Mixing quality evaluation in cotton type blended yarns

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ABSTRACT

In the first part of the chapter the main facts about mixing and blending statistics are summarized. Sectional and radial local variations are quantified byan index of blend irregularity IBI and statistics derived from the well-known Chi-test. These statistics are based on a comparison of local and global estimator probabilities. The division of the yarn cross-sections to the special segments (radial, sectional, regular squares) and their combinations are compared. The second part is devoted to the techniques of second order neighborhood analysis of yarn cross-sections. The configurations of fibers constructed from sequences in the yarn cross section are analyzed by using run's theory. Cross-sections of three types of PET/cotton blended yarns obtained by image analysis are analyzed. Radial mass fractions for three types of yarns are also evaluated. The bundling tendency of individual components is quantified.

Introduction

Problems of mixing quality are well known in textile practice. A common approach is to mix various cottons according to their properties and price, and to mix the natural and synthetic fibers to enhance blended yarn properties. In most cases, the homogeneity of mixing, leading to the homogeneity of its physical-mechanical characteristics of the blended yarns, is required. For some special applications, much as for sewing threads, the separation of components (one in the core and second in the sheath region) is advantageous. In the case of colored fibers uniform mixing leads to homogeneity of color and appearance.

Evaluation of mixing uniformity

Mixing uniformity can be defined in the following ways:

- Arrangement of fibers in the cross-section (radial homogeneity);
- Variation in mixing degree or composition between cross-sections (axial homogeneity);
- Variation in a number of fibers between different cross-sections (mass unevenness).

In some cases, the presence of fibrous bundles is interesting as well. For estimating the tendency to bundle formation two main procedures are useful. The first is to divide the yarn cross-section into a matrix of cells with suitable shape. The second possibility is the creation of sequences of close segments starting from specified fiber. For both procedures, the limited arrangement of fibers according to its specific needs is necessary. Sequentially, the problem of fibrous bundles in blended yarns is solved.

Cross section division

Cross sections are necessary to create the matrix (net) of cells and to investigate the variation in blend proportions between cells. The following arrangement of cells have been proposed:

- Rectangular matrix;
- Annular spaces between concentric circles with a constant increment in area or diameter;
- Radial segments (pie segments) having the same inner angle.

Index of blend irregularity

A specific arrangement of cells is capable of identifying the tendency to bundle formation for specific bundle shapes only. This approach is common for the analysis of random field variations. Due to non-constant packing density it is not possible to investigate the number of fibers in cells for individual components directly. It is better to investigate the local and global blend proportions (as estimators of corresponding probabilities). Let in the i-*th* cell be *Ni*, fibers, N_{1i} fibers in the first component and N_{2i} fibers in the second component. A local estimate of the probability of occurrence of the first component in the cell is equal to:

$$\alpha_{1i} = \frac{N_{1i}}{N_i} \qquad (1)$$

and for the second component:

$$\alpha_{2i} = \frac{N_{2i}}{N_i} \qquad (2)$$

Overall estimates of these probabilities are dependent on the accepted probability model for a random arrangement (e.g. Cox model, Cox, 1953). It is simpler is to use as overall estimates, the blend proportions of individual components a_1 and a_2 from the whole cross-section. Comparison of local and global estimates of probabilities can be realized by using the c^2 test (Coplan and Klein, 1958):

$$\chi^2 = \sum_{i=1}^{m} \frac{\left(N_{1i} - \alpha_1 N_i\right)^2}{\alpha_1 N_i} + \sum_{i=1}^{m} \frac{\left(N_{2i} - \alpha_2 N_i\right)^2}{\alpha_2 N_i} \qquad (3)$$

After rearrangement $N_{1i} + N_{2i} = N_i$ and $a_1+a_2 = 1$ the following criterion results:

$$\chi^2 = \sum_{i=1}^{m} \frac{\alpha_1\left(N_{1i} - \alpha_1 N_i\right)^2 + \alpha_2\left(N_{2i} - \alpha_2 N_i\right)^2}{\alpha_1 \alpha_2 N_i} = \sum_{i=1}^{m} \frac{\left(N_{1i} - \alpha_1 N_i\right)^2}{\alpha_2 \alpha_2 N_i} \qquad (4)$$

For random arrangements, this statistic has the c^2 distribution with $\nu = m-2$ degrees of freedom. The analysis of mixing quality can be realized by using the I.B.I. criterion (Cox, 1953).

$$I.B.I. = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\frac{(N_{1i}-\alpha_1 N_i)^2}{\alpha_1\alpha_2 N_i}} \qquad (5)$$

For sufficiently large *m* it becomes:

$$\text{I.B.I.}^2 = \frac{\chi^2}{\nu} \qquad (6)$$

Statistical analysis of I.B.I. is therefore very simple. By using mean blend ratios from a set of cross-sections IBI can be extended for estimating the axial mixing uniformity.

Radial mass ratio

Evaluation of mixing homogeneity in the cells of a net could be based on fibers in the cross-section as well. It is possible to evaluate yarn packing density. The yarn packing density is the volume portion filled by fibers. Experimentally it can be computed as the ratio of the fiber cross-sectional areas to the yarn cross-sectional area in the matrix of cells. For a system of annular spaces the radial packing density of both components together and packing density of a single component can be computed separately. The portion of packing density of one component in relation to the packing density of both components expresses the radial arrangement of the blend ratio in a volume sense. It is not a problem to convert the components of volume fraction to mass fraction by using fiber density. The results can be expressed as radial mass fractions.

Fibers configuration in the yarn cross-section

Configuration means the fully specified arrangement of fibers on the cross-sections in sequence according to specified criterion. In the Coplan paper (Coplan and Klein, 1958), the helix starting in the center of the yarns and having a width of one fiber is proposed. Very simple is the method of nearest neighbor. Here, the fiber configuration is created based on the distances from the first (starting) fiber. Very important is the selection of the first fiber. Here are some possibilities:

- Fibers nearest to yarn center;
- Fiber leading to the most arrangement (configuration);
- Exhaustive selection of all fibers in the cross-section.

The selection of all fibers to be first leads to the possibility to choose fibrous bundles. For the created configuration or configurations it is possible to test for the occurrence of sequences having a prescribed length (Lopez-Collado, 2002; Kremenáková and Militký, 1999) or the occurrence of bundles with a prescribed number of each component (Kremenáková *et al.,* 1998.).

The distribution of sequence numbers has been derived by Mood (1940). Sequence is defined as the set of fibers of one selected component. There exists two limit configurations of components; fibers of each component create one sequence only (case of limit aggregation) and fibers of both components regularly alternate (case of limit segregation). It is simple to prove, that for the total number of sequences S_1 and S_2 for individual two components, is a valid $|S_1-S_2|=1$ or $S_1=S_2$. The quantity S represents the total number of sequences of both components. For a sufficiently large number of configurations this distribution approaches a normal distribution. Let N_1 be the fiber number in the first component, N_2 the fiber number in the second component and the total fiber number $N=N_1+N_2$. The marginal distribution of the sequence number for the first component, termed the Ising-Stevens distribution, is defined by the relation:

$$P(\Sigma_1 = S_1) = \binom{N_1-1}{S_1-1}\binom{N_2-1}{N_2+1-S_1}\Big/\binom{N}{N_1} \qquad (7)$$

The corresponding mean value $E(S_1)$ is derived directly from its definition:

$$E(S_1) = (N_1+1)N_2/N \qquad (8)$$

and for variance is valid:

$$D(S_1) = N_1(N_1+1)N_2(N_2-1)/N^2(N-1)? \qquad (9)$$

For the second component the same relations are valid, only in the indices have to be changed. These relations can be used for deriving the mean and variance of the total number of sequences.

$$E(S) = 1+\frac{2N_1N_2}{N} \qquad (10)$$

$$D(S) = 2N_1\,N_2(2N_1N_2-N)/N^2(N-1) \qquad (11)$$

For a sufficiently large *N,* the distribution of the total number of sequences *S can be* approximated by a normal distribution (Wald and Wolfowitz, 1940) having parameters *E(S), D(S),* defined by equations (10)and (11). The total number of sequences can then be transformed to a standardized, random variable, Z, with a normal distribution N(0,1).

$$Z = \frac{S-E(S)\pm 0{,}5}{\sqrt{D(S)}} \qquad (12)$$

The correction factor 0.5 can be omitted for practical computations. By using *Z* the randomness of the total number of sequences in the configuration can be tested. The *Z* values can be used for all configurations resulting from the nearest neighbor method. For visualization of *Z,* special control charts can be constructed. In such a chart, the individual *Z* values are plotted for all the configurations and the control limit *KI*=-2,33 corresponding to the one sided test for the case of aggregation (probability level α=0.01), is marked. The mean value and the 95% confidence limit are marked as well.

Experimental procedure

For comparative purpose, the criterion IBI defined for the various types of the cell matrix and various types of cross-sections were computed. The results are summarized in Table 1 and the matrix of cells within the cross-sections of yarns is shown in Figure 1 to 4. A cross-section termed „*PER1*" was selected from a population of cross-sections of ring yarn with a composition of 65% polyester and 35% cotton. A cross-section termed „*SPOJ4*" is obtained from the joint of two yarn ends created by a splicer, the components here being kinds of cotton differing in colors. In this cross-section the aggregates of fibers are visible. From Figure 1 to 4 it is clear that the selection of the cells' matrix is decisive for the local estimation of the number of fibers and relative component portions. An ideal matrix for all situations cannot be selected. From Table 1 it is evident that the criterion IBI is sufficiently sensitive.

For the computation of the *Z* value sequences created by the method of nearest neighbor were used. *Z* values computed for all configurations in the yarn cross-section are shown in Figure 5. It is evident that the *Z* values for the cross-section *SPOJ4* are near the aggregation limit and the *Z* values for the cross-section *PER1* are above aggregation limit.

Criterion IBI and *Z* for three types of yarns produced by the classical cotton technology were computed (yarn n.1, 3 combed, yarn n.2 carded), see Table 1 and Figures 7 and 8. The yarns differ by their fractions of polyester and cotton. Figure 6 shows the radial mass fractions of these yarns. Radial mass fractions are computed without the contribution of any fibers that form the yarn hairiness. According to experience ring yarn having a polyester content of 50% and more, have more polyester fibers in the core than that exhibited from the blend ratio. If the radial blend fraction toward the yarn surface is assumed, the content of cotton varies around the ratio 50/50. This arrangement is advantageous from the point of view of yarn properties, using the strong polyester fibers predominal in the yarn core thereby ensuring its favorable yarn mechanical properties. While the predominance of cotton fibers in the yarn surface layers ensure favorable physiological properties.

If criterion IBI and *Z* values for the three types of yarns are compared, it can be seen that yarn n.3 has the most evenly distributed cross-section, with yarn n.1 having polyester fibers predominating in the yarn core and cotton fibers predominating in the surface layers. The criterion IBI between cross-sections, depends on the selection of the yarn cross-sections.

Conclusions

It is clear that there exist many possibilities for expressing mixing (blending) uniformity. A universal criterion sensitive to all kinds of local variations, cannot be created. The other possibility is for example computing K functions from experimental data and their comparison with a model based on the Poisson process (Kremenáková and Militky, 2002). For estimating the tendency of bundle formation, the Z and IBI characteristics are suitable.

Acknowledgments

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Table 1. Computed criterion I.B.I. defined for the various types of the cell matrix and various types of cross-sections.

Type	Yarn/fiber fineness (tex)	I.B.I. rectangular	I.B.I. radial	I.B.I. pie segments	I.B.I. between cr.-sect.	Z value
Cross-section						
PER1	-	0,75	0,88	0,42	-	0,09
Cross-section	-					
SPOJ4		2,61	3,12	3,57	-	-3,03
Yarn n.1	20/ PET 0,17	1,37	1,40	1,18		-0,48
65PET/35co	co 0,14	(1,23;1,51)	(1,18;1,62)	(1,04;1,31)	1,79	(-0,64;-0,33)
Yarn n.2	35/ PET 0,21	0,95	0,99	0,95		-0,20
50PET/50co	co 0,14	(0,85;1,05)	(0,83;1,17)	(0,82;1,08)	1,93	(-0,28;-0,13)
Yarn n.3	18/ PET 0,16	0,88	0,83	0,82		-0,04
35PET/65co	co 0,17	(0,79;0,96)	(0,72;0,95)	(0,71;0,93)	0,67	(-0,11;-0,03)

Values in the brackets are confidence limits.

Figure 1. *Rectangular net for cross-section PER1.*

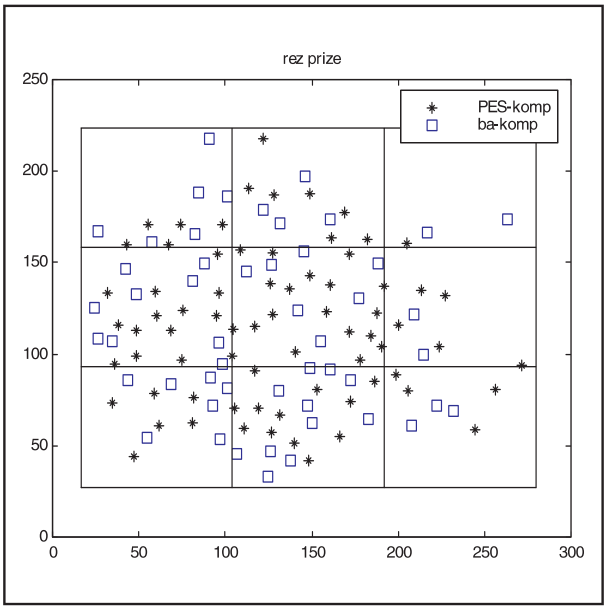
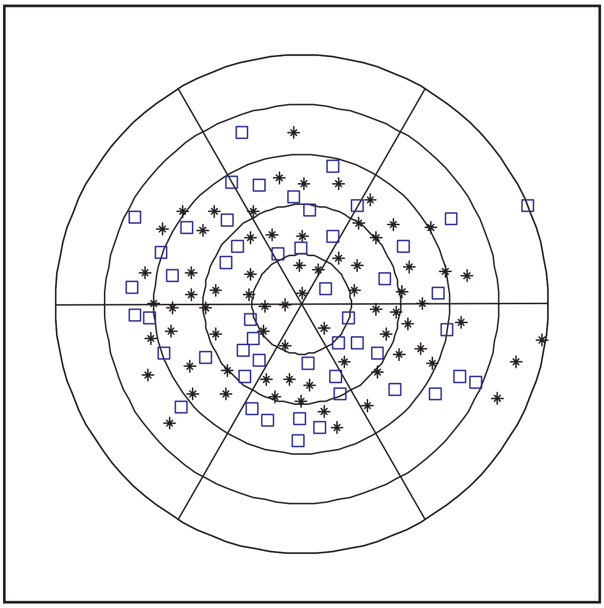


Figure 2. *Radial and pie segment net for cross-section PER1.*



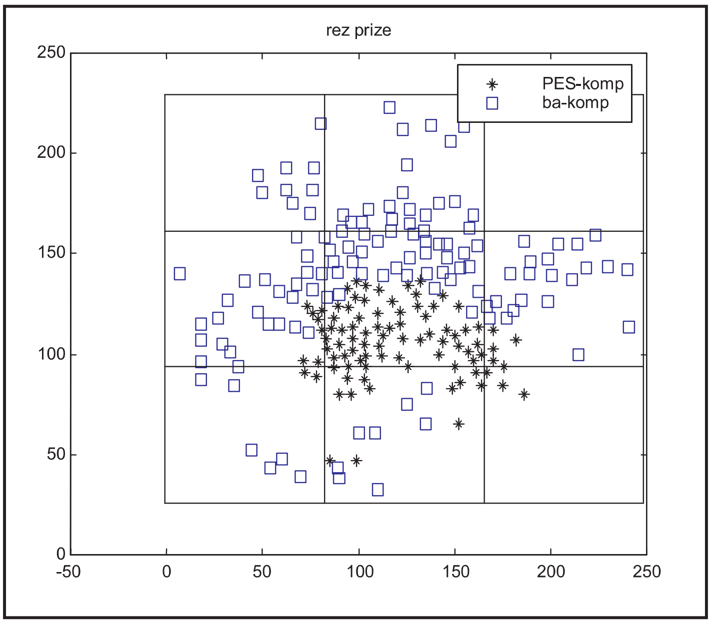


Figure 3. *Rectangular net for cross-section* SPOJ 4.

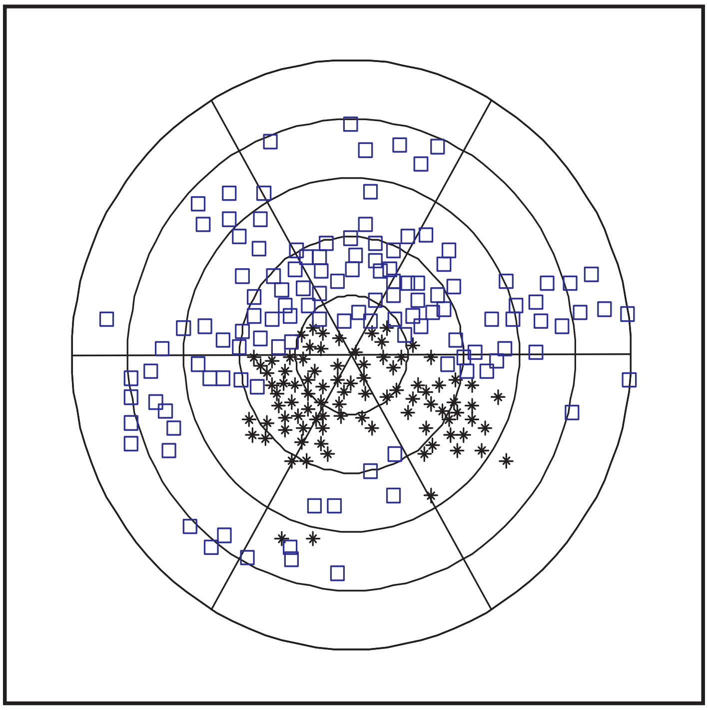


Figure 4. *Radial and pie segment net for cross-section* SPOJ 4.

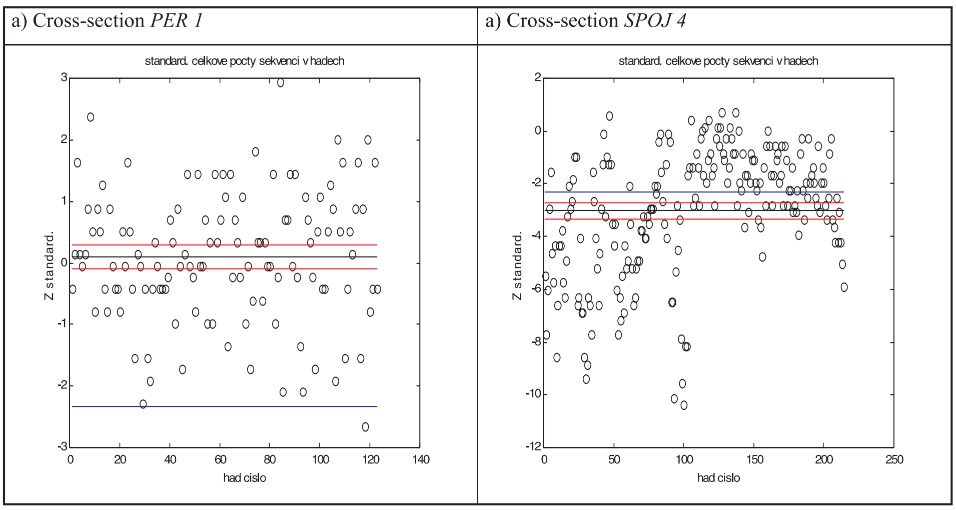


Figure 5. *Z-values for all configurations in cross-section.*

Figure 6. Radial mass fraction of PET component.

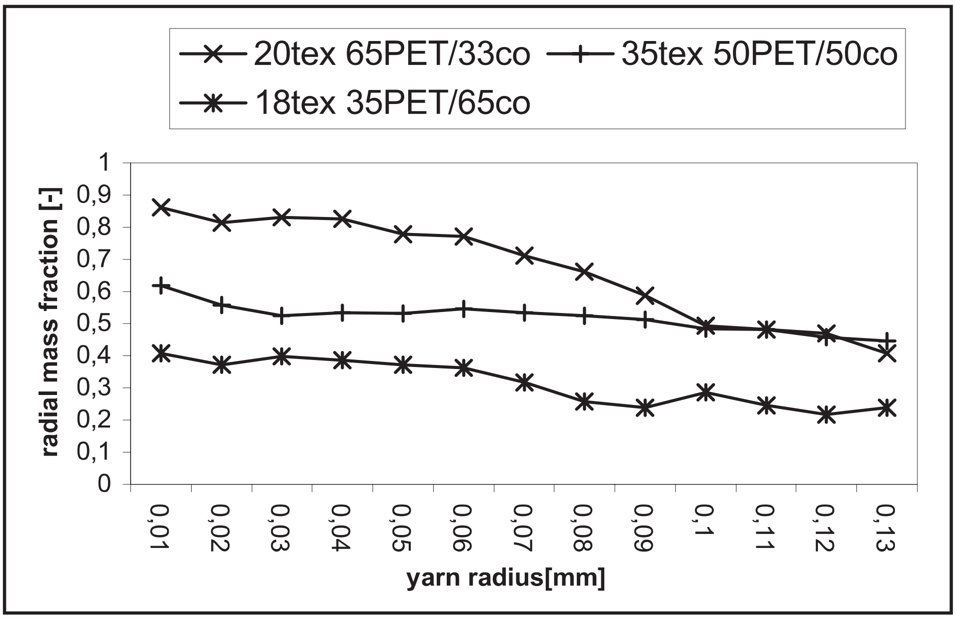


Figure 7. Index of blend irregularity.

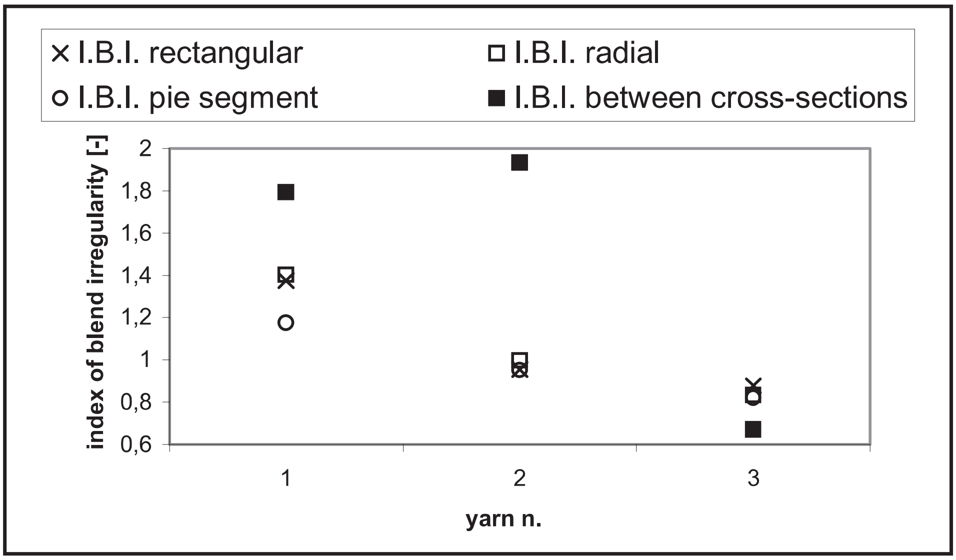


Figure 8. Z-values.