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Radial Distribution of Fibres in Compact-Spun Flax-Cotton Blended Yarns

Abstract
In recent years, compact spinning technology, recognised as a revolution in ring spinning, has been successfully used in the production of mono-fibre yarns and blended yarns. Understanding the radial distribution of fibres in compact-spun flax-cotton blended yarn is of importance for improvement in the performance of compact-spun flax-cotton blended yarns. This paper investigated the radial distribution of compact-spun flax-cotton blended yarn using the Hamilton migration index, and it was compared with traditional ring-spun flax-cotton blended yarn. The results indicated that the fibre migration of traditional ring-spun flax-cotton blended yarn was more obvious than that of compact-spun flax-cotton blended yarn, and the radial distribution of fibres in compact-spun flax-cotton blended yarns was more random. Therefore the traditional migration rule does not fully apply to compact spinning technology and should be given more attention in practice.

Key words: *flax-cotton blend yarn, compact spinning, ring spinning, hamilton migration index, fibre migration, radial distribution.*

Introduction

Compact spinning technology has drawn great attention from researchers and engineers in recent years. The feature that makes compact spinning different from traditional ring spinning is that it adds a condensation zone between the draft zone and twist zone. Using compact spinning technology, yarn hairness can be markedly reduced; the yarn strength can be improved and yarn evenness will decrease. There are two main types of condensing form used in the compact spinning system: the air current pressure condensing form and the magnetic force condensing form . However, the air current pressure condensing form has been more widely used.

Compact spinning technology has claimed to offer superior quality and better raw material utilisation [1]. Although the properties and appearance of compact flax-cotton blended yarn have been improved compared with traditional ring spinning, there has been no study concerning fibre migration and radial distribution in compact spun flax-cotton blended yarn. In this paper, the radial distribution of compact spun flax-cotton blended yarn was analysed using the Hamilton migration index, and compared with traditional ring spun flax-cotton blended yarn.

Fibre migration in a twisted triangle area has been studied extensively [2]. In traditional ring spinning centripetal or radial pressure is produced in the fibres in the twisted triangle area because of spinning tension and twist. Under centripetal pressure fibres have repetitious internal and external migration. Both ends of fibres are available outside the yarn, which leads to the formation of hairiness. The migrating fibres are arranged as a spiralled line in the ring-spun yarn; therefore the fibres in the yarn are not arranged by layer, which makes the fibres wind both inside and outside the yarn, tightens the yarn structure and increases the yarn strength. On the other hand, the arrangement of fibres in the yarn also forms layers in some short pieces. In these pieces some fibres are in the inner layer of the yarn and some fibres are in the external layer of the yarn, which makes the arrangement of fibres in ring spinning yarn very complex. Furthermore, it is a random phenomenon. The fibres in different positions migrate both outside and inside, which is the result of tension against resistance between fibres. The measure of resistance relies on such factors as the thickness, rigidity, elasticity and surface property of fibres, as well as the tightness of fringing in the twisted triangle area, which happens only when fibres pass through the triangle area. Hence, all the fibres in ring spinning yarn have different external and internal migrations. The different migrations of all fibres and existences of all kinds of fibres make the unevenness of the axial direction of the yarn increase, thus influencing the properties of the yarn.

In the process of twisting, the properties of fibres and their technical factors have an influence on the migration rule of fibres. To better understand this phenomenon, fibres with a radial distribution across the cross section of blended yarns need to be investigated. Fibre properties have a great influence on fibre migration behaviour for blended yarns because of the big difference in the properties of blended fibres. The distribution of fibres with different properties in the cross section is uneven. These fibres tend to form inner and outer layers respectively. Thin and long fibres, with a big initial modulus, tend to distribute themselves internally. The preferential distribution of fibres of different components in the cross section has a significant influence on the elongation, fastness and dyeing properties of yarn, eventually affecting the handle, appearance and durability of woven and knit fabrics. Therefore it is most important to study radial distribution of fibres in the cross section.

Experimental

Materials

The flax fibres used had a linear density of 11.47 dtex with a bulk weight of 3.21 g/cm^3.

The cotton fibre in this work had a linear density of 1.51 dtex and bulk weight of 1.52 g/cm^3.

Image observation

1. 27.8 tex flax/cotton (55/45) blended yarns were spun on a traditional ring spinning machine and compact spinning machine, comprising air current pressure condensing equipment, respectively.
2. Twenty sliced samples of each type of yarn were cut by a slicing cutter. A video microscope was used to observe the samples sliced, which was operated from a PC. Images of fibre distribution were taken, printed out, and finally analysed using the Hamilton

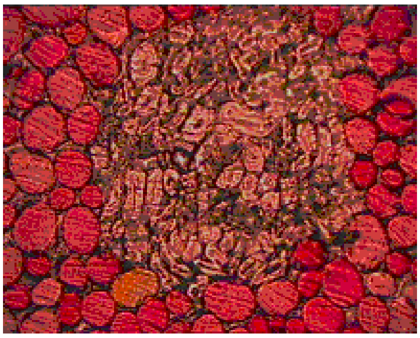

Figure 1. Image of ring spun yarn.

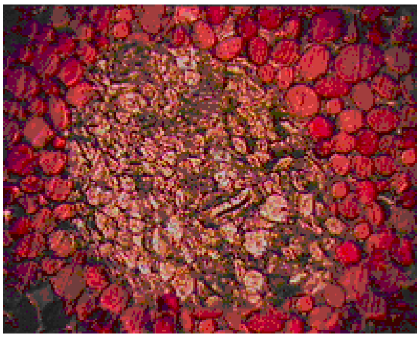

Figure 2. Image of compact spun yarn.

migration index. The two images in ***Figures 1** & **2*** show the fibre distribution of compact yarn and ring-spun yarn, respectively.

Hamilton migration index [3 - 5]

The Hamilton migration index is based on calculating the moment of distribution of fibre in the yarn cross-section, and then the distribution parameter of one type of fibre can be calculated in two ways: the inner or outer distribution trend.

Based on the images taken, the radial distribution of fibres in the yarn cross-section could be determined. The barycenter was found using the weight balance method. A circle was drawn using the barycenter as the centre of the circle and the distance between the barycenter and fibre borderline as the radius. Then by dividing the radius into five equipartitions, it was possible to draw five homocentric circles. Finally, the five yarn layers were labelled 1 to 5 from inside to outside.

The hamilton fibre migration index is usually used to calculate and analyse the radial distribution of fibre in a yarn cross-section, then the migration index of radial distribution of fibres M in blends can be calculated. The value of M often ranges between -100% and +100%. When M = 0 it means that the two types of fibres are blended evenly. If M > 0 it indicates that this kind of fibre migrates to the outer layer. When M < 0 it shows that this kind of fibre migrates to the inner layer.

1. Counting the number of fibres. The number of flax and cotton fibres in the blend were counted as x_i and y_i, respectively, then the distribution of fibres was determined. If the fibre happened to bestride two layers, it was apportioned to the layer which accounted for a larger area.
2. Conversting the fibre number distribution into fibre bulk distribution. Because of the different linear densities and densities of flax and cotton fibres, the actual cross-section areas were not equal. As a result, the ratio of fibre numbers for each layer had to be converted into a ratio of the fibre cross-section area as follows:
   - The number and bulk conversion coefficient of the flax fibre is 1, hence the flax fibre bulk $x'_i = 1 \times x_i$ (number of flax fibres);
   - The number and bulk conversion coefficient of the cotton fibre is C, hence the cotton fibre bulk $y'_i = 1 \times y_i$ (number of cotton fibres).

   And the C value can be calculated:

   $$C = \frac{N_y \gamma_x}{N_x \gamma_y} \qquad (1)$$

   N_x, γ_x are the linear density (dtex) and bulk weight(g/cm^3) of the flax fibre; N_y, γ_y are the linear density (dtex) and bulk weight(g/cm^3) of the cotton fibre.
3. Calculation of the fibre bulk distribution frequency. In each layer of the blend, if the ratio of one kind of fibre bulk in the overall fibre bulk (the fibre bulk distribution frequency) is always the same, the fibre bulk distribution is symmetrical. The calculation can be made as follows,

   $$V_i = x_i' + y_i' = x_i + C \cdot y_i ; V = \\ = \sum V_i ; X = \sum x_i' ; Y = \sum y_i' \qquad (2)$$

   flax fibre bulk distribution frequency $a_i = X \cdot V_i / V$

   cotton fibre bulk distribution frequency $b_i = Y \cdot V_i / V$

   V_i is the overall bulk of the flax-fibre and cotton-fibre in each layer of the blend; V is the overall bulk of the flax fibre and cotton fibre of the blend; X is the overall bulk of the flax fibre in the blend; Y is the overall bulk of the cotton fibre in the blend.
4. Calculation of the fibre bulk frequency in the case of distribution mostly inside and outside. If one kind of fibre in the blend moves towards the yarn core (or to yarn exterior) to a greater extent, the largest internal (or external) distribution frequency is formed. Equations 3 and 4 depict the calculation method for the largest internal (or external) distribution frequency.

   $$\begin{aligned} &\text{when } i = 1, 2; \quad x_n = y_n = V_i \\ &\text{when } i = 3; \; x_n = \sum x_i' - (V_1 + V_2); \\ &\qquad y_n = \sum y_i' - (V_1 + V_2) \\ &\text{when } i = 4, 5; \quad x_n = y_n = 0 \end{aligned} \qquad (3)$$

   $$\begin{aligned} &\text{when } i = 1, 2; \quad x_0 = y_0 = 0 \\ &\text{when } i = 3; x_\circ = \sum x_i' - (V_4 + V_5); \\ &\qquad y_\circ = \sum y_i' - (V_4 + V_5) \\ &\text{when } i = 4, 5; \quad x_0 = y_0 = V_i \end{aligned} \qquad (4)$$

   x_n is the largest internal distribution frequency of the flax fibre bulk; y_n is the largest internal distribution frequency of the cotton fibre bulk; x_o is the largest external distribution frequency of the flax fibre bulk; and y_o is the largest external distribution frequency of the cotton fibre bulk.
5. Moment of fibre bulk distribution. For the moment calculation, the moment of distribution of the third layer is calculated first. The methods of calculation for all kinds of distribution moment are given as follows.

   actual moment of flax fibre distribution: $F_{M1} = \sum x_i' \cdot k_i$ (5)
   even moment of flax fibre distribution: $F_{M2} = \sum a_i \cdot k_i$
   largest in by moment of flax fibre distribution: $F_{M3} = \sum x_n \cdot k_i$
   largest outward moment of flax fibre distribution: $F_{M4} = \sum x_\circ \cdot k_i$

   actual moment of cotton fibre distribution: $F_{M1} = \sum y_i' \cdot k_i$ (6)
   even moment of cotton fibre distribution: $F_{M2} = \sum b_i \cdot k_i$
   largest in by moment of cotton fibre distribution: $F_{M3} = \sum y_n \cdot k_i$
   largest outward moment of cotton fibre distribution $F_{M4} = \sum y_\circ \cdot k_i$

   k_i is the layer variation of each layer, k_i = -2, -1, 0, 1, 2. According to equations (5) and (6), we can calculate the bulk moment of distribution of each flax and cotton fibre.
6. Calculation of the fibre migration index. The calculation method is given as follows in equation (7).

$$\text{if } F_{M1}-F_{M2}>0,\ M= \quad (7)$$
$$=(F_{M1}-F_{M2})/(F_{M4}-F_{M2})\times 100\%$$
$$\text{if } F_{M1}-F_{M2}<0,\ M=$$
$$=(F_{M1}-F_{M2})/(F_{M2}-F_{M3})\times 100\%$$

From equation 7, we can calculate the fibre migration index M.

Results and discussion

The experimental results are listed in ***Table 1*** and ***Figures 3*** & ***4***. It can be found that the radial distribution of flax fibres was very different as far as traditional ring spun yarn and compact spun yarn are concerned. The fibres with a larger initial modulus migrated towards the inner layer of the blended yarn. Because the initial modulus of the flax fibre was bigger than that of the cotton-fibre, the flax-fibres tended to migrate towards the inner layer of the yarn. It clearly indicates that flax fibres have an obvious migration trend towards the inner layer of ring spun yarn, as shown in ***Figure 3*** and ***Table 1***. For compact spun yarn it can be seen that the migration trend of flax-fibres towards the inner layer of the yarn was not very obvious, and flax-fibres were distributed evenly, as indicated in ***Figure 4***.

These phenomena can be attributed to the twisted triangle area. In traditional ring spinning, fibre migration is very obvious, which also causes hairiness because of the larger twisted triangle area. However, in compact spinning, the suction device with an oblique trough makes fibre clusters tight under air current pressure, created by adding a condensation zone between the draft zone and twist zone before fibres enter into the front roller. Therefore, there is a very small twisted triangle area during spinning, resulting in the migration of flax fibres of bigger initial modulus which became unobvious, and the distribution of flax fibres became more random. Thus, the traditional migration rules do not fully apply in compact spinning.

According to the transfer laws of fibres in blended yarn, the longer the length and the larger the initial modulus , the easier it will be to transfer the fibres to the yarn core. The initial modulus of flax fibre is larger than that of cotton fibre, and the length is also longer than that of cotton fibre, therefore there is a trend of transferring inward, which is different from the transfer outward of cotton fibre. Meanwhile, in traditional ring spun flax-cotton blended yarn and compact spun flax-cotton blended yarn, a trend was found in which the flax-fibres shifted to the yarn core, and the cotton fibres convolved outside of the blended yarn. However, the extent of the transfer was different in the two kinds of spinning. The inward trend of flax fibre transfer and the outward trend of cotton fibre transfer were obvious in traditional ring spinning, but it was inconspicuous in compact spinning, leading to even fibre distribution .

Table 1. *Mean of Hamilton migration index M.*

Yarn type	Fibre type	Hamilton migration index M,%
Ring spun yarn	Flax	-12.46
	Cotton	+12.46
Compact spun yarn	Flax	-5.21
	Cotton	+5.21

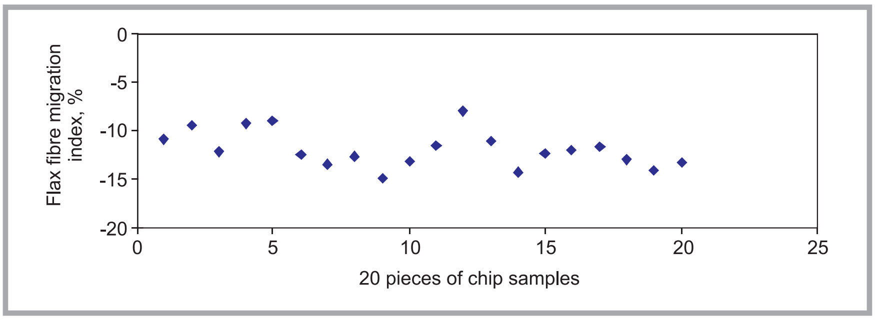

Figure 3. *Flax fibre migration in traditional ring spun flax/cotton blended yarn.*

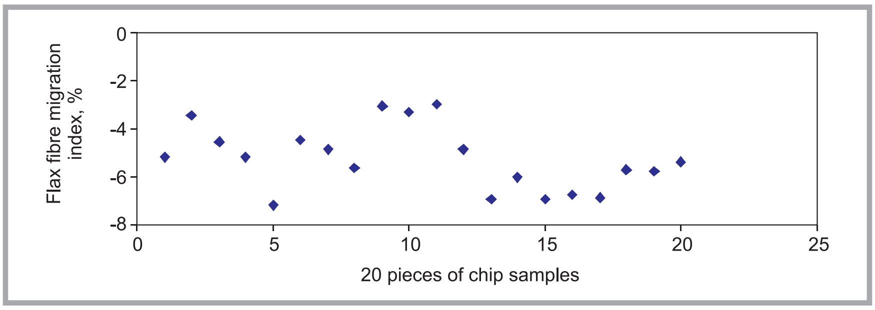

Figure 4. *Flax fibre migration in compact spun flax/cotton blended yarn.*

The main reason for these phenomena rests with the twisted triangle area. In the traditional ring spinning process, the twisted point of the yarn is not always fixed, but constantly shaking around. Because of the presence of the twisted triangle area, fibres in the flat sliver have, to some extent, internal and external migration by the geometric mechanism, and fibres on the left and right of the twisted triangle area are in different layers of the yarn at the same time, respectively. If the fibres on the left of the twisted triangle area are convolved outwards in one moment, the tension of these fibres was observed to increase. During the twisting process, fibres on the right side in the internal layer of the yarn have to withstand smaller spinning tension, meanwhile, in order to achieve a power balance, the point of twisting will shift to the left. On the contrary, the point of twisting would move to the right of the centre line. The point of twisting is almost on the left or right of centre because it always swings around. When it is on the left of the sliver centerline, fibres on the left side suffer larger tension, twisting the internal layer inwards, and then the right fibres wind externally. Conversely, the right fibres will suffer larger tension and twist the internal layer inwards, and then the left fibres wind externally. Under these circumstances, at the moment when the twisted point moves from the left of the sliver center to the right or from the right to the left, it is likely for fibres to shift rapidly between the inner and outer layers, and hence fibre migration is more likely to happen.

In compact spinning, the suction device which has a chute makes the fibre bundles gradually furl under negative pressure due to the pneumatic concentration zone fitted between the drafted area and twisted area, which is so tight as to hardly have a twisted triangle area before the fibres enter the front roller. The area of the twisted triangle in compact spinning is much smaller than that in traditional ring spinning, and its width is very close to the diameter of yarn. In this case, the extent of shaking the twisting point around is significantly reduced, and the fibres will have internal and external migration by the geometric mechanism. Furthermore, the degree of migration will be relatively lower. In this way, the migration trend of flax-fibres and cotton-fibres is not obvious, and all the fibres are evenly distributed in the yarn. In the compact spinning process, fibres in the yarn almost twist gradually in a parallel state, and they are mostly twisted into yarn, arraying in parallel and interweaving perfectly. These factors not only greatly reduce yarn hairiness but also improve yarn evenness, making the appearance of the yarns cleaner and closer compared with traditional ring spinning. They also make the utilisation of the fibre strength in flax-cotton blended yarn much higher than that in traditional ring spinning, leading to an increase in yarn tensile strength.

Conclusion

Compact spinning has been increasingly used in the textile industry since it has achieved a remarkable improvement in yarn quality and yarn structure through better utilisation of fibre properties. The improved yarn properties will provide better opportunities for cost savings in subsequent processing stages. In recent years a great deal of attention has also been given to the possibility of developing new textile products using compact spinning . This paper studied the radial distribution of compact-spun flax-cotton blended yarn using the Hamilton migration index. Fibre migration was analysed and compared with traditional ring-spun flax-cotton blended yarn. It was revealed that the radial distribution of fibres in compact-spun flax-cotton blended yarns was more random. Yarn hairiness was significantly reduced and the utilisation of fibre strength in flax-cotton blended yarn is much higher than that in traditional ring spinning, which contributes to the increase in yarn tensile strength.

References

1. *Stalder H.; Compact Spinning-A new Generation of Ring Spun Yarns, Melliand Textilberichte. 76(3), (1995) pp. 29-31.*
2. *Yao M.; Textile Materials, China Textile Press, Beijing, China, 1989.*
3. *Carvalho V., Cardoso P., Belsley M., Vasconcelos R. M., Soares F. O.; Yarn Irregularity Parameterisation Using Optical Sensors. FIBRES & TEXTILES in Eastern Europe, January/March 2009, Vol. 17, No. 1 (72) pp. 26-32.*
4. *Yu W. D., Wang J. C.; Effect of Blend Ratio and Fibre Distribution on Woolen-type Feeling of Wool/PET Yarns, Donghua University Transaction(Science Edition). 27 (4), (2001) pp. 24-28.*
5. *Yu W. D., Chu C. Y.; Textile Physics, Donghua University Press, Shanghai, China, 2002.*
6. *Zhang S. G.; The Radial Distribution of Fibres and Its Influenced Factors in PET/Viloft Blended Yarn, Journal of Nantong Textile Vocational Technology College. 3(4), (2003) pp. 12-15.*
7. *Krucińska I., Gliścińska E., Mäder E., Häβler R.; Evaluation of the Influence of Glass Fibre Distribution in Polyamide Matrix During the Consolidation Process on the Mechanical Properties of GF/PA6 Composites. FIBRES & TEXTILES in Eastern Europe, January/March 2009, Vol. 17, No. 1 (72) pp. 81-86.*
8. *Korycki R.; Method of Thickness Optimization of Textile Structures During Coupled Heat and Mass Transport. FIBRES & TEXTILES in Eastern Europe January/March 2009, Vol. 17, No.1 (72) pp. 33-38.*
9. *Xia Z., Yu J., Cheng L., Liu L., Wang W.; Scale Effect on Jute/Cotton Fibres and their Blended Yarns. FIBRES & TEXTILES in Eastern Europe 2009, Vol. 17, No. 4 (75) pp. 43-45.*
10. *Xu B., Dong B., Chen Y.; Neural Network Technique for Fibre Image Recognition, Journal of Industrial Textiles, V36, 2007. 04, pp. 329-336.*
11. *Liu J., Li Z.; Visualization and Determination of Slub Yarn Geometrical Parameters, Fibres and textiles in Eastern Europe, 2010, No 1.*
12. *Anandjiwala R. D., Goswami B. C.; Charles K. B., Bargeron J. D.; Structure Property Relationship of Blended Cotton Yarns Made from Low and High Tenacity Fibres, Textile Res. J. 69, (1999) pp. 129-138.*
13. *Hamilton J. B.; The Radial Distribution of Fibres in Blended Yarns, Part I: Characterization by a Migration Index, J. Textile Inst. 49, (1958) pp. 411-423.*
14. *Kumar R., Chattopadhyay R., Sharma I. C.; Feasibility of Spinning Silk/Silk Blends on Cotton System, Textile Asia 2, (2001) pp. 27-31.*
15. *Zhang H. W, Chen D. S., Wan Y. B.; Fibre Migration and Twist Radial Distribution in Rotor Spun Yarns, Textile Res. J. 73(11), (2003) pp. 945-948.*

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