

Study on Influences of Linen Fiber Modification Treatment on Dressing Prickle Sensation[★]

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Abstract

Prickle sensation is a key factor influencing the comfort of dressing. In this paper, the diameter, quantity and fiber bending property of hairiness on the surface of linen fabrics are measured after modification treatment of linen fiber. Meanwhile, the prickle sensation of linen clothing is evaluated by dressing experiments. And the changes of surface hairiness, fiber bending performance and their influences on the dressing prickle sensation of linen clothing are analyzed before or after the modification treatment of linen fiber. The results show that the diameter of the surface hairiness becomes thinner and much more in quantity after modification treatment, but the bending rigidity decreases. Furthermore, the perception value of prickle sensation of linen clothing after modification treatment decreases whether it is under sweating condition or not.

Keywords: Prickle Sensation; Linen; Dressing; Modification Treatment

1 Introduction

As one kind of natural fiber, linen has excellent properties, such as moisture absorption, breathability and cool, etc. In such an era advocating environment protection, linen has extensive market prospect. Because of the streak flaws, cracks and high crystallinity on its microcosmic surface, the fabric owns certain prickle sensation and hard to meet the requirements of consumers, which limits the development of high-end application of linen. Therefore, it is necessary to improve the property of linen fiber and its fabric via modification treatment.

As seen from the studies that, prickle sensation is caused by the mechanical stimulation of coarse and hard hairiness to the nerve terminals of epidermis. Prickle sensation often occurs on the fabrics of fur and linen fabric or those with coarse, short and hard fibers [1]. At present, scholars at home and abroad have paid much more attention to the prickle sensation of wool

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fabrics, including its generation mechanism and influence factors. The studies show that fiber diameter is the main factor for the generation of prickly sensation in wool fabrics [2,3]. However, the study on prickly sensation of linen fabric is relative rarely focused.

With linen fabric after modification treatment made by the research group from Jiangsu Sulong Textile Technology (Group) Co., LTD as experimental material [4], in this paper, the influences of the changes on the surface hairiness diameter, hairiness quantity, and the fiber bending performance of the linen fabrics before and after modification treatment on prickly sensation of linen clothing are discussed.

2 Experiments

2.1 Modification Treatment of Linen Fiber

Most of the researches at home and abroad paid attention to the liquid ammonia treatment of cotton or linen fabrics, while not focused on the liquid ammonia treatment of linen fiber or yarn. In this paper, modification medium (liquid ammonia) is employed to treat with the linen fiber or yarn. The research group [4] has developed the modification equipment for fibers and yarns independently, which comprises the modification medium transmission and recovery part, gaseous medium transmission and recovery part, modification treatment part and microwave heating part.

The developed modification equipment is employed to conduct modification treatment. The modification treatment process of linen fiber is as follow: drying the moisture, immersing it into liquid modification medium for modification treatment, removing the modification medium, pumping in air and removing the linen fiber. Through the treatment, the physical and chemical properties of linen fiber are improved.

2.2 Linen Fiber Property Test

The experimental materials are three pure linen plain woven fabrics designed by the company, among which, sample 1 is the linen fabric not going through modification treatment, sample 2 is that going through preliminary modification treatment, and sample 3 is that going through refined modification treatment.

The experiment is carried out in a laboratory with constant temperature and humidity (temperature: $20 \pm 2^\circ$, humidity: $65 \pm 3\%$).

2.2.1 Test of the Hairiness form on the Surface of Linen Fabric

10 small samples of $3 \text{ cm} \times 3 \text{ cm}$ are clipped from each sample fabric and the yarns around the four sides are unweave to turn into the size of $2 \text{ cm} \times 2 \text{ cm}$. The fabrics are folded along the same yarn and covered with glass slides, then are placed on the loading platform of optical microscope. The protruding hairiness on the head of folded yarn is observed with the magnification of 200 x. The diameters of the upper, middle and lower parts of each hairiness is measured by using CAE measuring software in the optical microscope, and the mean value is calculated as the diameter of hairiness, then count the quantity of the protruding hairiness on the yarn per 2 cm.

2.2.2 Test of Bending Behavior of the Fiber

50 fibers are drawn from each sample, and the fibers are arrayed one by one on the prepared plate. The diameters of fibers are measured by using optical microscope to obtain average values. Then, the fiber is placed between the rubber chucks of INSTRON in the original array order. The tensile strength, tensile displacement and elasticity modulus of the fibers is recorded by using INSTRON MERLIN.

2.3 Dressing Evaluation of Prickle Sensation

2.3.1 Experimental Preparation

In order to exclude the influences of the factors such as clothing style and fashion trends on the experimental results, the fabrics are clipped and sewed as the normal long-sleeve male’s shirt with the same style and size specification according to the body sizes of the subjects. The detailed sizes are shown in Table 1, and the style is shown in Fig. 1. The shirts are thoroughly washed before the experiment, and are balanced for over 12h in the laboratory with constant temperature and humidity.

As shown in Fig. 2, the evaluation scale of prickle sensation adopts five-grade marking system. Among which, 1 refers to “totally not prickly”, 2 refers to “a little prickly”, 3 refers to “prickly”, 4 refers to “very prickly”, and 5 refers to “extremely prickly”.

Table 1: Size specification of clothing (175/96A unit: cm)

Parameters	N	L	B	S	SL
Size	40	75	116	49	24.8

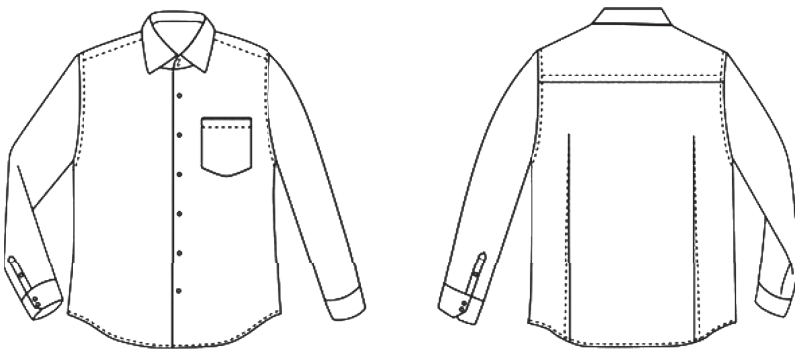


Fig. 1: Clothing sketch

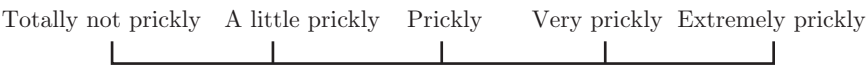


Fig. 2: Evaluation scale of prickle sensation

2.3.2 Experiment Conditions and Subjects

The experiment is carried out in a laboratory with constant temperature and humidity, and the wind speed is less than 0.1 m/s. The subjects are free from strenuous exercises within 24 hours before the experiment, and from spicy foods or those with alcohol or caffeine within 17 hours. During the experiment, the subjects are asked to wear the experimental shirt and the same trousers, with the shirt bottom inserting into the waist part of trouser, and the buttons at collar and cuff part are fastened. The same subject is required to complete dressing experiment within the same period of each day.

Three healthy male college students are selected as subjects, wearing three different shirts for the experiment. The selected male subjects are of the ages of 23 ± 2 years, the weight of 60 ± 5 Kg, and the stature of 170 ± 2 cm.

2.3.3 Experiment Contents

Before the experiment, the subjects are asked to sit still for 30min in the laboratory with constant temperature and humidity to adapt to the environment. According to the results of several preliminary experiments, the evaluation process is set as two phases: Phase I is the “Non-sweating status”, under which the subjects wear the shirts and wring the upper body to rub the clothes with human skin, and evaluate their perception of prickle sensation; Phase II is the “Sweating status”, under which the subjects wear the shirts and walk with constant speed on the treadmills at the speed of 3.8 km/h. Then, the subjects finish the exercise when feeling obvious hot and sweating at the neck and chest part, etc, and evaluate the perception of prickle sensation according to the experiment standard.

3 Results and Discussion

3.1 Analysis on the Dressing Prickle Sensation

The evaluation results for the prickle sensation of the three fabrics are shown in Table 2.

Table 2: Evaluation results of prickle sensation

Linen fabric No.	Prickle perception value	
	Non sweating	Sweating
1	2.2	2.6
2	2	2.3
3	1.6	1.8

Note: 1-non modification, 2-primary modification, 3-refined modification

As shown in Table 2, the perception intensity of subjects on dressing prickle sensation after sweating is greater than that before sweating. Pared-sample T test is done to distinguish the perception difference of dressing prickle sensation in non-sweating status and that in sweating status, and the analyzed result is shown in Table 3.

Table 3: Result of pared-sample T test

Status	Mean	Std. deviation	Std. error mean	t	Sig.
Non sweating	1.933	0.305	0.176	10	0.035
Sweating	2.233	0.404	0.233		

As shown in Table 3, it is clear that the value of sig. (2-tailed) is smaller than 0.05, i.e., $P < 0.05$; it means that there is significant difference of dressing prickle sensation in non-sweating status and that in sweating status.

When the subject running to sweat, the quantity of heat accumulated on human skin surface obviously increases, the receptor activities in skin activated by the surface hairiness of fabric become much more frequent, and the reflection of human body against prickle sensation becomes much more sensitive. In addition, after running, the surface skin of human body becomes softer, and surface hairiness of fabric brings greater prickle perception to human body. Garnsworthy [5] found that, the skin receptors perceive prickle sensation is because of the extensively distributed histamines in human cells are released and activated under mechanical stimulation, while temperature is a significant factor influencing the activities of histamines. When body heat goes up, histamines become much more active, thus the prickle sensation felt by human body after sweating gets greater.

The results of Table 2 also indicate that, no matter under non-sweating or sweating status, the perceptive prickle sensation of fabrics through refined modification treatment is less than that through preliminary treatment or not treated.

Although modification treatment has no obvious influence on the chemical composition of linen cellulose, after modification treatment, parts of crystals in the linen fiber are converted from cellulose I into cellulose II. It swells the amorphous region, damages some crystals and decreases the crystallinity, which makes the linen fiber softer, and promotes the comfortable property of linen fabric [4].

3.2 Variations of Surface Hairiness form and Its Influences

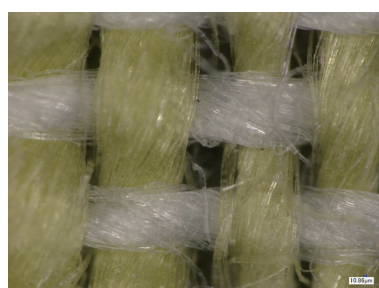
The hairiness diameter, quantity and dressing prickle sensation of the linen fiber before and after modification treatment is analyzed by using SPSS 20.0, and the relevant analyzed result is shown in Table 4.

From Table 4, it is clear that the mean diameters of surface hairiness of linen fabrics by refined modification treatment are obvious smaller than that not treated or going through preliminary treatment, but the hairiness quantity on each 2 cm yarn increases. This indicates that the modification treatment reduces the diameters of linen fibers, but increases the quantity of hairiness, which is shown in Fig. 3.

The bivariate correlation analyzed result shows that there is obvious relationship between dressing prickle sensation and the mean diameter of hairiness as well as quantity of hairiness. It means that the thicker the surface hairiness diameter is, the greater the dressing prickle sensation is; while with the increase of surface hairiness quantity, the dressing prickle sensation is reduced on the contrary. Hence, it is apparent that the hairiness diameter of surface fabrics is a significant factor influencing dressing prickle sensation.

Table 4: Correlation coefficient between prickle sensation and hairiness diameter, quantity

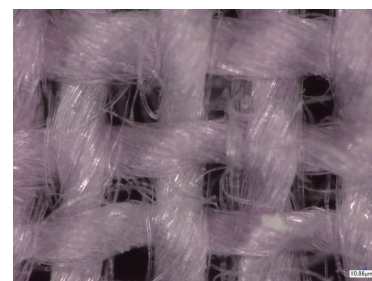
Sample No.	1	2	3	Correlation coefficient
Hairiness mean diameter/ μm	14.22	13.46	12.92	0.96
Hairiness quantity of yarn per 2 cm	28	30	38	−0.99
Hairiness quantity on $\geq 20 \mu\text{m}$ per 2 cm yarn	4	2	2	0.76
Hairiness quantity on $\geq 18 \mu\text{m}$ per 2 cm yarn	7	4	4	0.76
Hairiness quantity on $\geq 16 \mu\text{m}$ per 2 cm yarn	10	7	9	0.14
Hairiness quantity on $\geq 14 \mu\text{m}$ per 2 cm yarn	13	13	15	−0.95
Hairiness quantity on $\geq 12 \mu\text{m}$ per 2 cm yarn	18	19	20	−0.98
Hairiness quantity on $\geq 10 \mu\text{m}$ per 2 cm yarn	22	24	29	−0.99



Sample 1



Sample 2



Sample 3

(Note: 1—Non modification, 2—Primary modification, 3—Refined modification)

Fig. 3: Scanning electron microscope of linen fibers

Table 4 also indicates that the dressing prickle sensation of fabrics has positive correlation with the quantity of fibers with the diameter $\geq 16 \mu\text{m}$ on each 2 cm yarn, and negative correlation with those with the diameter $< 16 \mu\text{m}$, which means that the surface hairiness with the diameter $\geq 16 \mu\text{m}$ is a main factor influencing dressing prickle sensation of linen clothing. That is to say, the threshold value of single fiber diameter for judging dressing prickle sensation of linen clothing is $16 \mu\text{m}$.

3.3 Variations of Bending Behavior of Fibers and Its Influences

Fiber rigidity is a significant factor for the fibers contacting human skin to generate mechanical effects. In order to explore the relationship between surface fibers' bending behavior of fabrics and dressing prickle sensation, the diameter, breaking strength and breaking elongation of fibers are measured. Then the bending property of linen fibers not going through modification treatment and those going through primary or refined modification treatment is calculated by using bending rigidity calculation.

It can be seen from bending behavior of materials, bending rigidity can be calculated by multiplying the Young's modulus of material by the minimum centroid inertia moment of the cross section. The stretch formula of the material is shown in Eq. (1).

$$\frac{F}{S} = E \frac{\Delta L}{L} \quad (1)$$

From Eq. (1), we can obtain the Young's modulus of the material, see Eq. (2).

$$E = \frac{FL}{S\Delta L} \quad (2)$$

where, L is the object length, F is the acting force of the object at its length direction, L is the elongation under the acting force, and S is the sectional area of the material. The minimum centroid inertia moment of the perfect round section is shown in Eq. (3).

$$I = \frac{\pi D^4}{64} \quad (3)$$

where, D is the diameter of the material. As far as textile fiber is concerned, their section shapes are generally not perfect round, and the common calculation method is shown in Eq. (4).

$$I = \frac{\pi^3 \eta_f D^4}{64} \quad (4)$$

where, η_f is the section shape coefficient of the bending fiber, and the sectional shape coefficient of the linen fiber is 0.87 [6]. Thus, it can be derived that the calculation formula of bending rigidity R of the linen fiber is shown in Eq. (5).

$$R = EI = \frac{0.87\pi^2 D^2 FL}{16\Delta L} \quad (5)$$

The diameter of 50 fibers of each fabric is measured with optical microscope, and the tensile strength and tensile displacement of the linen fiber is measured by using INSTRON to form tensile curve. The unusual tensile curve arising from the relatively big error during the tensile process is excluded to select tensile curves of 40 fibers of each fabric for the calculation, as shown in Fig. 4.

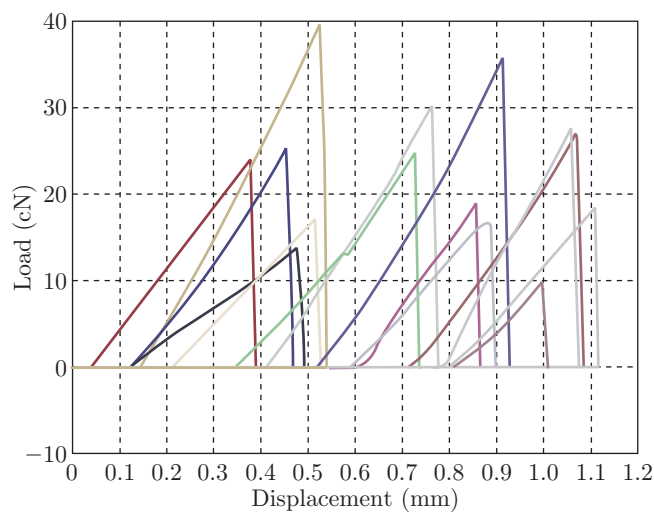


Fig. 4: Stretch curves of fibers

According to the definition of Young's modulus, Young's modulus is the strain ratio of the stress of the fiber within the elastic deformation range. As shown in Fig. 4, the tensile curve of linen is close to straight line, which can be considered that linen fiber is always within the elastic tension

range from beginning to the time of fracture. For the convenience of evaluation and calculation, the tensile force and corresponding elongation value at the tensile fracture point are evaluated to obtain the ratio of them, then the fiber diameter D and clamping distance L (with the standard of 10 mm) of INSTRON is measured, and the bending rigidity of each fiber is calculated by using the derived bending rigidity formula. The average of 40 times of calculation results of each fabric is obtained to serve as the average bending rigidity of the fiber of each fabric. Then, the bivariate correlation analysis on bending rigidity and dressing prickle sensation of fibers is done by using SPSS 20.0, as shown in Table 5.

Table 5: Correlation coefficient between prickle sensation and bending rigidity

Sample No.	1	2	3
Bending rigidity of fibers ($\times 10^{-4}$ cN* cm ²)	20.86	17.22	8.05
Correlation coefficient		0.999	

Table 5 shows that the bending rigidity of linen fabric fiber after modification treatment is significantly less than that not going through modification treatment or going through preliminary modification treatment, which means that modification treatment has reduced the bending rigidity of linen fibers, and made the fibers easier to be bent. Meanwhile, the correlation coefficient between the bending rigidity and prickle sensation of the fibers is 0.999, which indicates that the higher the bending rigidity of the fibers is, the greater the prickle sensation is. That is to say, the bending rigidity of fibers has influenced the degree of prickle sensation. This may because that the higher the fiber rigidity is, it is harder to be bent and deform when contacting with human skin, and will generate greater mechanical stimulation to skin, and thus make human body feel greater prickle sensation.

4 Conclusions

In this paper, the influences of the changes on the surface hairiness diameter, hairiness quantity, and the fiber bending performance of the linen fabrics before and after modification treatment on prickle sensation of linen clothing are discussed. Some conclusions can be obtained.

(1) No matter it is under non-sweating status or sweating status, the dressing prickle sensation of linen fabrics going through refined modification treatment is obvious less than that not going through modification treatment or going through preliminary modification treatment, and sweating will make the dressing prickle sensation greater.

(2) After refined modification treatment, the surface hairiness of linen fabrics become relatively thinner and much more, which means that refined surface modification treatment will make linen fibers be split into thinner fibers.

(3) The mean diameter of surface hairiness of fabrics and bending rigidity of fibers are positively correlated with the dressing prickle sensation, which means that the coarse hairiness on the surface of fabrics is the main factor causing dressing prickle sensation of linen fabrics.

(4) The threshold value of single fiber diameter causing the dressing prickle sensation of linen clothing is 16 μm and above.

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