FIBRES & TEXTILES in Eastern Europe

Research Article • DOI: 10.2478/ftee-2022-0023 FTEE • 151(3) • 2022 • 57–60

Shrink-Proof Treatment Parameter Optimisation of Cashmere Yarn

Long Li[1]*, Wei Wang[2], Xian Zhang[1], Lei Wu[1], Dan Yang[1]

[1] School of Textile Science & Engineering, Xi'an Polytechnic University, Xi'an 710048, P.R. China
[2] Science and Technology Department, Xi'an Polytechnic University, Xi'an 710048, P.R. China
* Corresponding author. E-mail: lilong2188@126.com

Abstract
Cashmere fiber has soft hand and good elasticity. However, it exhibits shrink because of its scale. In this work, cashmere yarn (38.26 tex) was treated using NaCl-$KMnO_4$ to reduce the shrink of cashmere yarn. Orthogonal design and fuzzy comprehensive evaluation were used for optimizing treating parameters. Experimental results showed that the yarn shrink percentage of treated yarn was 0.56% which was less than that untreated yarn, and the treated yarn strength had a little drop compared with untreated yarn. The fiber scale outline of treated yarn could be observed by SEM, but the scale edge is blunt and irregular.

Keywords
cashmere yarn; shrink-proof, potassium permanganate treatment, yarn shrinkage percentage.

1. Introduction

Cashmere fiber, as a special animal fiber and high quality textile material, has soft handle and good elasticity. In the delicate and expensive processing or excellent comfort during wearing, water is inevitable [1]. Zhan [2] investigated the interaction between water and pore size distribution in cashmere fibers. The pore structure of cashmere and the interaction of water with fibers caused a difference in the melting enthalpy between bulk water and free water in cashmere. Cashmere consists of a cortex layer and scale layer. The scales of cashmere fibers are damaged in the process of high-temperature dyeing, consequently the mechanical properties of cashmere fiber decrease [3,4]. Moreover, cashmere fiber is more sensitive to oxidants as compared with wool fibers, for example the scales of cashmere fiber are damaged at a potassium permanganate content of 9%, while the scales of wool fiber are clear [5].The scales of animal fibers are believed to be a major contributor to the felting shrinkage of products made from these fibers. Whewell [6] reported that the felting or milling shrinkage of wool fabric is primarily due to the scaliness of the fibers. Therefore, the scales of cashmere fibre cause the felting thereof or of fabrics as well. However, the felting property of cashmere fibers influences the dimensional stability of cashmere fabric [7]. The dimensional stability of fabric influences the comfort and look of such articles after repeated laundering [8]. The mechanism of fiber felting is very complicated. In general, felting is a form of tangling produced by the persistent rootward migration of the individual fibers, which is caused by the directional frictional effect of the fibers [9,10]. Studies on wool fiber anti-felting treatment have been reported widely, however there are few reports on the anti-felting treatment of cashmere fibers. Li [11] reported the anti-felting treatment of cashmere fibers using potassium permanganate, where oxidised cashmere had a low felting assembly volume and directional frictional effect. Fibre anti-felting treatment is beneficial to large lot production. To be suited to small production, we investigated the shrink-proof treatment of cashmere yarn by potassium permanganate in a saturated solution of sodium chloride.

2. Experimental

2.1. Materials

White cashmere yarn was purchased from Huixing Cashmere Limited Co., China, The yarn linear density was 38.26tex, yarn strength 151.6cN, and yarn breaking elongation 37.8%.

Chemical agents were as follows: potassium permanganate (Tianjin Fine Chemical Limited Co.), glacial acetic acid (HAc) (Tianjin Fine Chemical Limited Co.), and sodium sulfite (Tianjin Hongyan Chemical-agents Co.).

2.2. Yarn shrink-proof treatment procedure

The disulfide bonds and peptide bonds in the fiber scale break when the fiber reacts with potassium permanganate in the solution of potassium permanganate and additives under a certain temperature. Moreover, the fiber surface has manganese dioxide (MnO_2) which shows a brown colour on the surface. The reaction is shown by Equation (1) as follow

$$\begin{array}{l} HOOC-CH(NH_2)-CH_2-S \\ \qquad\qquad\qquad\qquad\quad | \; + KMnO_4 \rightarrow 2HOOC-CH(NH_2)-CHSO_3H + MnO_2\downarrow \\ HOOC-CH(NH_2)-CH_2-S \qquad\quad \downarrow \\ \qquad\qquad\qquad\qquad\qquad\quad P-COO^- \\ P-CONH-P + KMNO_4 \rightarrow \qquad\qquad + MnO_2\downarrow \\ \qquad\qquad\qquad\qquad\qquad\quad P-NH_3^+ \end{array} \tag{1}$$

Oxidised fibers are treated in the reducing solution of sodium sulfite and additives to remove the brown colour on the surface; the reaction process is as follows (Equation 2):

$$MnO_2 + 4H^+ + 2e = Mn^{2+} + 2H_2O \tag{2}$$

Cashmere yarn was treated by potassium permanganate in a saturated solution of sodium chloride **(**NaCl-$KMnO_4$**). A** saturated solution of sodium chloride can prevent the over-oxidation of fiber during the treatment and, in turn, serious fibre damage.

Yarn pretreatment in water (40°C for 10 min) → NaCl-$KMnO_4$ treatment → rinsing (25°C, three times) → Na_2SO_3 reduction treatment → rinsing (25°C, three times) →drying

Bath ratio 1:50. Reduction treatment condition: Na_2SO_3 content 25 g/L, HAc 20 ml/L, and 45°C for 15 min

NaCl-$KMnO_4$ treatment of yarn was done using the orthogonal experiment method. Orthogonal design parameters are shown in Table 1.

Level	Temperature °C	Time min	$KMnO_4$ content %	Auxiliary content %
1	30	10	1	1
2	40	20	2	2
3	50	30	3	3
4	60	40	4	4

Table 1. Orthogonal design parameter for NaCl- $KMnO_4$ treatment

2.3. Property test

Yarn shrinkage percentage (YFP):

100 cm yarn was folded four times lengthwise, then folded yarn was put into a plastic bottle of 65 mm×65 mm×85 mm dimensions, next 150 ml of liquid soap was added at 40°C, and the bottle was capped. The bottle was put into a box at a rotating speed 60 rpm for 30 min, after which the yarn was taken out from the bottle, dried at 80°C in an oven, and then the yarn length *L* (cm) was measured. In accordance with reference [12], the yarn felting percentage was calculated by Equation 3:

$$\text{YFP}(\%) = \frac{100 - L}{100} \times 100\% \qquad (3)$$

20 yarns were tested for each sample, and then the average of YFP was calculated.

Yarn tensile property:
The yarn tensile property was tested on a YG020A single yarn strength tester according to the GB/T3916-1997 standard. The yarn length was 500 mm and the tensile speed 500 mm/min. 50 yarns were tested for each sample, and then the average of the yarn strength and elongation was calculated.

Yarn elastic recovery (YER):
Yarn of 300 mm length was selected as a test sample. One end of the yarn was fixed, the other loaded at 46 g for 3 min, and the yarn length (L_1) was tested again. Taking off the load, the yarn was relaxed for 2 min, and then the yarn was loaded at a pre-tension of 1.5 g,, and the yarn length (L_2) was tested. The yarn elastic recovery (YER) was calculated according to Equation (4):

$$\text{YER}(\%) = \frac{L_1 - L_2}{L_2} \times 100\% \qquad (4)$$

20 yarns were tested for each sample, and then the average of YER was calculated.

Scale observing of fiber:

The fibers were taken out from yarn, and the scale of the fiber was observed by means of a scanning electronic microscope, where the fibers were coated with gold, and then the observation was performed.

3. Results and Discussions

The results of NaCl-$KMnO_4$ treatment are shown in Table 2. Fuzzy mathematics has been widely used in many fields to solve engineering problems. In an multi-index orthogonal experiment, the multi-index system of the orthogonal experiment is analysed by the related method of fuzzy mathematics [13,14]. The fuzzy orthogonal method fuzzifies the results of orthogonal experiments, and then the experimental data is processed with the theory and method of fuzzy mathematics, which can estimate not only the main effect of factors but also their optimum combination, and more information can be obtained under the same experimental workload. To evaluate the YEP, strength, elongation and YER of treated yarn and obtain an optimum combination of treatment parameters, fuzzy mathematical theory is used for analysis of orthogonal experimental results in shrink-proof of cashmere yarn. Based on fuzzy mathematical theory [15], the subordination degree and comprehensive evaluation value for YEP, strength, elongation and YER is shown in Table 3. Based on the results listed in Table 3, four fuzzy sub-sets of experimental factors are as follows:

C_1=(0.329, 0.327, 0.191, 0.153),
C_2=(0.265, 0.296, 0.262, 0.177)
C_3=(0.231, 0.319, 0.236, 0.214),
C_4=(0.229, 0.217, 0.260, 0.293)

According to the principle of the maximum subordination degree, the individual factor influencing degree is as follows: C_1=0.329, C_2=0.260, C_3=0.319, C_4=0.293

Thus, the degree of individual factors influencing the fuzzy comprehensive evaluation value is listed as: C_1>C_3>C_2 >C_4, that is, the temperature>$KMnO_4$ content >time>auxiliary content. The optimum parameters for shrink-proof of cashmere yarn are 2% $KMnO_4$, 4% auxiliary, temperature 30°C and 20 min treatment time.

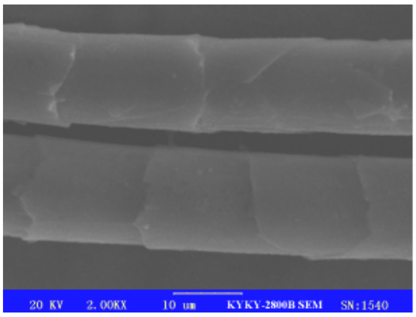
Cashmere yarn was treated under the optimum parameters, where the treated yarn properties were as follows: YFP 0.56%, strength 136.7cN, elongation 40.9%, and YER 4.5%. For untreated yarn, the YFP was 1.16%, strength 151.4cN, elongation 37.8%, and YER 4.5%. Figure 1 displays the scale morphology of fibre from the yarn, which shows that the scale of fibers from the treated cashmere yarn can be seen by SEM; however, the scales of fibers from the treated cashmere yarn have some damage and no bamboo-like

No.	Temp. °C	Time min	$KMnO_4$ content %	Auxiliary content %	YFP %	Strength cN	Elongation %	YER %
1	30	10	1	1	1.25	146.3	44.68	4.36
2	30	20	2	2	0.97	144.8	43.49	4.15
3	30	30	3	3	0.84	141.5	42.88	4.09
4	30	40	4	4	0.76	138.2	40.01	3.82
5	40	10	2	3	0.54	142.8	42.95	3.95
6	40	20	1	4	0.66	146.2	44.65	4.34
7	40	30	4	1	0.59	136.8	39.62	3.76
8	40	40	3	2	0.54	133.6	37.78	3.48
9	50	10	3	4	0.49	140.0	42.02	4.01
10	50	20	4	3	0.58	134.5	37.98	3.47
11	50	30	1	2	0.83	138.3	39.88	3.81
12	50	40	2	1	0.63	134.8	38.12	3.51
13	60	10	4	2	0.72	133.7	37.76	3.40
14	60	20	3	1	0.74	134.8	38.01	3.49
15	60	30	2	4	0.88	138.2	40.02	3.84
16	60	40	1	3	0.82	135.6	38.16	3.54

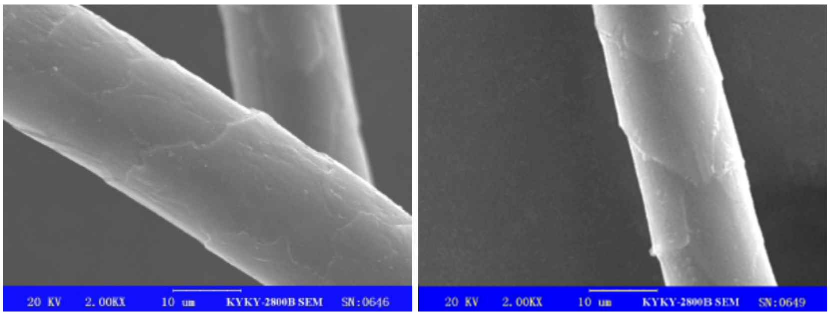
Table 2. Results of NaCl-$KMnO_4$ treatment

No.	Temp. °C	Time min	$KMnO_4$ content%	Auxiliary content %	YFP %	Strength cN	Elongation %	YER %	Comprehensive evaluation value
1	30	10	1	1	0.000	1.000	1.000	1.000	0.685
2	30	20	2	2	0.364	0.882	0.828	0.777	0.680
3	30	30	3	3	0.542	0.622	0.740	0.713	0.648
4	30	40	4	4	0.643	0.362	0.338	0.426	0.461
5	40	10	2	3	0.935	0.724	0.750	0.564	0.756
6	40	20	1	4	0.774	0.992	0.996	0.979	0.921
7	40	30	4	1	0.863	0.252	0.269	0.362	0.476
8	40	40	3	2	0.924	0.000	0.003	0.064	0.308
9	50	10	3	4	1.000	0.504	0.616	0.628	0.402
10	50	20	4	3	0.875	0.071	0.032	0.000	0.297
11	50	30	1	2	0.548	0.370	0.306	0.415	0.423
12	50	40	2	1	0.818	0.095	0.052	0.096	0.313
13	60	10	4	2	0.691	0.008	0.000	0.021	0.225
14	60	20	3	1	0.664	0.095	0.036	0.075	0.252
15	60	30	2	4	0.480	0.409	0.327	0.447	0.422
16	60	40	1	3	0.558	0.158	0.058	0.128	0.253
Σb_{i1}	2.473	2.068	1.571	1.725					
$(\Sigma b_{i1})'$	0.329	0.265	0.231	0.229					
Σb_{i2}	2.461	2.150	2.171	1.635					
$(\Sigma b_{i2})'$	0.327	0.296	0.319	0.217					
Σb_{i3}	1.434	1.967	1.608	1.954					
$(\Sigma b_{i3})'$	0.191	0.262	0.236	0.260					
Σb_{i4}	1.151	1.334	1.458	2.206					
$(\Sigma b_{i4})'$	0.153	0.177	0.214	0.293					

Table 3. Subordination degree and comprehensive evaluation value



(a)



(b)

Fig. 1. Scale morphology (SEM) of cashmere fibers from yarns: a) untreated yarn, b) treated yarn

morphology, the scale edge of fibers from the treated cashmere yarn are blunt and irregular, compared with the scales of fiber from untreated cashmere yarn. The scale change is believed to be the major contributor to the shrink-proofing of the treated cashmere yarn.

4. Conclusions

Cashmere yarn can be treated by potassium permanganate in a saturated solution of sodium chloride ($NaCl-KMnO_4$) under optimum parameters to reduce its shrinkage. Treated cashmere yarn has a low yarn felting percentage, but the strength shows a little drop and elongation has a little rise compared with untreated yarn. Although the scale morphology of fibers from the treated cashmere yarn has some damage, the fiber scales' outline of the treated yarn can be seen by SEM, which plays an important role to cashmere identification. Shrink-proof treatment of cashmere yarn provides a new way for developing cashmere fabric with a shrink-resistant function.

Acknowledgement

We are grateful for the support of this work by the Science and Technology Department of Xi'an City (No. CXY1018).

References

1. Zhan L, Yang Y, Li G, et al. 2020. Drying kinetics and mechanical properties of low temperature microwave dried cashmere fibers. *Textile Research Journal* 90: 2745-2754.
2. Zhan L, Li Y, Ji F, et al. 2021. Analysis of states of water in cashmere fibers and utilizing water as molecular probe for pore size distribution. *Polymer Testing* 101: doi: 10.1016/j.polymertesting.2021.107285
3. Zhan L, Wang G, Zhao X, et al . 2021. Effect of low-temperature dyeing on properties of cashmere fibers, *Journal of Natural Fibers*, doi: 10.1080/15440478.2020.1870617
4. Li Q, Li L, Shao J. 2012. Effect of low temperature dyeing on physical property and surface morphology of cashmere fibers. *Journal of Engineered Fibres & Fabric* 7(1) :58-61.
5. Li L, Qin C, Liu C. 2018. Comparison of the structure and properties of wool and cashmere fibers under potassium permanganate treatment. *Fibers & Textiles in Eastern Europe* 26 (4): 29-33.
6. Whewell C. S., Rigelhaupt L., Selim A. 1944. Mechanism of the milling shrinkage of wool fabrics. *Nature* 154(16): 772.
7. João C, Bonner P. L. R and Martin G. 2004. Application of transglutaminases in the modification of wool textiles. *Enzyme and Microbial Technology* 34(1): 64-72.
8. Li L, Li H. 2004. Cashmere processing technology. Shanghai: Donghua University Press.
9. Makinson K. R. 1964. Felting: the Present Picture. Recent Observation on the Mechanism of Felting. *Wool Science Review* 24:34-48.
10. Mercer E. H, Makinson K. R. 1947.The Friction Properties of Wool and Other textile Fibres. *Journal of Textile Institute* 38:T227-240.
11. Li L, Jiang F, Jia G. 2012. Anti-felting oxidation treatment of cashmere fibers. *Journal of Engineering fibers and Fabrics* 7(3): 111-117.
12. Huang S. 1988. Felting test of wool fibers. Beijing: Textile Industry Press.
13. Wang W, Yuan X, Li T. 1998. Study on the optimization of sugar manufacture parameters by fuzzy orthogonality. *China Beet & Sugar* 3: 4-7.
14. Wang Z, Li G, Liu J, et al. 2001. The optimum design for gleditsin dishwashing detergent by fuzz transform and orthogonal methods. *China Surfactant Detergent & Cosmetics* 31(3):14-16.
15. He Z. 1983. Fuzzy mathematics and its application. Tianjin: Tianjin Science and Technology Press.