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Fabric-evoked prickle of fabrics made from single fibres using axial fibre-compression-bending analyzer

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Fabrics made from cotton, cashmere, flax, hemp, ramie, jute, and wool fibres, have been used to investigate and analyze the prickle comfort properties of fabrics worn as garments. Physical properties include single-fibre critical load, compression and bending modules, which greatly affect the fabric physiological comfort. The fibres are tested using a ‘fibre axial compression-bending analyzer’. The behavior mechanisms of single-needle fibre are also analyzed, evaluated, and explained using fibre’s critical load, fineness, and protruding length. Physical and neuro-physiological basis for prickle sensation force from single-needle fibre depends on its bending modulus and axial compressive behavior. This experimental work shows that the bending modulus of ramie, jute, and wool fibre is significantly high as compared to other fibres. Thus, high prickle values of ramie, jute and wool fibres make them more uncomfortable due to the cross-section parameters and bending modulus of the single fibre needle. It is observed that the prickle feeling comes from the axial-compressive behavior and the number of effective fibre needles protruding from worn fabric surface.Therefore, prickle sensation aroused during skin–fabric contact is mostly related to the fibre and surface roughness characteristics of fabrics, and the effect of the fabric material on prickle is found to be more.

Keywords: Bending modules, Cashmere, Cotton, Fibre critical load, Fabric-evoked prickle, Fibre fineness, Fibre protruding length, Flax, Jute, Ramie, Wool

1 Introduction

In recent years, the textile industry has gradually focused its attention on consumer trends in clothing, particularly the comfort properties of wear fabrics. Fabric-evoked prickle is recognized as a fundamental quality of somatic sensation, separate from others such as touch, temperature, and itch. Fabric prickle is a complex perception associated with the interaction of a garment and the human skin, also described as a lack of comfort[1]. Furthermore, it has been identified as one of the most irritating discomfort sensations for clothing worn next-to-skin. This sensation results from the pressure exerted by the coarse fibre ends, which protrude from the surface of the worn fabric and press on the human skin hard enough to activate nerve ends[2,3]. The sensation is associated with any fibre that can exert sufficient pressure on the skin. The maximum force that a fibre will exert on the skin before it buckles depends on its diameter and the free length of the protruding end [2,4-7].

Fabric-evoked prickle sensation, one of the main factors for fabric wear comfort, has been objectively and psychophysically widely studied[4,5,8-12]. Thus, main findings from past studies of measuring prickle comfort characterization of a fabric or garment require a significant amount of work with the incipient psychophysical subjective (sensory) responses from human skin in contact with the worn fabric.

From an engineering standpoint, fibre ends protruding from the fabric surface act as a simple columns under compression. The fibre ends will thus buckle at a particular threshold force applied to the top of the fibre and parallel to the fibre axis, which is proportional to Ed^4/l^2 (where E is the Young’s modulus of the fibre, d is the fibre diameter and l is the length of the protruding fibre end)[13-15]. Thence, the critical buckling forces of fibre ends are commonly recognized as an objective indicator of prickliness when human skin contacts with the protruding short and coarse fibre ends from fabric surfaces. From the individual fibre end protruding above the fabric

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surface that is in contact with the skin, the neurophysiological experiments in combination with the critical buckling force of fibres have led to conclusions that the fabric-evoked prickliness is an increasing mechanical action [4,5,11,16]. This assumption guides most of the subsequent studies on fabric-evoked prickliness. Matsudaira *et al*[17].has found a method to objectively measure the surface prickle of fabrics. They compared the critical buckling force of simple Euler's column under low-pressure compression with a modified audio-pick-up method. The mean force per unit contact between fibres and the audio-pick-up stylus was found to correlate well with the subjectively determined relative degree of prickliness. The critical buckling force of simple Euler's column was widely used to explain the relationship between fabric-evoked prickliness and fibre end property. Little work has been reported on the matching of the well-known end restraints of the simple Euler's column with that of fibre end prickling human skin, which is very critical to precisely model and predict the level of fabric-evoked prickliness.

The classical buckling theory of a slender rod has been used to describe the buckling deformation of wool fibres, and hence identify an appropriate end-restraint condition of the surface fibres prickling human skin[13]. Hence, which are clamped firmly at one end against a fixed or unattached or hinged end, leading us to conclude that the end held in fabric surface is fixed and the other end is hinged if the fibre slippage is avoided.

The above discussion shows that the mechanical interaction between fibre's ends and human skin is a basic and common phenomenon that can be used to measure and investigate the fabric-evoke prickliness for worn fabrics. In this study, the critical load and flexural rigidity of protruding fibres of worn fabrics by axial compression have been all analyzed using Euler's theory of a buckling thin rod. A new technique for fabric-evoked prickle, which is based on a kind of axial fibre-compression-bending analyzer (FICBA), for single fibres taken from wear fabrics, is applied to examine and characterize prickle tactile discomfort[18].

2 Theoretical Consideration

The buckling of fibre protruding from the fabric surface when in contact with human skin can be imitated theoretically, by using Euler's formula for critical load of an axially compressed column with pinned ends [19]. Consequently, the buckling theory of a slender rod to uniform fibres was applied. Schematics of the axial-compression-bending analyzer and the coordinate system used for analysis are shown in Fig. 1. A compression force P_{cr} was applied to a single fibre of length l and fineness N_t. The critical force and buckled, mode shape of the single fibre was fixed at the base and pinned at the top[20].

Axial bending properties of single fibres were tested on the fibre-compression-bending analyzer [21,22] [Figs 1(a) and 1(b)]. Based on the critical load rule, proposed by Euler's, one end of the fibre was fixed, and the other was pinned onto moving clamp. The fibre was axially compressed between the mechanical stage and the loading piece, to determine the relationship of the critical force and the displacement. Figure 1(a) represents the axial compression bending model. Consequently, consider a fibre that is fixed at

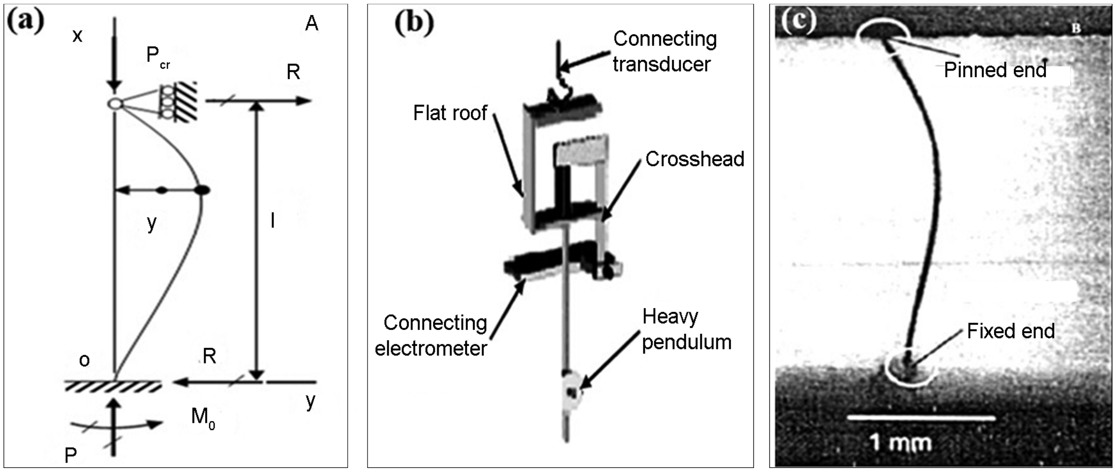

Fig. 1—Buckled column theory of axial-compression-bending analyzer (a), schematics of the axial fibre-compression-bending analyzer (b), and actual photograph of bending and buckling of single fibre (c)

the base and pinned at the top, to solve the differential equation in order to find P_{cr}. When the fibre buckles, horizontal reactive force's R develops at the supports and reactive couple M_0 develops at the base. The bending moment in the buckled fibre at distance x from the base is:

$$M = Py - R(l - x) \qquad \ldots(1)$$

From Eq. (1), the differential equation can be evaluated as shown below:

$$EIy'' = -Py + R(l - x) \qquad \ldots(2)$$

As a result, the general solution of the differential equation is:

$$y = C_1 \sin kx + C_2 \cos kx + R(l - x)/P \qquad \ldots(3)$$

where k denotes differentiation of the displacement y with respect to the longitudinal coordinates x; $k^2 = P/EI$ (where l is the extending length of fibre needle, P is the force in compressive axial load and E is the elastic modulus of the fibre); I, the moment of inertia; and R, the horizontal reactive forces.

There are three unknown constants (C_1, C_2, and R)which can be solved through the three boundary conditions, which are: $x = 0, y' = 0, x = l, v = 0$. By using Eq. (3) to match the three conditions, the following relationship was obtained:

$$C_2 + Rl/P = 0, C_1 k - R/P = 0, C_1 \tan kl + C_2 = 0$$

Non-triviality C_1, C_2, and R yield the following equation:

$$\begin{pmatrix} 0 & 1 & l/P \\ k & 0 & -1/P \\ \tan kl & 1 & 0 \end{pmatrix} = 0$$

The buckling equation is:

$$kl = \tan kl \qquad \ldots(4)$$

The value of kl can be determined by trial and error. The smallest nonzero value of kl satisfying Eq. (4) is: kl=4.493. Therefore, the corresponding critical force is:

$$P_{cr} = (kl)^2 \frac{EI}{l^2} = \frac{20.19EI}{l^2} \qquad \ldots(5)$$

To obtain the critical load value, Eq. (5) can be expressed as in following Eq. (6) by considering the effect of a single fibre shape factors η_f and fineness:

$$P_{cr} = \frac{20.19E\eta_f I_0}{l^2} = \frac{20.19\pi r^4 E\eta_f}{4l^2} = \frac{5.05E\eta_f S^2}{\pi l^2}$$
$$= \frac{5.05 \times 10^{-5} E\eta_f N_t^2}{\pi\rho^2 l^2} \qquad \ldots(6)$$

where E is the bending modulus; ηf, the shape factor; Nt, the fineness; s, the slope of linear fit line of critical load; ρ, the density; and l, the length of single fibre. Therefore, from the Eq. (6), the stiffness of the single fibre protruding from fabrics worn depends on the value of E, or and Nt or and l.

3 Materials and Methods

3.1 Materials

Several types of wear fabrics were used to prepare single needle fibre for single fibre bending experiment, namely cotton, cashmere, lenin, hemp, ramie, jute and woolen wool fabrics. For the experiment, single fibres were taken from each wear fabric to prepare single needle fibre for the study.

3.2 Single-needle Fibre Shape Factor

The shape factor (η_f), according to different cross-sectional shapes and area, has been adapted by calculation and experimentation.

3.3 Fibre Linear Density

Linear density of all samples was determined by calculating length and diameter of single fibre. Twenty-five readings were taken for each sample and the average was reported for 5 groups of fibre fineness (A, B, C, D, and E).

3.4 Sample Preparation

The fibre was conditioned for 24 h under the standard temperature of 20 ± 2°C and relative humidity of 65±2 %. The fibre samples were then prepared into single-fibre needles of different lengths (0.5, 1, 1.5, 2, 2.5, 3 , and 3.5 mm) to simulate the fibres in contact with the human skin when wearing cloth. The steps used to prepare protruding single-fibre sample for test have already been reported[18].

3.5 Axial Compression Bending Test

The axial compressionbending tests were carried out using a fibre compression bending analyzer (FICBA). The FICBA was designed by the Textile Materials and Technology Lab at Donghua University[21-23], and manufactured by Powereach® Co., Shanghai[18]. The single-fibre sample with certain protruding length was clamped by two metal grooves.

The protruding length of single fibre is determined by fibre thickness. This means that the single-fibre slenderness (length/thickness) should be appropriate, neither short enough to be compressed directly to yield, nor long enough to detect the miniature load of the critical force.

4 Results and Discussion

4.1 Fibre Shape Factor (η_f)

One of the most important characteristics that determine the behavior of a single fibre during compression is a cross-section. So, for cotton, cashmere, flax, hemp, ramie, jute and wool single fibre, the shape factors are not the same because each single fibre type has a different cross-section. Consequently, fibres usually bend, fracture and break at the thinnest part and in the direction offering least resistance. As we know well that the shape factor is the ratio of moment of inertia for a given cross-sectional area, it can be easily proved that the shape factor of equilateral is bigger than that of ellipse, as shown below:

$$I_{\text{circle}} : I_{\text{equilateral}} : I_{\text{ellipse}} = \frac{1}{4\pi} : \frac{\sqrt{3}}{18} : \frac{1}{4\pi e} \qquad \ldots(7)$$

where e is the ratio of the major axis to minor axis in ellipse. Therefore, the shape factor of equilateral triangle is 1.209 and the shape factor of ellipse is 1/e. Furthermore, the shape factor according to different cross-sectional shape of all single fibre samples has been calculated. Thus, the shape factor results for cotton, cashmere, flax, hemp, ramie, jute, and wool single fibre are shown in Table 1. The data indicate that there are significant variations between different single fibres. So, sometimes it is not appropriate to use a generic shape factor as cross-sectional shape, because they can vary significantly between fibres within the same fibre type.

4.2 Fibre Fineness

Table 2 shows that the linear density is different for all samples types, decreasing from jute single fibres to wool, ramie, cashmere, hemp, flax, and cotton sequentially.

4.3 Bending Modulus Estimation of Single-needle Fibre

According to Eq. (6), the critical load P_{cr} is directly proportional to N_t^2/l^2. Figure 2 shows the experimental data diagrams which include linear regression, variance analysis and linear fit with x error (error of fitting). The regressive Eqs (1) and (2) for two linear fit were obtained for each single fibre (Table 3). From statistical analysis results (Table 3), we can see that jute single fibre has highest correlation than other single fibres, while flax fibre has lowest correlation. Also, from linear fit with x error equations; we found that jute single needle fibre has the highest value of b (fitting from zero point) and cotton has less value. Therefore, due to this result the jute single-needle fibre has highest cross-section, fineness and has a high value of bending modulus.Generally, there is a large difference between regression Eqs (1) and (2) for single fibre needle, particularly cashmere and wool single fibre needle. Thus, single fibre binding modulus depends on single fibre shape factor and fineness, and it is different for each fibre longitudinally. Therefore, it has a high impact on the direction of fibre bent when in contact with human skin, as in cashmere and wool fibres. This is because it has helical properties. The statistical analysis will be used to calculate the bending modulus based on Eq. (1) intercept, because from the graphs in Fig. 2 it is shown that the slopes of the best fit line depends on the line, forced through the origin point. This is because the linear correlation of the relationship result from Pcr and N_t^2/l^2, when passed through the origin point, is significant than non-zero intercept.

Table 1—Fibre density, cross-section shape and area

Fibre	Density g/cm^3	Cross-section shape	Cross-section area(s), µm^2	Shape factor (mean)
Cotton	1.55	Oval to convolute	323.65	0.75
Cashmere	1.31	Nearly a circle	388.82	1.10
Flax	1.45	Polygonal	363.05	0.92
Hemp	1.48	Polygonal	306.04	0.97
Ramie	1.54	Oblong	277.00	0.78
Jute	1.36	Polygonal	977.57	0.98
wool	1.32	Nearly a circle	633.03	1.20

Table 2—Fineness of single fibre sample

Fibre	Linear density, tex				
	A	B	C	D	E
Cotton	0.595	0.556	0.459	0.366	0.256
Cashmere	0.802	0.739	0.658	0.561	0.468
Flax	0.757	0.713	0.643	0.549	0.457
Hemp	0.780	0.725	0.670	0.513	0.428
Ramie	0.815	0.692	0.621	0.570	0.484
Wool	0.988	0.937	0.852	0.689	0.630
Jute	1.170	0.949	0.928	0.886	0.814

A-E are the groups of fibre fineness.

Table 3—Statistical analysis result of single fibre critical load

Fibre	Regressive Eq. (1)	Correlation coefficient (R^2)	Regressive Eq. (2)	Correlation coefficient (R^2)
Cotton	$y=(0.0106)\,Nt^2/l^2$	0.8574	$y=(8.8962\text{x}10^4)Nt^2/l^2+0.0101$	0.6897
Cashmere	$y=(0.0016)\,Nt^2/l^2$	0.7878	$y=(0.0011)\,Nt^2/l^2+0.0440$	0.4147
Flax	$y=(0.0167)\,Nt^2/l^2$	0.7760	$y=(0.0011)\,Nt^2/l^2+0.1097$	0.7280
Hemp	$y=(0.0244)\,Nt^2/l^2$	0.8810	$y=(0.0033)\,Nt^2/l^2+0.1433$	0.8277
Ramie	$y=(0.\ 0555)\,Nt^2/l^2$	0.8241	$y=(0.0041)\,Nt^2/l^2+0.1693$	0.7527
Jute	$y=(0.\ 0526)\,Nt^2/l^2$	0.9345	$y=(0.0041)\,Nt^2/l^2+1.3688$	0.8514
wool	$y=(0.0398)\,Nt^2/l^2$	0.8080	$y=(0.0013)\,Nt^2/l^2+0.8230$	0.3249

The critical load can be expressed in terms of the slope K as shown below:

$$P_{cr} = K\frac{N_t^2}{l^2} \qquad \ldots(8)$$

Thus, when the slope $K = \dfrac{5.05\times10^{-5}E\eta_f}{\pi\rho}$

The bending modulus is:

$$E = \frac{\pi K\rho}{5.05\times10^{-5}\eta_f} \qquad \ldots(9)$$

To calculate the bending modulus of single fibre, K, ρ, and η_f values of all fibres were applied in Eq. (9). Thus, the bending modulus values of the cotton, cashmere, flax, hemp, ramie, jute, and wool are 14.113, 1.271, 16.026, 23.694, 69.053, 47.343, and 32.642 cN/mm^2 respectively. Therefore, these results, consistent well with previous studies [18-22], show that the method is useful. Because, in Euler's buckling equation the buckling force is linearly dependent on the single fibre modulus, but more importantly is proportional to the fourth power of the diameter (fineness) and the second power of the length. Thus, small changes in the physical dimensions will probably have a much larger influence on the buckling behavior and hence it's potential for prickle will be higher than that with relatively small changes in modulus. Therefore, from the calculated fibre bending modulus, fineness, and shape factor, it can be seen that ramie, jute and wool have large prickle values [Figs 2 (e), (f) and (g)], and the other fibres have low values, especially cashmere single fibre [Figs 2 (a), (b), (c) and (d)]. These results indicate that a single fibre which has higher fineness and cross-section, shows high modulus. Therefore, these fibres tend to be stiff and difficult to bend when in contact with human skin. Thus, it is easy to agitate the human nerve, resulting in discomfort when wearing fabric made from ramie, jute, and wool. So, single needle fibres are easy to bend when the equivalent bending modulus of single fibre is relatively small. Under the same conditions the prickliness for jute, wool, and ramie fabrics, when worn next to the skin, has a higher influence than other fibres since it is difficult to bend these fibres when they are in contact with human skin.

It is well known that the fabrics made from 100% tough single fibres possess high bending modulus, flexural rigidity, and tensile resilience, while offer low shear rigidity and hysteresis magnitudes. The fibre structure and morphology definitely affect the yarns physical properties, including friction properties. Particularly, with increase in fibre fineness and decrease in fibre length, prickleness of fabrics does increase. Therefore, higher fibre-to-fibre friction limits the ability of fibres to slide against or slide past each other during yarn and fabric deformation, hence affecting the yarn flexibility when in contact human skin. Also, fibres of higher crystallinity and alignment are generally tough and posses higher bending rigidities. Prickleness is an undesirable sensation, common with coarse and stiff fibre especially animal fibres such as wool.

Subsequently, the direct effect of the length and fineness of a single needle fibre is great for wearing fabrics. The fibres that are in contact with human skin experience different compressional forces, between the skin and the fibre protruding from the fabric surface. Subsequently, the amount of bending that fibre experiences depends on its length and fineness or cross-section area. The critical load P_{cr} is very sensitive to fineness and length as shown in Eq. (6). Hence, the experimental data and regression analysis of correlation between fibre fineness and fibre bending modulus of all single fibre (R_1) as well as the fibre lengths and bending modulus (R_2), of each group of all fibre needles are shown in Table 4. Thus, high correlation between bending modulus of cotton, cashmere, flax, hemp, ramie, jute, and wool single

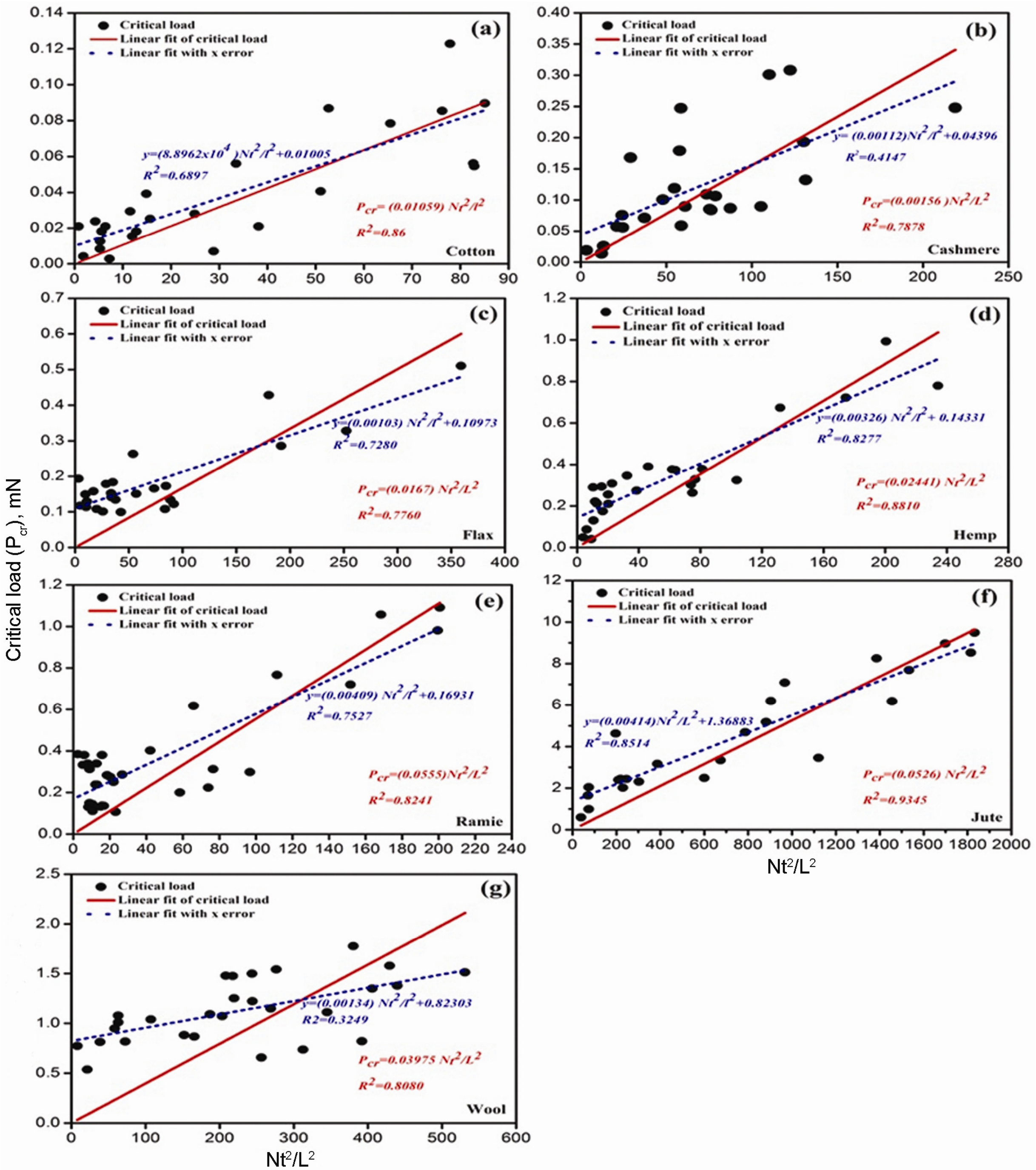

Fig. 2—Correlation of P_{cr} with N_t^2/l^2 and linear fit with x error of cotton (a), cashmere (b), flax (c), hemp (d), ramie (e), jute (f), and wool (g) of single needle fibres

needle fibre for different fineness of all single fibres with different length is observed statistically by using regression analysis.

Therefore, it is clearly observed that when fibre length and fineness are increased the critical load decreases. However, single fibre end distribution in wearing fabric surface is extremely complicated. This complexity is initially manifested in the coarseness of the single fibre ends at different locations as well as in the hairiness density of protruding fibre. Moreover, there are other differences between individual fibres, which include lengths, fineness and bending modulus properties, which refer to the inclination, bending and coiled level of the fibre ends.

Table 4—Regression analysis of fibre length *vs.* P_{cr} denoted by R_1^2 and fibre fineness *vs.* P_{cr} denoted by R_2^2 of single fibre of wear fabric

Single fibre	Regression analysis R_1 and R_2						
Cotton							
R_1	0.9769	0.9844	0.9861	0.9617	0.9831	0.9739	0.9459
R_2	0.9513	0.9468	0.9436	0.9432	0.8905		
Cashmere							
R_1	0.997	0.9911	0.9726	0.9932	0.9834	0.961	0.9735
R_2	0.9066	0.9056	0.9607	0.9551	0.8961		
Flax							
R_1	0.9943	0.9878	0.9878	0.9797	0.9979	0.9853	0.9914
R_2	0.9614	0.9094	0.9639	0.9293	0.9774		
Hemp							
R_1	0.9965	0.9677	0.9578	0.9843	0.9845	0.9675	0.8797
R_2	0.9492	0.9234	0.9132	0.8972	0.9745		
Ramie							
R_1	0.9962	0.9735	0.9925	0.9831	0.9856	0.9778	0.9689
R_2	0.9400	0.9529	0.9709	0.9217	0.8742		
Jute							
R_1	0.9967	0.9993	0.9902	0.99	0.9825	0.9993	0.9979
R_2	0.9350	0.9319	0.8866	0.8552	0.7167		
Wool							
R_1	0.9879	0.9906	0.9902	0.9844	0.9945	0.9973	0.9995
R_2	0.9796	0.9856	0.9949	0.9792	0.9732		

Furthermore, we have seen from the result of the statistical analysis of the critical load P_{cr} in Table 4 that there is a strong correlation between length and fineness of protruding fibres and the critical load for different sample individually. Thus, Figs 3(a), (c), and (b), for cotton, flax and cashmere respectively, show that the critical load of single fibre increases when fibre length decreases in all single fibres. Also, it is notable that the same fibre length with different fineness gives different critical load, because the single fibre has different and smaller cross-section shape in different single fibres structures. Also, it can also be seen from Fig. 3(d) that the critical load for hemp fibres is increased when the fibre length decreases and vice versa. Moreover, the values of the critical force are found to be the highest for the ramie, jute and wool single fibres critical force, as shown in Figs 3(e), (f) and (g) respectively. Hence, this result is clearly observed when single fibres diameters and fineness decrease.

Therefore, it is found that jute, wool and ramie have high critical loads, especially jute fibre, because it has a larger cross-section. Also, morphological structure and physical properties of single-needle fibre are considered to greatly contribute to the rigidity of a fibre. There is a hysteresis loop during bending courses of single fibre and the possible explanation for internal friction and slippage between the fibrils and the molecular chains that occurs during bending.

Furthermore, the critical load of jute, wool and ramie single fibre is larger than other single fibres as shown in Table 5. When the average P_{cr} and E of all single-needle fibres are compared with variance, it can be seen that jute, wool and ramie fibres have higher values for average and variance. This means that the single fibre needles of these fibres are difficult to bend and hence when these are in contacts with human skin, a prickly feeling accurse and fabric becomes uncomfortable. Therefore, fabrics manufactured from these fibres are uncomfortable because the critical force of the coarser and shorter fibres in the range sometimes fulfills the criteria above the 0.75 mN force threshold when its length is 0.5, 1.0 or 1.5 mm. Hemp, flax, cashmere and cotton have low critical force and hence the fibres easily bend when in contact with human skin thereby making the fabric comfortable. Consequently, Fig. 3, shows that the objective evaluation of fabric wear prickle discomfort according to the actual tactile data

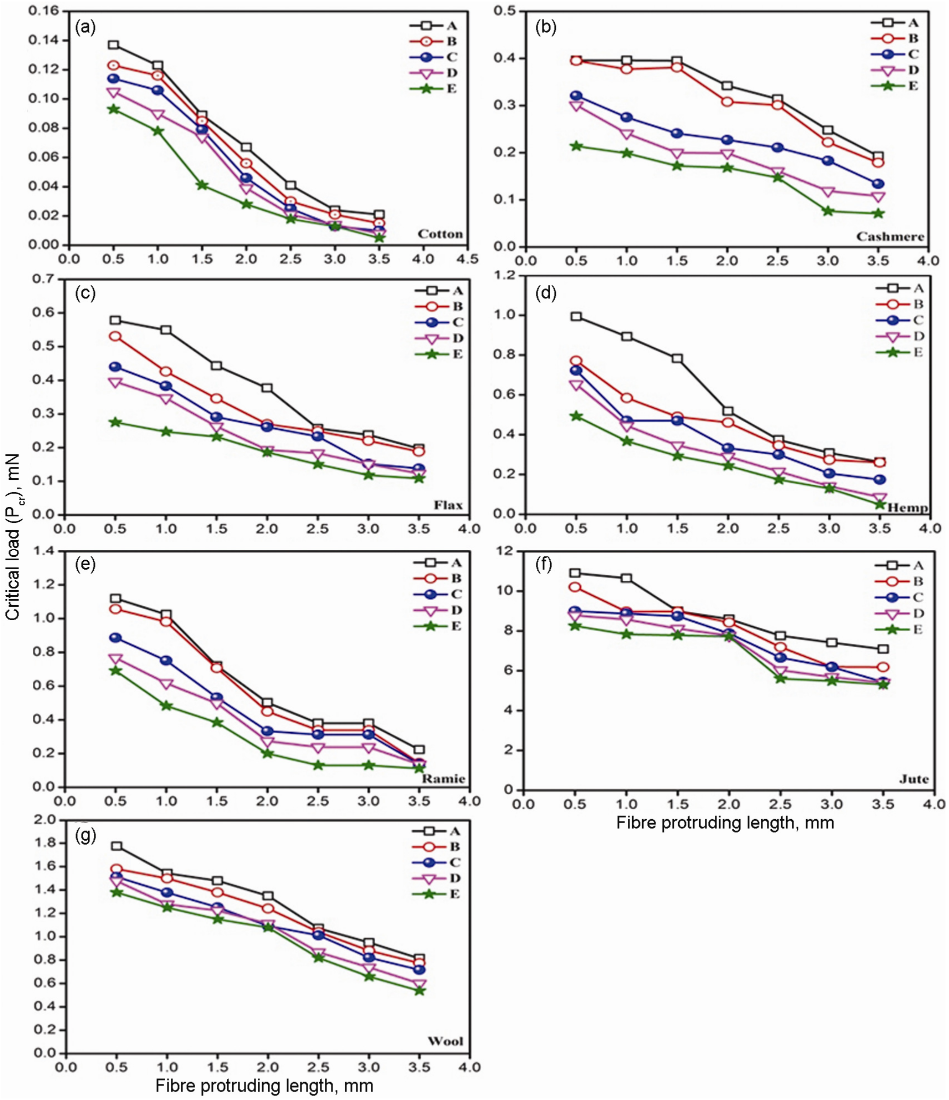

Fig. 3—Relationship between critical load P_{cr} and fibre protruding length *l* of cotton (a), cashmere (b), flax (c) , hemp (d), ramie (e), jute (f), and wool (g) of single-needle fibres

Table 5—Averages values of $P_{cr}$and *E* and their CV

Fibre	P_{cr}, mN		*E, cN*/mm^2	
	Average	CV	Average	CV
Cotton	0.0562	0.0017	14.113	0.0459
Cashmere	0.2404	0.0160	1.2710	0.0548
Flax	0.2783	0.0160	16.026	0.0323
Hemp	0.3977	0.0528	23.694	0.0279
Ramie	0.4721	0.0872	69.053	0.0246
Jute	7.6745	2.3209	47.343	0.1989
wool	1.1233	0.1002	32.642	0.0991

obtained by FICBA is found consistent well with the subjective results in many research [15,16,24].

From all the results of single fibre critical force P_{cr}, Fig. 3 shows the relationship between critical force and fibre protruding length from the worn fabric surface. Thus, it has been found that for same fibre length the critical load increases when fibre length decreases for all single fibre types. Further, cotton, flax, cashmere and hemp have low critical force when bent. But ramie, wool and jute have high critical load when bent, thereby making the fabric uncomfortable to wear. As cashmere, cotton, flax and hemp have hysteresis less than ramie, jute, and wool, they are easier to bend compared to other fibres. Therefore, when a vertical force is applied on the different macro-structure for all single fibres, it is found that the critical force increases with the decrease in length.

This study gives resourceful insights relevant to subject selection and the general research trend on clothing wear comfort. For clothing manufacturers, the compiled consumer feedbacks by wearers of particular clothing are tools for product improvement to enhance utility. Finally, this research informs consumers about fabric clothing comfort, which will contribute to decision making during purchasing.

5 Conclusion

The stiffness of cotton, cashmere, flax, hemp, ramie, jute, and wool fabrics can be objectively achieved by the axial compression bending test of single fibre. Concurrently, cotton, cashmere, flax, and hemp single fibre assemblies have better compression than those of ramie, jute, wool because of the morphological structure and physical properties of single fibres, which are considered to greatly contribute to the rigidity of a fibre. When a vertical force is applied on the different macro-structure for all single fibres, it is found that the critical force increases when fibre length is decreased. In addition, the lower bending modulus of single fibre is another factor that makes fibre assemblies compress easily when bent. Subsequently, the lower bending rigidity of single fibres and the better compression behavior for fibres, such as cashmere, cotton, flax and hemp comparatively, contribute to the soft handle of their fabrics. Statistically the line fit of P_{cr}-Nt^2/l^2 can be regressed and gives us good correlation for all fibres. The experiments and results can be used to estimate the fabric evoked prickle caused by short and coarse protruding fibres, which generate a sufficient force to evoke human skin. The results of single-fibre bending test verify that the method is useful, and provides a basis for researchers to investigate the fabric-evoked prickle of wear fabric. It can be concluded that this measurement technique can be used as a criteria test to evaluate and characterize the comfort properties of fabrics.

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