fibers and the bulk properties of materials remain unchanged[5-6].

In this paper, rabbit hair fibers were treated with oxygen plasma to roughen the surface, increase fiber crimps, improve the cohesion between fibers, reduce the advancing contact angle and receding con-

* Corresponding author: Associate professor, Tel: 0086-13955323995; E-mail: houdayin0141@sina.com

tact angle, and increase the dye uptake. AFM was used to observe the surface morphology, and dynamic contact angle measuring apparatus was employed to measure the advancing and receding contact angles.

1 Experimental

1.1 Materials

The fibers used in this study were the down hairs of rabbits (native to Anhui China), with an average diameter of 18.8μm and an average length of 38.5mm.

1.2 Experimental processes and methods

Plasma treatment was performed in a HD-1A vertical plasma treatment machine. Oxygen was used as a working gas at a pressure of 20Pa. With a process power of 100W, the reaction time was adjusted to 10s, 30s and 60s, respectively.

A CSPM4000 AFM made by Benyuan Co,Ltd. was employed to scan the surface morphology of rabbit hair fibers before and after plasma treatment in contact mode. The maximum scanning size was 20 ×20μm, and the scanning frequency was set at 1.0Hz.

A CDCA-100F Dynamic Contact Angle Fibre Tensiometer produced by the Camtel ltd. in the U.K. was used to measure the surface contact angles of the untreated and treated rabbit hair fibers based on the Wilhelmy principle.

An YG362A crimp elasticity instrument was utilized to investigate the crimp performance of rabbit hair fibers.

Prior to testing the dye uptake using a 721 grating spectrophotometer, the rabbit hair fibers were dyed with acid dyes.

2 Surface structures and dynamic contact angles

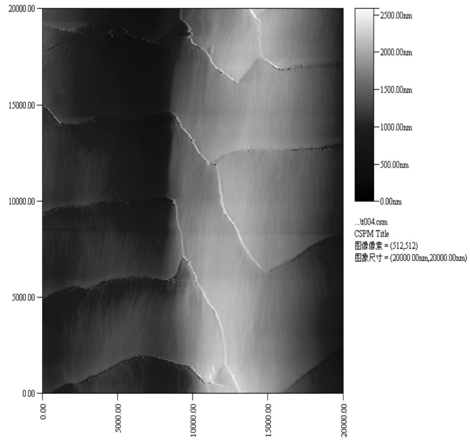
2.1 AFM observation

The rabbit hair fibers without plasma treatment seem to be smooth, but with cuticle layers closely arranged like roof tiles, as shown in Fig.1(a). The image also indicates that the flare angles of scales are rather small, and the surface roughness of the rabbit hair fibers is about 34.9nm. Subsequent oxygen plasma treatment significantly modifies the surface morphology. Fig.1(b)～(d) shows the rabbit hair fibers treated with oxygen plasma for 10s, 30s and 60s, respectively. In Fig.1(b), it can be seen that after treated for 10s, the cuticle layers are in irregular alignment with aggregates in varying sizes emerged on its surface, which indicate that plasma etches the surface of rabbit hair fibers. The surface roughness is about 108nm. The cuticle layers of rabbit hair fibers are almost disappeared, as the treatment time is increased to 30s, and its surface roughness is increased to 168nm, as shown in Fig.1(c). The AFM image in Fig.1(d) shows the details of surface structure of the rabbit hair treated for 60s. The image clearly reveals that cuticle layer has completely vanished, and its surface roughness reaches 213nm. From the AFM images, it appears that longer treatment results in the increase of surface roughness.

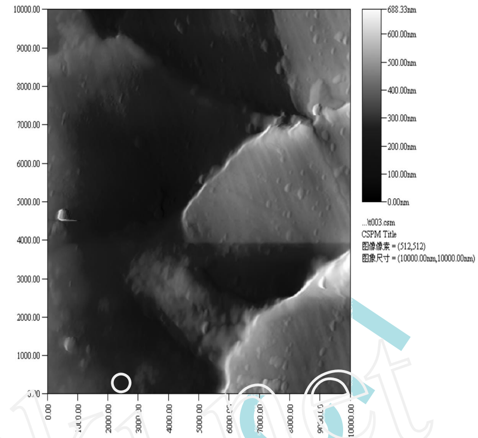
2.2 Dynamic contact angle

The dynamic contact angles (including advancing contact angle and receding contact angle) before and after plasma treatment are listed in Tab.1.

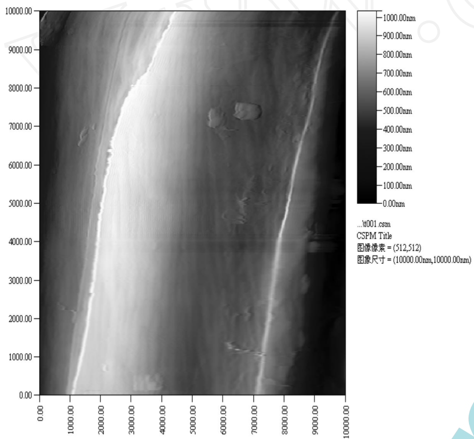
Results in Table 1 indicate that both the advancing and receding contact angles are significantly reduced after oxygen plasma treatment. The fibers show very high advancing and receding contact angles due to surface fat and other substances before plasma treatment. The advancing and receding contact angles are considerably reduced after the plasma treatment for only 10s. After treated for 60s, the advancing contact angle is reduced to about 38° and the receding contact angle is less than 10° (when the contact angle is less than 10°, the data displays as 0°), which indicates that the rabbit fiber has been proper-



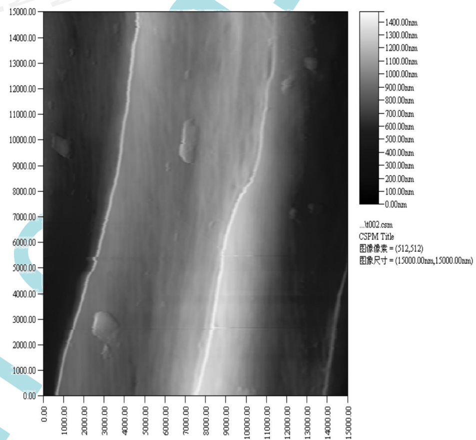
(a) Untreated



(b) Oxygen plasma treated for 10s



(c) Oxygen plasma treated for 30s



(d) Oxygen plasma treated for 60s

Fig. 1 AFM images of rabbit hair fibers

ly wetted. It is believed that due to plasma reaction occurring on the fiber surface, the fatty substances on the surface of rabbit hair fibers are etched and oxygen hydrophilic groups are grafted onto the surface of rabbit hair fibers, which are the main reason for the significantly improved wettability.

Table 1 The advancing contact angle and receding contact angle

Working gas	untreated		10s		30s		60s	
O_2	θ_a	θ_r	θ_a	θ_r	θ_a	θ_r	θ_a	θ_r
Contant angle/ (°)	110	80	72	55	65	48	38	0

Note: Power is 100W, pressure is 20Pa, θ_a is advancing contact angle, θ_r is receding contact angle

3 Properties of rabbit hair fibers after plasma treatment

3.1 **Crimp property**

The testing results of crimp properties of rabbit hair fibers before and after plasma treatment are listed in Table 2.

From the results, it can be seen that after plasma treatment, the crimp degree is increased by 64.76 %, and the crimp recovery is also increased by 55.91 %, however, the crimp elasticity is decreased by 4.61 %. It appears that crimp degree after plasma treatment is considerably increased, contributing to the increased cohension between rabbit hair fibers, therefore, the problem of hair loss with the fabric is improved. It can be attributed to the roughening of the fiber surface, because of the etching effect of plasma on cuticle layers.

Table 2 Fiber crimpness, crimp recovery and elasticity of rabbit hair fibers *

Performance index	Untreated	After plasma treatment
Crimp degree(%)	0.37	1.05
Crimp recovery(%)	0.41	0.93
Crimp elasticity(%)	105.59	97.98

* Treatment condition of oxygen plasma: under 20Pa at 100W for 30s

3.2 Dye uptake

Dyeing formula: Dyes (domestic products) 1%; Duisburg sodium sulpate 8.0%; Acetate pH value 5; Bath ratio 1 ∶50.

Dye uptake is shown in Fig.2, Fig.3 and Fig.4.

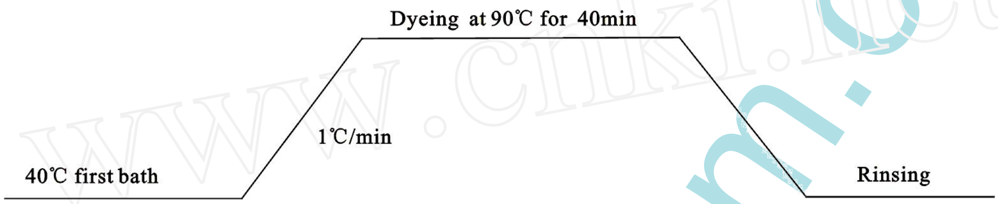


Fig.2 Dyeing technics

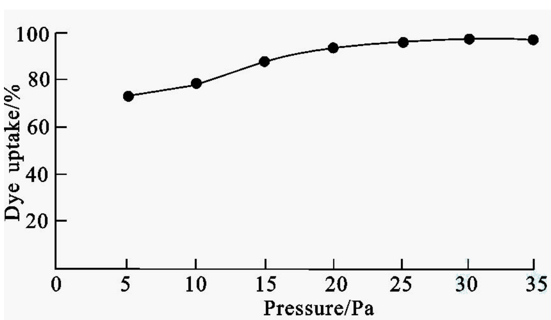


Fig.3 Dye uptake of rabbit hair fibers treated with plasma at different pressures (power of 100W for 60s)

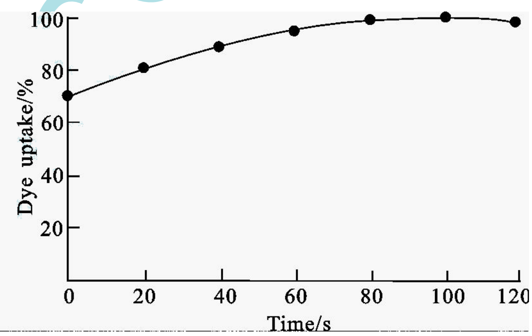


Fig.4 Dye uptake of rabbit hair treated with plasma for different times (power of 100W under 20Pa)

From Fig.3 and Fig.4, it can be seen that the dye uptake of rabbit hair fibers can be increased from 75.9% for the untreated samples to the maximum of 97.8% after plasma treatment. The dye uptake of rabbit hair fibers treated with a power of 100W at a pressure of 20Pa for 60s reaches 95.8%, indicating the significant improvement in dyeability by plasma treatment. It is conceivable that oxygen plasma treatment considerably increases the surface free energy of the fibers, reduces the advancing and receding contact angles, increases the surface polarity of the fiber, and introduces hydrophilic groups onto the fiber surface. Meanwhile, the cuticles are flared by plasma treatment, which facilitates the penetration of the dyes into the interior of fibers, contributing to the increase of dye uptake.

4 Conclusion

Due to plasma reaction occurring on the surface of rabbit hair fibers, the cuticle layers were etched by plasma treatment. As the reaction time was prolonged, the cuticle layers were completely vanished, and the surface roughness was increased.

Cold gas plasma treatment could considerably reduce the advancing contact angles and receding contact angles of rabbit hair fibers. As the reaction time was increased to 60s, the receding contact angle was reduced to less than 10°.

Plasma treatment significantly increased the crimp degree, crimp recovery and the dye uptake of rabbit hair fibers.

References:

[1] Liu Jianzhong. Modification of rabbit hair fibers and its property analysis. Journal of Tianjin Polytechnic University. 2005,24(1):37-38. (in Chinese)

[2] Pan Fugui. Study on reducing the hairfalling of rabbit hair knitted fabrics by use of sericin. Journal of Qingdao University Engineering & Technology Edition,2001,16(2):14-16. (in Chinese)

[3] Xi Bojun. Modification of rabbit hair fibers by use of enzyme. Knitting Industries,2005(9):54-56. (in Chinese)

[4] Mao Zhiping, Mao yahong. Modification of rabbit hair fiber with natural polymer. Textile Auxiliaries,2002,19(6):17-21.

[5] Luigi Carrino,Govanni Moroni. Cold plasma treatment of polypropylene surface:a study on wettability and adhesion. Journal of Materials Processing Technology,2002,121:373-382.

[6] Tsai PP Y,Wadsworth L C,Roth J R. Surface modification of fabrics using a one atmosphere glow discharge plasma to improve fabric wettability. Textile Research Journal,1997(5):359-369.