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Investigation of Fibres Migration in Cotton/Polypropylene Blended Yarn

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This study is devoted to theoretical and experimental research of fibres migration in blended yarns. A hypothesis states that due to fibres migration their tension in yarn becomes equal. On the basis of that hypothesis, we identified the factors that affect the migration. The main factors influencing are differences in Young's modulus and density of fibres. Simulating the fibres migration we obtained the formulae for determining the proportion of fibres in the external and inner layers of blended yarn. These formulae were proved by analysis of cross-section of cotton/polypropylene yarn. Results of blended yarn processing in knitting showed that migration of polypropylene fibres in direction to the yarn surface leads to significant increase of yarn breakages due to growth of its friction coefficient. Reduction of the input yarn tension by 10 % – 15 % helped to stabilize the process of knitting. It was found that the usage of theoretical information about fibres migration allows to draw conclusions about the necessity of adjustments to settings of subsequent processing of blended yarns.

Keywords: blended yarn, migration, fibre, cross-section.

1. INTRODUCTION

Distribution of fibres of different types in cross-section of blended yarn has a strong impact on yarn properties and settings of its further processing.

For example, if yarn consists of different colored fibres then migration of fibres of one type to yarn surface leads to obtaining of yarn and fabric hue that differ from the color of fibres blend.

Yu Weidong and Wang Jincheng [1] conducted research for assessing of possibility of blended yarn perception as a wool yarn. Based on the analysis of cross-sections of yarn they found the ratio of components that yields the desired sensation.

On the other hand, the difference in friction properties of fibres influences yarn tension in knitting. But to determine the optimal setting it is advisable to take into account not average fibres properties in blend but mean fibres properties in yarn outer layer.

The study of fibre migration began when Morton, Yen and Riding [2 – 4] developed trace fibre technique. Morton proposed that one of the mechanisms, which cause fibre migration, is the tension differences between fibres at different radial positions in a twisted yarn. During the twist insertion fibres are subjected to different tensions depending on their radial positions. According to the principle of the minimum energy of deformation, fibre lying near the yarn surface will try to migrate into inner zones where the energy is lower. This will lead to a cyclic interchange of fibre position.

Subsequently, Hearle et al. [5] and Treloar [6] proposed the ideal fibre migration patterns to analyze the geometry of yarns with the assumption that the fibres migrates regularly and uniformly from the outside to the center of the yarn and then returns to the outside again, thus keeping constant the packing density.

Tao [7] proposed a mathematical model of the helix as sine wave pattern with variable radius and this model was used in the analysis of the geometrical and mechanical properties of a migrating fibre.

Hearle [8] introduced the concept of migration in the analysis of mechanics of staple yarns. He showed that appropriate values of twist and migration could generate a self-locking and strong structure which can take some load, and obviates the need to assume arbitrary pressure at the surface.

There are several factors that influence to the fibre migration in blended yarn. The migration increases if increasing of fibre staple length and their tension in spinning. Also fibre migration depends on the methods of yarn manufacturing.

As for the blended yarns the greatest interest is the distribution of fibres in their cross-section. There are several points of view on this matter.

Kabanov and Shutova [9] were analyzing results of their research of blended yarns containing wool, rayon and polyester fibres. They explained migration of man-made fibres to the center yarn as the influence of differences in the fibres length and density. They emphasize that the surface yarns layer contains fibre of lower density than average density of the fibres in the yarn.

Hamilton and Cooper [10] established that that the direction and extent of migration is determined mainly by the relative staple lengths and deniers of the components. Relative shortness and coarseness of fibre are cumulative factors tending to induce outward migration towards the surface of the yarn. Koricky [11] supports that point of view.

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Murugesan and Ramesh Chandran Nayar [12] found out also that longer fibres occupy the core and short fibres occupy the surface of the cotton yarn.

For blended yarns, according to the tension mechanism of fibre migration, it is likely that the fibres having higher initial Young's modulus tend to occupy the inner zones of the structure. Those having the lower modulus tend to be in the outer zones [13 – 15]. The experiments have confirmed this hypothesis [8].

The objective of the research described in this paper is a theoretical and experimental evaluation of different points of view on the basis of study of fibres migration in the cross-section of blended yarn from cotton and polypropylene fibres. Polypropylene (PP) fibres are substantially different from other textile fibres of lower density. They have specific properties and therefore their location in the yarn structure can significantly influence the processing of blended yarn and the properties of textile fabrics.

2. THEORETICAL

Theory of fibres migration developed in this study is based on hypothesis that due to this phenomena tensions of all fibres in yarn become equal.

For yarn manufactured from two kinds of fibres we have the following equation:

$$\bar{\varepsilon}_1 E_1 = \bar{\varepsilon}_2 E_2 , \qquad (1)$$

where $\bar{\varepsilon}_1$ is the extension of fibres of the first component, %; $\bar{\varepsilon}_2$ is the extension of fibres of the second component, %; E_1 is the Young's modulus of fibres of the first component, N/m^2; E_2 is the Young's modulus of fibres of the second component, N/m^2.

Usually in investigation of fibres migration the cross-section of yarn is divided by several layers. Due to the small diameter of yarn, the information on the distribution of fibres in two (inner and external) layers of its cross-section is of concern [16]. We assume that the internal layer is limited to the so-called "neutral line".

Using yarn helix model we can define "neutral line" as a circle where fibres extension is zero. For determination of this circle radius it is necessary to know the influence of fibres extension on their occupation in yarn.

In Figure 1 «opened out» diagram of fibre helix at radius R is shown. Due to yarn twist contraction size h is smaller than the respective fibre segment length l in untwisted drafted strand:

$$h = \frac{l}{C} , \qquad (2)$$

where C is the contraction.

In yarn structure the fibre has extended and the length of its segment rises from l to L.

$$L = l\left(1 + \frac{\varepsilon}{100}\right) , \qquad (3)$$

where ε is the extension of fibre in yarn, %.

From Figure 1 with reference to the yarn helix model for radius R we can calculate L:

$$L = \sqrt{(2\pi R)^{1} + h^2} . \qquad (4)$$

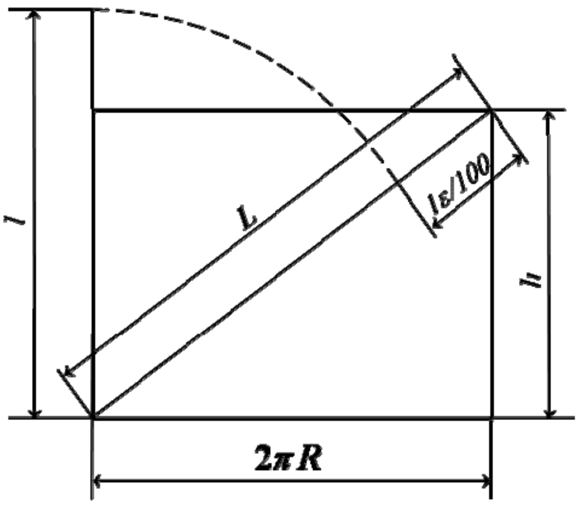

Fig. 1. «Opened out» diagram of fibre helix

If h is the length of one yarn turn in mm then twist of yarn per meter can be calculated:

$$T = \frac{1000}{h} . \qquad (5)$$

Using these equations we can obtain following formula for calculation of fibre extension:

$$\varepsilon = 100\left[\sqrt{\frac{1}{C}\left(\frac{2\pi RT}{1000}\right)^2 + 1} - 1\right] . \qquad (6)$$

Considering $\varepsilon = 0$ we can obtain formula for calculation of "neutral line" radius:

$$R_N = \frac{5\sqrt{C^2 - 1}}{\pi T} . \qquad (7)$$

Model of blended yarn cross-section is shown in Figure 2, where R_Y is radius of yarn.

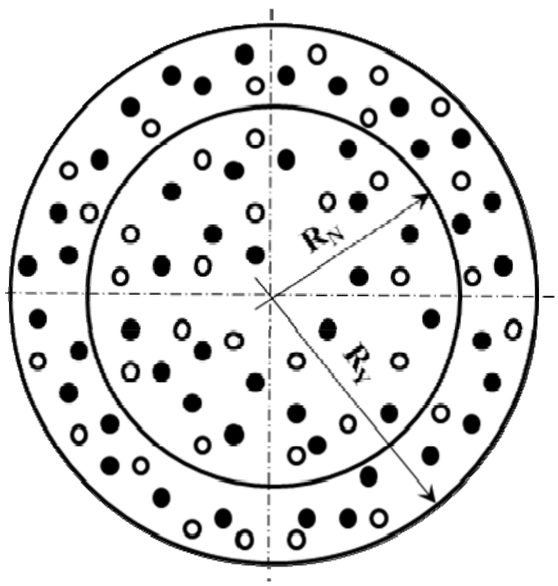

Fig. 2. Model of blended yarn cross-section

To evaluate the influence of fibres properties on their distribution in layers of yarn the simulation of fibres migration was carried out. Following assumptions were accepted in the simulation:

– the area occupied by the fibres in the cross-section of the inner layer was defined by the formula:

$$F_I = \pi R_N^2 \eta, \tag{8}$$

where η is the fill factor of cross-section of yarn.

– the area occupied by the fibres in the cross-section of the external layer was defined by the formula:

$$F_{\mathrm{II}} = \pi\left(R_Y^2 - R_N^2\right)\eta, \tag{9}$$

– the extension of fibres of the inner layer was equal 0;

– the extension of fibres of the inner layer was calculated by formula:

$$\varepsilon_{\mathrm{II}} = 100\left[\sqrt{\frac{1}{C}\left(\frac{2\pi R_{\mathrm{II}} T}{1000}\right)^2 + 1} - 1\right], \tag{10}$$

where R_{II} is the equivalent radius of external layer that can be defined as:

$$R_{\mathrm{II}} = R_N + \frac{2}{\pi}(R_Y - R_N). \tag{11}$$

The objects of simulation were various yarns (cotton/polyester, cotton/polypropylene, wool/viscose) with different blend ratio for mixed fibres. These yarn samples differed also linear density and twist.

The most probable distribution of the fibres was considered components distribution, for which the following expression was valid:

$$\varepsilon_{\mathrm{II}} m_{\mathrm{II}(1)} E_1 = \varepsilon_{\mathrm{II}} m_{\mathrm{II}(2)} E_2, \tag{12}$$

where $m_{\mathrm{II}(1)}$ is amount of fibres of the first type in cross-section of external layers of yarn.

$$m_{\mathrm{II}(1)} = \frac{F_{\mathrm{II}} B^F_{\mathrm{II}(1)}}{F_{f(1)}}, \tag{13}$$

where $F_{f(1)}$ is area of cross-section of one fibre of the first type, mm^2; $B^F_{\mathrm{II}(1)}$ is part of external layer area that was occupied by fibres of the first type.

The amount $m_{\mathrm{II}(2)}$ of fibres of the second type in cross-section of external layers of yarn was calculated similarly.

The simulation found that the above conditions are fulfilled at the next share ratio of the components in the external layer of yarn:

$$\frac{B_{\mathrm{II}(1)}}{B_{\mathrm{II}(2)}} = \frac{B_1 E_2}{B_2 E_1} \tag{14}$$

or

$$\frac{B^F_{\mathrm{II}(1)}}{B^F_{\mathrm{II}(2)}} = \frac{B_1 \gamma_2 E_2}{B_2 \gamma_1 E_1}, \tag{15}$$

where $B_{\mathrm{II}(1)}$ is the mass ratio of the first type fibres in external layer of blended yarn; $B_{\mathrm{II}(2)}$ is the mass ratio of the second type fibres in external layer of blended yarn; B_1 is the mass ratio of the second type fibres in yarn cross-section; B_2 is the mass ratio of the first type fibres in yarn cross-section; γ_1 is the density of the first type fibre, g/cm^3; γ_2 is the density of the second type fibre, g/cm^3.

Thus, the analysis of the above formulae may be noted that the different migration characteristics of fibres depend on mass percentage of components in the yarn, the Young's modulus and density of mixed fibres.

These formulae were used for calculating of fibre migration characteristics for cotton/polypropylene (70/30) yarn of linear density 18.5 tex (Ne 32).

Fibres properties that were taken into account are shown in Table 1.

Table 1. Fibres properties used in theoretical and experimental investigations

Type of fibres	Linear density, mtex	Density, g/cm^3	Young's modulus, mN/mm^2
Cotton	165	1.52	584.6
PP	180	0.9	451.0

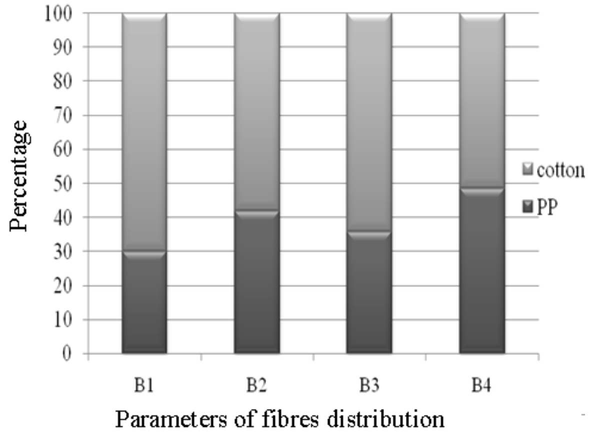

Fig. 3. Results of calculation of cotton/polypropylene blended yarn parameters: B1 – mass percentage (B) of each type fibres in yarn, %; B2 – part (B^F) of area of yarn cross-section occupied by each type fibres, %; B3 – mass percentage (B_{II}) of each type fibres in external layer of yarn cross-section, %; B4 – part (B^F_{II}) of area of external layer cross-section occupied by each type fibres, %

The results of calculation are shown in Figure 3. Analyzing these results we can draw following conclusions:

– For the reason that density of polypropylene fibres significantly is lower than the density of cotton fibres, part of the area occupied by them in the cross-section of yarn is 1.4 times bigger than their mass percentage in the yarn.

– On the other hand, it can be seen that due to the differences in the properties of fibres part of the area that polypropylene fibres occupy in the external layer is 1.2 times bigger than its part in yarn cross-section.

Similar results were obtained for the blended yarn of different counts and fibres compositions.

So, as a result of the theoretical studies we specified that polypropylene fibres migrate to the surface of the blended yarn and cotton fibres do to its axis.

3. EXPERIMENTAL

For verification of the calculated data, experimental investigations of cross-sections cotton/polypropylene (70/30) ring spun yarn (18.5 tex) were carried out.

Fifty images of cross sections of the yarn were tested using optical microscope "Micmed 2" (Lomo, Russia). Each cross-section was divided to inner and external layers with the calculated radius of the "neutral line" using the formula (7).

For more precise identification of cotton fibres they were colored brown. The image of a blended yarn cross-section is shown in Figure 4. The results of the statistical analysis of the obtained experimental data are shown in Figure 5.

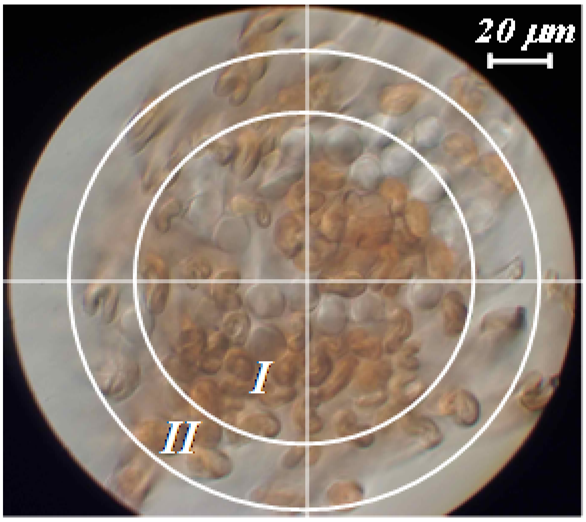

Fig. 4. Image of blended yarn cross-section

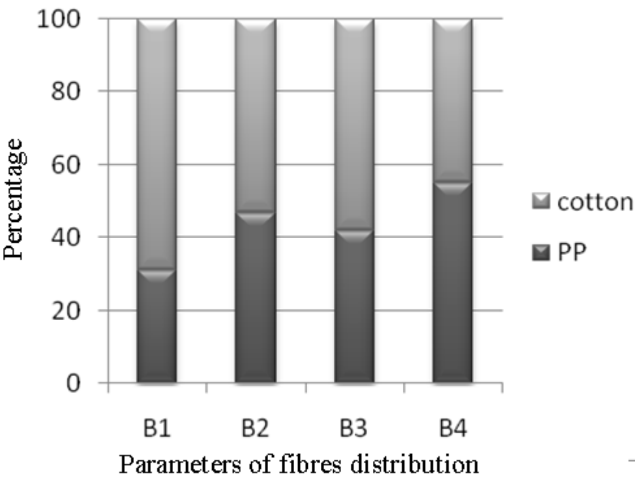

Fig. 5. Results of investigation of cross-section of cotton/ /polypropylene blended yarn parameters: B1 – mass percentage (B) of each type fibres in yarn, %; B2 – part (B^F) of area of yarn cross-section occupied by each type fibres, %; B3 – mass percentage (B_{II}) of each type fibres in external layer of yarn cross-section, %; B4 – part (B_{II}^F) of area of external layer cross-section occupied by each type fibres, %

It was found experimentally that the external layer contains about 18.2 polypropylene fibres and 26.7 cotton fibres. The average numbers of fibres in a blended yarn cross-section were 31.5 and 76.2, respectively. The coefficient of variation of polypropylene fibres number was found to be 5.45 %, for cotton fibres number this coefficient was equal 2.32 %.

The assigned amount of fibres in a cross-section corresponds to yarn linear density 18.24 tex (the coefficient of variation was 2.48 %). This linear density differs from the nominal value by 1.4 %. This deviation is explained by statistical error and yarn evenness. In addition, it should be emphasized that in this research yarn hairiness was not taken into account. It has also led to decrease in the number of fibres in yarn cross-sections.

The actual mass percentage of polypropylene fibres in yarn was 31.1 % (excluding hairiness), which is slightly higher than its nominal value. Consequently these fibres content in the external layer increased in comparison with the calculation results given in Figure 3. The coefficients of variation of polypropylene fibres mass percentage in yarn and in its external layer were 3.90 % and 4.75 %, respectively.

Comparing the results of theoretical and experimental studies we can conclude on the validity of the obtained formulae and the accepted hypothesis and assumptions.

Ratio polypropylene fibres in the external layer of yarn was actually significantly higher than in its cross-section , as was found by the calculations.

It is important to emphasize that the studies do not take into account the yarn twist. Thus it is proved that the twist of blended ring spun yarn does not influence distribution components in its cross-section.

The further research of blended yarn processing in knitting has shown that the migration of polypropylene fibres in direction to the yarn surface leads to significant increase of friction coefficient of blended yarn. The effect of this change was the increase of yarn tension, which led to the increase of yarn breakages and worsening of the structure of knitted fabric.

In order to prevent these problems, it was decided to reduce the input yarn tension by 10 % – 15 %. This adjustment helped to stabilise the process of knitting.

It should be noted that these phenomena were expected based on the analysis of the experimental and theoretical results.

4. CONCLUSIONS

- As a result of analysis of yarn twisting process new formulae were obtained for calculation of parameters of different fibres distribution at layers of blended yarns. Theoretical study was based on hypothesis that due to this phenomena tensions of all fibres in yarn become equal.
- In accordance with the results of theoretical and experimental investigations of cross-sections cotton/polypropylene ring spun yarn it was found that the location of different fibres in cross-section of blended yarn depends on the percentage of these fibres in the yarn components and their following properties: density and Young's modulus.
- With the increasing Young's modulus of fibres of one kind, the mass percentage of these fibres in external layer is reduced. With the reduction of fibres density increases the proportion of the area occupied by these fibres in external layer of yarn.
- The obtained formulae can be used for prediction of fibres distribution in the cross-section of blended ring-spun yarns from any mixtures of heterogeneous components. The usage of the calculation results allows to draw conclusions about the necessity of adjustments in settings of subsequent processing of the yarns.

REFERENCES

1. **Yu Weidong, Wang Jincheng**. Influence of Ratio of Wool and Polyester Fibres in Blended Yarn on Perception of it as Wool Yarn *Journal of Donghua University* (*Natural Science Edition*) 27 (1) 2001: pp. 24 – 28 (in Chinese).
2. **Morton, W. E., Yen, K. C.** The Arrangement of Fibres in Fibro Yarns *Journal of the Textile Institute* 43 1952: pp. 60 – 66. http://dx.doi.org/10.1080/19447025208659646
3. **Riding, G.** An Experimental Study of the Geometrical Structure of Single Yarns *Journal of the Textile Institute* 50 (7) 1959: pp. T425 – 442.
4. **Riding, G.** Filament Migration in Single Yarns *Journal of the Textile Institute* 55 (1) 1964: pp. T9 – 17. http://dx.doi.org/10.1080/19447026408660204
5. **Hearle, J. W. S., Gupta, B. S.** Migration of Fibres in Yarns Part III: A Study of Migration in Staple Fiber Rayon Yarn *Textile Research Journal* 56 1965: pp. 788 – 795.
6. **Treloar, L. R. G.** A Migration Filament Theory of Yarn Properties *Journal of the Textile Inst*itute 56 1965: pp. 359 – 377.
7. **Tao, X.** Mechanical Propertied of a Migrating Fiber *Textile Research Journal* 66 1996: pp. 754 – 762.
8. **Hearle, J. W. S., Grosberg, P., Backer, S.** Structure Mechanics of Fibres, Yarns, and Fabrics. Vol. 1. *A Division of John & Sons*, London, 1969.
9. **Kabanov, G. N., Shutova, N. E.** Influence of Fibres Geometrical Properties on their Distribution in Cross-section of Yarn *Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti* 1 1996: pp. 103 – 103 (in Russian).
10. **Hamilton, J. B. Cooper, D. N. E.** The Radial Distribution of Fibres in Blended Yarns. Part II – Factors Affecting the Preferential Migration of Components in Blends *Journal of the Textile Institute Transactions* 49 (12) 1958: pp. T687 – T698.
11. **Koricky, K. I.** Basics of Yarn Properties Design. Gislegprom, USSR, 1963 (in Russian).
12. **Murugesan, M.**, **Ramesh Chandran Nayar.** Study of Fibre Migration at Different Yarn Layers *Indian Journal of Fibre & Textile Research* 32 March 2007: pp. 33 – 39.
13. **Morton, W. E.** The Arrangement of Fibres in Single Yarns *Textile Research Journal* 26 (5) 1956: pp. 325 – 331. http://dx.doi.org/10.1177/004051755602600501
14. **Wang, X., Chang, L, McGregor, B.** Hairiness of Worsted Wool and Cashmere Yarns and the Impact of Fiber Curvature on Hairiness *Textile Research Journal* 76 (4) 2006: pp. 281 – 287.
15. **Bojun Xu, Jian Ma.** Radial Distribution of Fibres in Compact-spun Flax-cotton Blended Yarns *Fibres & Textiles in Eastern Europe* 18 (1) 2010: pp. 24 – 27.
16. **Rashkovan, I. G.** Methods of Evaluation of Fibres Distribution in Yarn Cross-section. Legkaya Industriya, USSR, 1970 (in Russian).