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Influence of Selected Parameters of the Spinning Process on the State of Mixing of Fibres of a Cotton/Polyester-Fibre Blend Yarn

Abstract
In this report, we present investigations concerned with the influence of selected parameters of the spinning process such as the spinning system, machine settings, and percentage content of cotton and polyester fibres in the blended yarn on the state of mixing of the fibres in yarn. The coefficient of variation of the quantitative contents of fibres in the yarn's cross-sections and the irregularity blending index (IBI) were used to estimate the state of mixing of fibres in the blended yarn. The technique of low-vacuum scanning electron microscopy (LV SEM) was used to give a picture of the fibre's distribution in the yarn's cross-sections. The influence of yarn mixing unevenness on the quality parameters of the yarn blends tested was analysed in the next stage of this research.

Key words: *yarn blends, cotton, polyester, per cent content, spinning, mixing, quality parameters.*

Introduction

Fibre mixing is one of the most important operations of the spinning process. The start of chemical fibre production and processing in the 1950s caused an increase in the role played by mixing, and decreased the cost of materials, thus improving the technological and usage properties of the blends obtained.

The aim of the mixing process is to obtain yarns which are uniform in their various properties. As the mixing process takes place in each of the individual machines working as a part of the technological spinning line, and some of which are also characterised by de-sorting actions, obtaining a uniform product is very difficult, and often even impossible.

Mixing, also called blending, is a combination of at least two components, which differ by at least one parameter which characterises the component fibres [1 - 3]. Fibre mixing consists of assuring a configuration of fibres in the fibre stream in such a way that the content of each component is the same at every point of the stream [3 - 6].

In the technological process of spinning, mixing may be the result of the following factors:
- displacing fibres along the stream,
- displacing fibres across the stream,
- joining of layers, and
- simultaneous displacing and joining of the layers.

Joining the layers of the blend may take place in:
- the raw material,
- the loose mass of fibres, and
- the formed fibre layers, for example, when slivers are mixed.

Thanks to appropriate selection of the blend components and their per cent content, as well as by maintaining the correctness of the mixing process, the following yarn parameters can be changed, compared with the uniform one-component yarns : tensile strength (tenacity), elongation at break, elasticity, hairiness, abrasion resistivity, susceptibility to creating electric charges, dyeability, pilling, friction coefficient, as well as the coefficients of variation of these parameters. The problems of mixing have also been discussed by El Mogahzy [7], Gusiew & Usienko [13], and You Huh [15], whereas the arrangement of fibres in the structure of yarn cross-section has been analysed by Goktepe & Lawrance [16].

The aim of this investigation

The aim of this investigation was to test the influence of selected parameters of the spinning process such as the spinning system, the machine settings, the percentage content of cotton and polyester fibres in the blends on the mixing state of fibres in the yarn, and the influence of the fibre mixing state on the quality parameters of the blended yarns. Yarns with linear density of 30 tex were manufactured with the use of R1 & BD200S rotor spinning frames, as well as a Rieter ring spinning frame.

Research plan

Middle-staple cotton of 32/33 mm fibre length, fibres' linear density of 1.65 dtex, tenacity of 24.9 cN/tex, and elongation at break of 7.7%, and polyester staple fibres (polyethylene terephtalate PET fibres, produced by Elana, Poland), of 38 mm staple length, a linear density of 1.50 dtex, a fibre tenacity of 36.2 cN/tex and elongation at break of 36.1 % were used in our investigation.

Slivers with a linear density of 4.45 ktex and a roving with a linear density of 600 tex [2] were the preliminary products for manufacturing yarns of linear density of 30 tex. Slivers manufactured from fibres of middle-staple cotton, carded and combed with noil at the level of 24%, and from polyester fibres were used to obtain the following blends: cotton carded-polyester fibres, and cotton combed-polyester fibres. The blends were composed with the use of a Globe 740 drawing frame. The slivers were joined and drawn in order to obtain 9 blend variants and 3 variants of one-component yarns. The percentage content of both fibre types in the blends was changed by 25% within the range from 25% to 75%. In order to obtain yarns with the assumed linear density, the settings of the machine parameters were chosen in such a way that optimal machine working conditions could be maintained. The R1 rotor spinning frame worked at the rotor speed of 100,000 rpm and a rotor diameter of 30 mm. The related rotary speed of the opening rollers was set at 7,000 rpm. The working rotor speed of the BD200S rotor spinning frame was set at 45,000 rpm, with a rotor diameter of 56 mm, and the rotary speed of the opening rollers was set at 7,000 rpm.

The rotary speed of the spindles of the ring spinning frame was set at 14,000 rpm, and the total drawing ratio at 20.

OE yarns were manufactured from slivers prepared as described above, with a constant twist coefficient of α_m = 140, as well as the ring-spun yarns with a constant twist coefficient of α_m = 110. Next, all the yarns were laboratory tested and the quality parameters analysed. The linear density, the unevenness of linear density, the breaking strength and its coefficient of variation, the hairiness, and the numbers of faults were used to analyse the mixing of the blends. Other quantities such as tenacity, elongation at break, and the number of twists were additionally measured and calculated, in order to monitor the repeatability of the manufactured samples of yarn blends.

The content of component fibres in the cotton/polyester blends was assessed on the basis of the microscopic method [11, 12]. The blend's fibre composition by this method is determined on the basis of the difference in the microscopic images of the polyester and the cotton fibres. This is related to the longitudinal view of these fibres. The twists of fibre tapes are characteristic for cotton fibres, whereas smoothness is a feature of polyester fibres.

The working samples were obtained by cutting a segment of a length up to 5 mm from the yarn whose composition was being tested. The fibres of this segment were separated by a preparation needle and placed, fibre after fibre, on a microscopic slide which had previously been wetted by immersion oil. Ten preparations were prepared using such yarn segments. The fibres were placed on the slides individually and arranged in vertical columns. After arranging the fibres on the slide, they were covered by a microscopic cover glass. Ten working samples were prepared to carry out measurements for each yarn blend.

The preparations prepared in this way were placed in the field of view of a lanameter with a magnification of 125×, and the cotton and polyester fibres visible on the screen were separately counted.

In order to test the mixing state of the cotton and polyester fibres in the blended yarns, the following factors were used [3, 4, 11 - 15]:

- coefficient of variation of percentage contents,
- irregularity blending index – *IBI*,
- CV_M – coefficient of variation of the fibre blend,
- $CV_{T\text{-}100\,m}$ – coefficient of variation of the yarn's linear density at 100 m segments,
- CV_F – coefficient of variation of the breaking force,
- CV_m –unevenness of the yarn's linear density (coefficient of variation) at short segments according to Uster and the number of yarn faults,
- H – yarn hairiness.

Fibre mixing in yarn was estimated on the basis of the dispersion of the components' contents in the subsequent yarn samples. As a measure of estimation of the state of mixing, the coefficient of variation CV_M of the blend is accepted, which is the arithmetical average of the coefficients of variation CV_a and CV_b of the component's percentage contents:

$$CV_M = 1/2\,(CV_a + CV_b) \qquad (1)$$

where:

$$CV_a = \delta_a / Z_a$$
$$CV_b = \delta_b / Z_b$$

Z_a, Z_b – average mass contents of the components a and b, and

δ_a, δ_b – standard deviations of the contents of components a and b.

The unevenness index of the blend in the yarn cross-sections denoted as *IBI* was calculated from the following dependency, derived by Coplan & Klein [16]:

$$IBI = \sqrt{\frac{1}{N}\sum \frac{(pn_{Ci} - n_{Ai})^2}{n_{Ci}\,pq}} \qquad (2)$$

where p and q are described by:

$$p = \frac{\sum_{i=1}^{N} n_{Ai}}{\sum_{i=1}^{N} n_{Ci}} \qquad (3)$$

where

n_{Ai}, n_{Bi}, n_{Ct} – the number of fibres of the components A and B, and the total number of fibres in the yarn cross-section.

The *IBI* index is the measure of the blend's deviation from the state of ideally mixed fibres.

The estimation of the fibre displacement in the yarn cross-section was based on the visual estimation of the regularity of distribution of the blend's components.

The technique of low-vacuum scanning electron microscopy (LV SEM) was used to determine the polyester fibre distribution in the fibre blends produced by the rotor-spinning technique and the classical ring-spinning technique [12]. Special samples were prepared for the observation of the yarn cross-sections. The yarns were initially drawn through orifices with a diameter of about 0.2 mm placed in plastic stands. The distances between the subsequent yarn cross-sections were greater than the average fibre length, and were accepted at about 45 mm. The yarns were tested with a JSM-5200LV SEM made by JEOL (Japan). An MP-24061 type semi-conductor detectorof reverse dispersed electrons was used to observe the samples prepared. The observations were carried out at an accelerating voltage of 15 kV, and at magnifications of 100× and 200× under low vacuum conditions. The air pressure in the chamber was 1 – 100 Pa. The images were recorded by a digital method with the use of the Semafore system. For

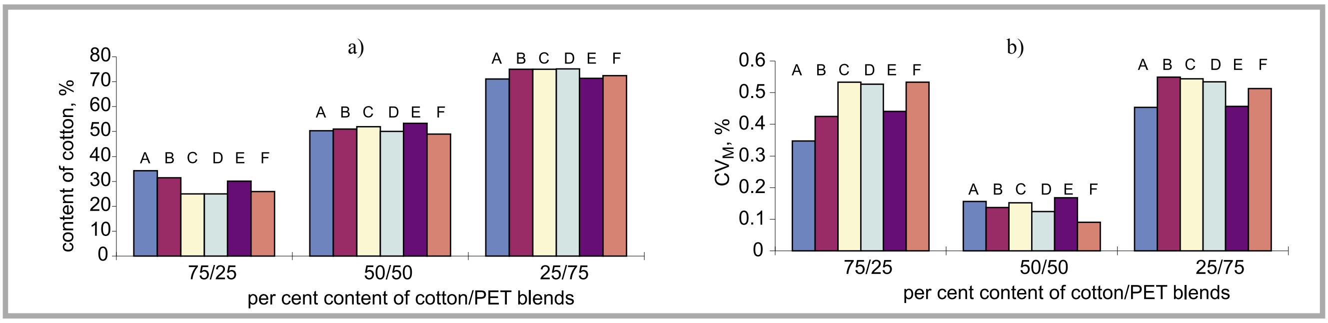

Figure 1. *Real percentage content of cotton in the blend (a), and coefficients of variation of the fibre blends (b); A) cotton ring-spun carded, B) cotton ring-spun combed, C) cotton rotor-spun (BD-200S) carded, D) cotton rotor-spun (BD-200S) combed, E) cotton rotor-spun (R1) carded, F) cotton rotor-spun (R1) combed.*

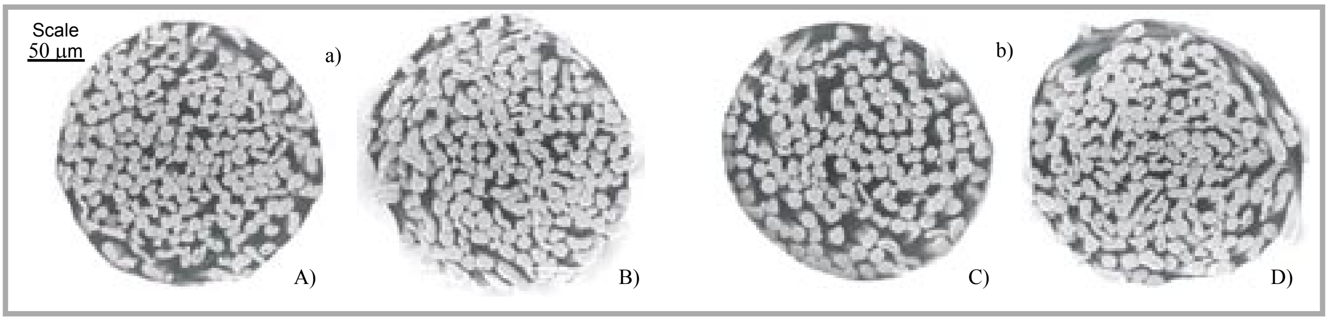

Figure 2. Cross-sections of 50%/50% cotton/PET blended yarns manufactured a) with the use of the ring-spinning frame; A) cotton carded, B) cotton combed; and b) with the use of the R1 rotor-spinning frame; C) cotton carded, D) cotton combed.

each sample, images taken at two random selected positions were recorded, at magnifications of 350× and 500×.

Research results

Determining the fibre contents of the cotton/PET blend components based on the microscopic method

The determination results of the real content of cotton fibres in blends and the coefficients of variation of the fibre blends are presented in Figures 1.a and b.

The experimental tests carried out demonstrated that the average content of the fibre components in cotton/PET yarn blends manufactured by rotor and ring spinning is approximately equal to the assumed value. Yarn blends with the 50%/50% content of the fibre components are characterised by the lowest coefficients of variation of the fibre blends.

Determining the distribution of cotton and polyester fibres in yarn blends

The fibre distribution in the yarn cross-section and the variation of component contents in the subsequent yarn segments were estimated on the basis of an analysis of the coefficients of variation of the yarn parameters, the *IBI* factors and a visual estimation of the regularity of distribution of the blend's components.

The test results obtained by the electron microscope are given in Figures 2 and 3 as digitally recorded images.

The cross-section images which we obtained allow us to make qualitative estimates of the contents and the type of distribution of polyester fibres & cotton in the particular yarn samples. The cross-sections of the samples tested confirm the differentiated content of polyester fibres and cotton. Both fibres are statistically randomly distributed over the yarn's cross-section. The cotton fibres used for manufacturing our yarns were characterised by a relatively high content of fibres with a low degree of maturity.

Determining the polyester fibre and cotton distribution in the yarn blends on the basis of the IBI unevenness coefficient of blends

The values of the *IBI* unevenness coefficients of blends as determined for yarn blends are presented in Figure 4.

On the basis of the data shown in Figure 6, we can state that yarns with percentage content of the components 50%/50% are characterised by the smallest unevenness of blends (as measured by the *IBI* factor). This signifies a better mixing of the fibres in yarn.

A mathematical interpretation of the *IBI* coefficient [15] allows for the following statements:

- if *IBI* = 0, the fibre mixing is ideal;
- if *IBI* = 1, random distribution of the components is observed; this is practically a normal mixing, as no preference of any of the components exists;
- if *IBI* > 1, the mixing of the components is abnormal.

is the closer the *IBI* value is to one, the more correct is the fibre mixing in the blend, and the distribution of the components' fibres is more random.

On the basis of the data presented in Figure 6, we can state that the distribution of the particular blend components is rather random in all cases, which means that the mixing proceeded normally.

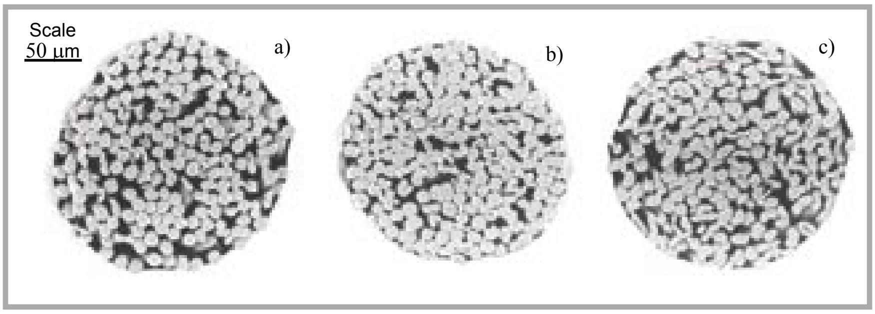

Figure 3. Cross-sections of cotton combed/PET blended yarns manufactured with the use of the BD200S rotor spinning frame, percentage content of cotton/PET: a) 25%/75% blend., b) 50%/50% blend, c) 75%/25% blend.

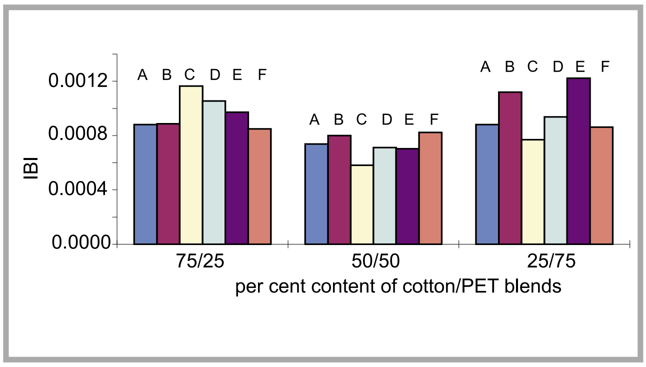

Figure 4. The IBI index component distribution in the yarns'cross-sections; a) cotton ring-spun carded, b) cotton ring-spun combed, c) cotton rotor-spun (BD-200S) carded, d) cotton rotor-spun (BD-200S) combed, e) cotton rotor-spun (R1) carded, f) cotton rotor-spun (R1) combed.

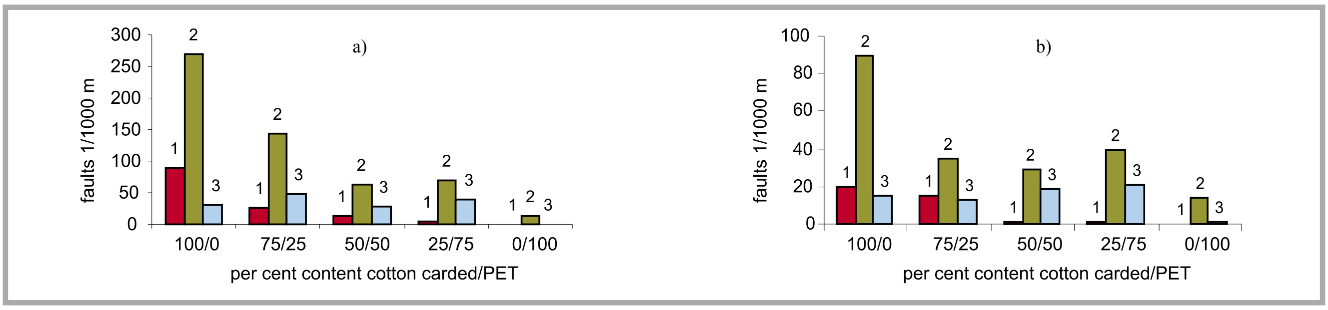

Figure 5. *Faults of ring spun yarns for different fibre percentage contents of the blend; 1 – thin places, 2 – thick places, 3 – neps; a) cotton carded/PET, b) cotton combed/PET.*

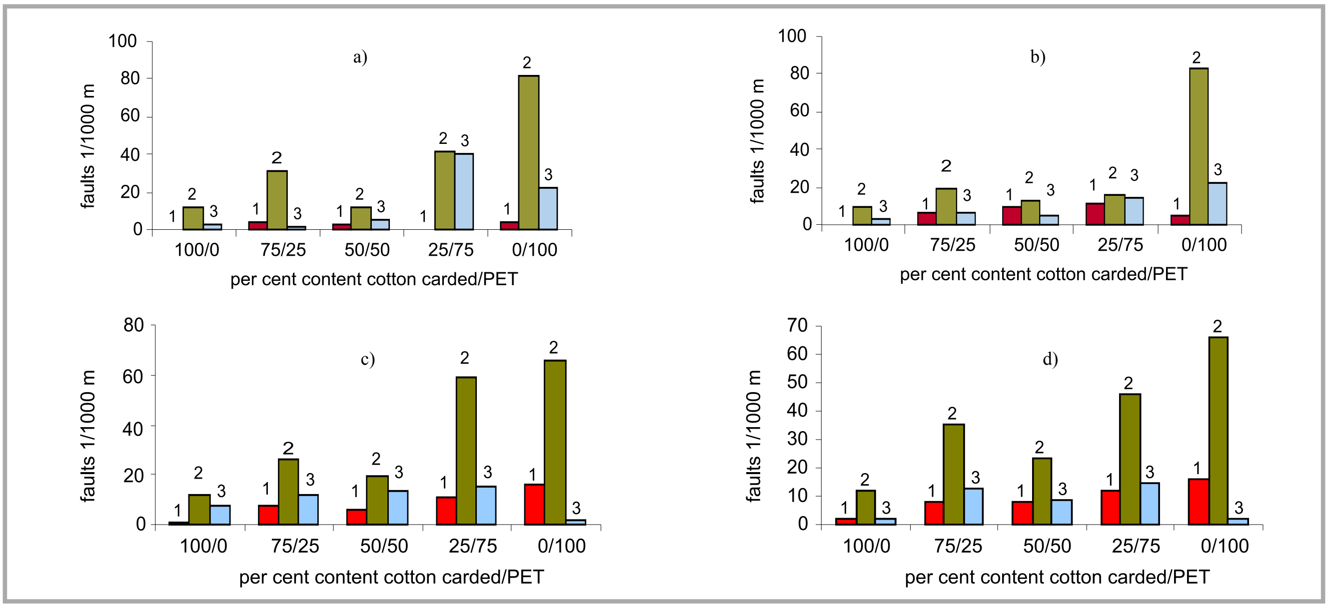

Figure 6. *Faults of rotor spun yarns (OE) for different fibre contents of the blend; 1 – thin places, 2 – thick places, 3 – neps; a) BD-200S spinning frame, cotton carded/PET. b) BD-200S spinning frame, cotton combed/PET; c) R1 spinning frame, cotton carded/PET; d) R1 spinning frame, cotton combed/PET.*

Determining the mixing irregularity of polyester fibres and cotton in blend yarns on the basis of coefficients of variation of the yarn parameters, the numbers of thick places & neps, and the hairiness

The values of the coefficients of variation of the yarn parameters, the number of thick places & neps and hairiness are presented in Figures 5 - 8.

The test results presented in Figures 5 and 6 indicate that for almost all variants of the yarn blends manufactured, the thick places represent the highest content of faults. On the basis of the data presented in the figures, we can state that yarns of the cotton/polyester fibres percentage content 50%/50% are characterised by the lowest number of faults.

On the basis of the hairiness results obtained with the Uster Tester III apparatus, the graphic interpretation of hairiness presented in Figure 7.a was prepared.

From the hairiness measurements carried out, it appears that the percentage content of polyester fibres influences the intensity of hairiness of the blends tested. On the basis of the data obtained, we can state that yarn blends with the percentage content of components of 50%/50% are characterised by the lowest hairiness.

Figures 7.b to 8.b present graphic dependencies of the following coefficients of variation as functions of the percentage content cotton/PET of the blend:

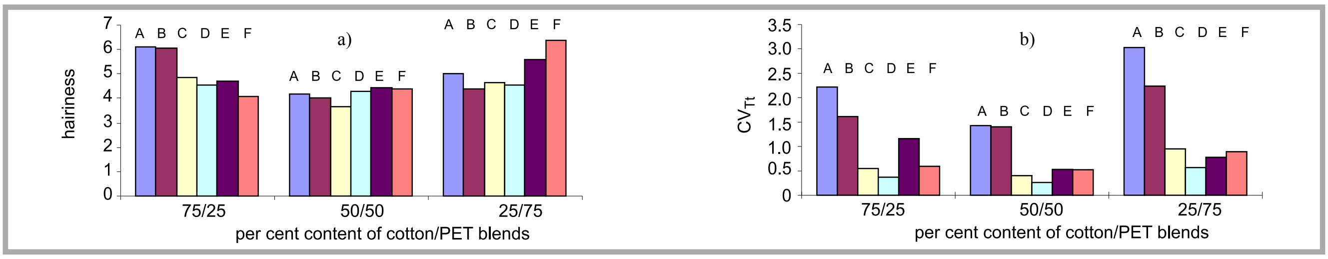

Figure 7. *Dependence between hairiness values and percentage content of blend (a) and coefficient of variation of the yarn's linear density on 100 m segments as function of the percentage content cotton/PET of the blend (b); A) cotton ring-spun carded, B) cotton ring-spun combed, C) cotton rotor-spun (BD-200S) carded, D) cotton rotor-spun (BD-200S) combed, E) cotton rotor-spun (R1) carded, F) cotton rotor-spun (R1) combed.*

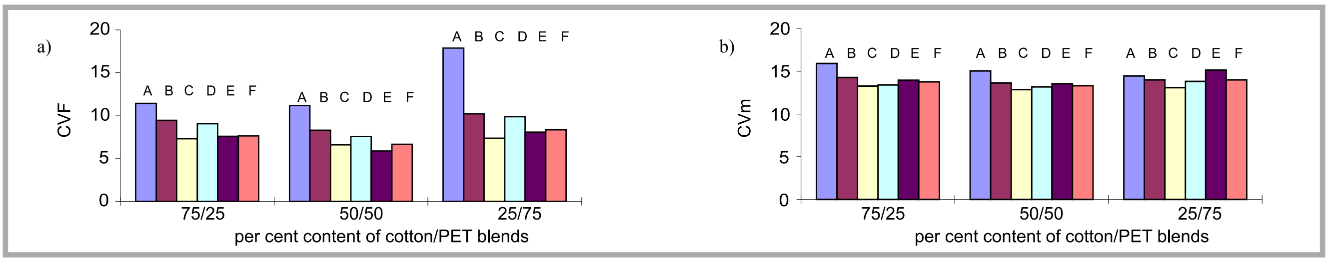

***Figure 11.** Coefficient of variation of the breaking strength as function of the percentage content cotton/PET of the blend (a) and coefficient of variation of the yarn's linear density on short m segments as function of the percentage content cotton/PET of the blend (b); a) cotton ring-spun carded, b) cotton ring-spun combed, c) cotton rotor-spun (BD-200S) carded, d) cotton rotor-spun (BD-200S) combed, e) cotton rotor-spun (R1) carded, f) cotton rotor-spun (R1) combed.*

- CV_{Tt} – coefficient of variation of the yarn's linear density on 100 m segments,
- CV_F - coefficient of variation of the breaking strength,
- CV_m - coefficient of variation of the yarn's linear density on short segments.

On the basis of the data presented in Figures 7.b to 8.b, we can state that yarns with the percentage component content of 50%/50% spun from combed cotton are characterised by the lowest values of the coefficients of variation, as shown in these figures.

On the basis of an analysis of the investigations presented, we can state that the fibre mixing unevenness measured by the *IBI* factor and the coefficient of variation of the fibre blend influence the quality parameters of the blended yarns and their coefficients of variation. With the increase in the *IBI* factor and the coefficient of variation CV_M of the fibre blend, the coefficients of variation of the yarn's parameters, the number of thick places, and the yarn's hairiness also increase.

Conclusions

1. Low-vacuum scanning electron microscopy (LV SEM) turned out to be useful in determining polyester fibre distribution in fibre cross-sections of classical rotor- and ring-spun yarns. The factors tested, such as the coefficient of variation of the percentage fibre contents for given yarn segments, the *IBI* unevenness coefficient of the blend, the coefficient of variation of the breaking force, the coefficient of variation of the yarn's linear density according to Uster, and the visual estimation of regularity of distribution of the blend's components, may be used to estimate the state of mixing of the fibres in two-component yarn blends.
2. The average content of the fibre components in rotor- and ring-spun cotton/PET blended yarns is similar to that initially assumed. Blended yarns with a percentage content of 50%/50% are characterised by the lowest coefficients of variation of the fibre blends.
3. The yarn cross-section images enable a estimation of the content's quality, as well as the type of distribution of the polyester fibres and cotton in the particular yarn samples. The yarn cross-section images which our tests obtained proved the differentiated content of polyester fibres and cotton.
4. The distribution of the particular components of the blends can be accepted as random for all the cases analysed.
5. The fibre mixing unevenness measured by the *IBI* factor and the coefficient of variation of the fibre blend influence the quality parameters of the blended yarns and their coefficients of variation. With the increase in the *IBI* factor and the coefficient of variation CV_M of the fibre blend, the coefficients of variation of the yarn's parameter, the number of thick places, and the yarn's hairiness also increase.

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