Lidia Jackowska-Strumillo*, Danuta Cyniak, Jerzy Czekalski, Tadeusz Jackowski

Department of Spinning Technology and Yarn Structure
Faculty of Textile Engineering and Marketing
Technical University of Łódź
ul. Żeromskiego 116, 90-543 Łódź, Poland
e-mail: s-k44-1@sir.p.lodz.pl

***Computer Engineering Department**
Technical University of Łódź, Poland
Al. Politechniki 11, 90-942
e-mail: lidia_js@kis.p.lodz.pl

Modelling the Dependencies Between the Structure of Feeding Streams and the Parameters of Cotton/Polyester Blended Yarns Manufactured with the Use of Ring- and Rotor Spinning Machines

Abstract
This work presents an analysis of the parameters of cotton, polyester, and blended cotton/polyester yarns manufactured using PJ ring-, and BD 200S & R1 Rieter rotor spinning machines. Cotton/polyester blended yarns of 30 tex with a share of polyester fibres from zero to 100% were spun with the use of each of the selected spinning frames. We analysed the influence of the polyester fibre content in the blends on the structural parameters of carded and combed yarns with a constant twist coefficient.

Key words: *cotton, polyester fibres, yarn blends, quality parameters, ring-spinning frame, rotor spinning frame, linear regression, parabolic regression, mean square approximation.*

Introduction

The world production of chemical fibres is continually increasing, at a present rate of 7.7% per year. Polyester fibres are produced in the greatest amount, with 24.5 mln tonnes of staple fibres and filaments for technical applications alone [8]. Western European countries, the United States, and Japan are the greatest producers. It should be stressed that their production is increasing, and that this increase is characterised by the greatest dynamic among chemical and especially synthetic fibres.

The production of chemical fibres and their processing in blends with natural fibres has contributed to the increase in importance of the fibres' blending process. Blending allows the technological and usage properties of blended yarns composed of natural and chemical fibres to be improved [3, 16].

Much research has been carried out on modelling the dependencies between the structure of feeding fibre streams and the parameters of classical & rotor blended yarns. Neckar [13] modelled the fibre arrangement in the yarn cross-section. Göktepe & Lawrence [7] analysed the deformations of yarn cross-sections in dependence on the fibre structure. Baykal & Babaarslan [2] predicted the tenacity and elongation at break of cotton/polyester rotor yarn blends on the basis of fibre parameters. Jiang & Chen [12] used geometrical and algebraic algorithms for modelling yarns dedicated to woven products. Das & Ishiaque [5] applied artificial neuron networks to predict the properties of rotor yarns. Oxenham [14] worked on innovations in manufactured yarns and predicted future changes in the yarn structure. Jackowski, Chylewska, Cyniak, Czekalski, & Jackowska-Strumillo [4, 9, 10, 11] have been working for years on modelling yarn parameters in dependency on the selected fibre parameters and the structure of the fibre streams feeding the spinning machine. Notwithstanding this, many questions need further investigation, which will be conducted by the authors, among others.

Aim and scope of research

The aim of our work was to determine the dependencies of selected structural and utility properties of the blended yarns on the percentage share of polyester fibres in the carded and combed fibre streams which fed the ring and rotor spinning frames. The following parameters were selected: tenacity, elongation at break, coefficient of variation of the yarn's linear density, the number of faults (thin & thick places, neps) and hairiness. The dependencies were determined experimentally.

Materials and test programme

Middle-staple cotton and polyester staple fibres with a linear density of 1.5 dtex and 38 mm length were used as raw materials for our investigations. Blended cottons from Uzbekistan, Turkmenistan, Tajikistan, West Africa, Syria, and Greece were used.

We used three kinds of sliver with a linear mass of 4.45 tex manufactured of the following fibres as initial semi-products:
- 100% carded cotton,
- 100% combed cotton, and
- 100% polyester fibres (PES).

The combed slivers were obtained by combing middle-staple cotton, accepting 24% of noils.

Two kinds of blends were composed from these slivers:
- carded cotton / polyester fibres, denotation: C_{car} /PES,
- combed cotton / polyester fibres; denotation: C_{com} /PES.

The blends were mixed with the use of a Globe 740 drawing frame. Table 1 shows that 14 blend variants and 3 initial variants were obtained as a result of mixing, i.e. joining and drawing. The percentage content (share) U_P of polyester fibres in

Table 1. *Blend variants.*

Carded cotton / PES (C_{car} /PES)	**Combed cotton / PES (C_{com} /PES)**
C_{car} – 100%	C_{com} – 100%
C_{car} / PES 87.5/12.5%	C_{com} / PES 87.5/12.5%
C_{car} / PES 75/25%	C_{com} / PES 75/25%
C_{car} / PES 62.5/37.5%	C_{com} / PES 62.5/37.5%
C_{car} / PES 50/50%	C_{com} / PES 50/50%
C_{car} / PES 37.5/62.5%	C_{com} / PES 37.5/62.5 %
C_{car} / PES 25/75%	C_{com} / PES 25/75%
C_{car} / PES 12.5/87.5%	C_{com} / PES 12.5/87.5 %
PES – 100%	PES – 100%

the blend was changed by 12.5% within the range from 0% to 100% of polyester fibres. Yarns with equal linear density of 30% were manufactured from these slivers by ring and rotor spinning, the latter with the use of BD 200 S and R1 Rieter spinning frames.

In order to manufacture yarns with the accepted linear density of 30 tex, the machine settings were selected in such a way as to maintain optimum working conditions. The working speed of the R1 spinning machine's rotors were set at 100,000 r.p.m., at a rotor diameter of 30 mm. The suitable rotary speed of the opening rollers was accepted at a level of 7,000 r.p.m. The working speed of the BD 200 S spinning machine's rotors were set at 45,000 r.p.m., a rotor diameter of 56 mm, and a rotary speed of the opening rollers also at 7,000 r.p.m. The spindle rotary speed of the ring spinning frame was set at a level of 14,000 r.p.m. at a total drawing ratio of 20.

Rotor-spun yarns with a constant twist coefficient of α_m = 140, and ring-spun yarns with a coefficient of α_m = 110 were manufactured from the prepared slivers, followed by a laboratory analysis of quality parameters, such as linear density, number of twists, breaking force, elongation at break, tenacity, unevenness of linear density, hairiness, and number of faults (thin & thick places, neps).

The arrangement of fibres in the yarn cross-section and the estimation of the variability of the component contents in the subsequent yarn segments were tested within the scope of our work [3], on the basis of an analysis of coefficients of variation of yarn parameters, the IBI mixing factors (Irregularity Blending Index), and a visual evaluation of the blend components' regularity of arrangement.

Modelling the yarn tenacity

The dependence of the yarn's tenacity W_w on the percentage share of polyester fibres U_p was modelled with the use of parabolic regression [15]:

$$W_w = a_2 U_p^2 + a_1 U_p + a_0 \qquad (1)$$

where:
W_w – the yarn tenacity,
U_p – the percentage share of polyester fibres.

The values of coefficients a_2, a_1, and a_0 of the function (1) for various spinning methods and spinning frame types were determined by the least-squares method. These values, the estimators of the standard deviation S_W of the function W_W, and the coefficients of linear correlation r and parabolic correlation R [15], are listed in Table 2. Figure 1 (see page 34) presents the measurement results and dependencies determined for the PO ring spinning frame, and the BD 200S & R1 rotor spinning frames, for blended yarns manufactured of carded (C_{car}) and combed (C_{com}) cotton.

The values of the coefficient r are within the range of 0.92 – 0.96, and those of R within 0.99 – 1. This confirms that the parabolic regression model is better than the model of linear regression and of higher accuracy for the dependency tested. The closeness of the R values to 1 confirm the statistical conformity according to the parabolic dependency.

The yarn tenacity increases with the increase in the percentage share of polyester fibres in the blend; in addition, higher tenacity values were obtained for yarns manufactured by ring spinning, especially for the combed cotton/polyester fibres variant in relation to the variant carded cotton/polyester fibres. The share of polyester fibres of up to 30% influences the increase in tenacity to only a small degree. We did not state that the combing process would have such a significant influence on the tenacity values of rotor yarns, as in the case of ring-spun yarns.

Modelling the elongation at break

The dependence of the elongation at break E and the remaining parameters tested on the percentage share U_p of polyester fibres in the blend were modelled by the following linear regression:

$$y = a_1 U_p + a_0 \qquad (2)$$

where: a_1, a_0 – the regression coefficients, y – the parameter tested (elongation at break – E, the coefficient of variation of the yarn's linear density – CV_y, the number of thin places – p, the number of thick places – z, the number of neps – n, the hairiness – H).

The values of coefficients a_2, and a_1, were determined by the least-squares method. Their values for various spinning methods and spinning frame types, the estimators of the standard deviation S_E of the function E, the standard deviations S_{a1} and S_{a0} of the coefficient determined, and the coefficients of linear correlation r and parabolic correlation R [7] are listed in Table 3.

The results of experimental investigations and the dependencies of yarn elongation as a function of the percentage share of polyester fibres in the blended yarn are presented in Figure 2 (see page 34).

Elongation at break depends mainly on the content of polyester fibres, and increases with the increase in the share of polyester fibres in the blend. For ring-

Table 2. *Coefficients a_2, a_1, and a_0 of the function (1), standard deviation S_W of the function W_w, and the coefficients of linear correlation r and parabolic correlation R.*

Yarn	a_2	a_1	a_0	S_w	r	R
ring-spun, carded cotton	0.0019	-0.006	13.98	0.39	0.959	0.999
ring-spun, combed cotton	0.0017	0.013	14.79	1.06	0.958	0.990
rotor-spun by BD 200 S, carded cotton	0.0012	-0.010	12.13	0.48	0.949	0.994
rotor-spun by BD 200 S, combed cotton	0.0014	-0.038	12.90	0.28	0.928	0.998
rotor-spun by R1, carded cotton	0.0011	-0.024	12.34	0.43	0.933	0.993
rotor-spun by R1, combed cotton	0.0011	-0.022	11.98	0.31	0.938	0.996

Table 3. *Coefficients a_1 and a_0 of the function (2), standard deviation S_E of the variable E, standard deviations S_{a1} and S_{a0} of the coefficients determined, and coefficient of linear correlation r.*

Yarn	a_1	a_0	S_E	S_{a1}	S_{a0}	r
ring-spun, carded cotton	0.099	5.3	0.60	0.002	0.1	0.987
ring-spun, combed cotton	0.091	5.6	0.73	0.002	0.2	0.977
rotor-spun by BD 200 S, carded cotton	0.067	7.1	0.58	0.002	0.1	0.973
rotor-spun by BD 200 S, combed cotton	0.069	6.8	0.68	0.002	0.1	0.966
rotor-spun by R1, carded cotton	0.076	6.1	0.56	0.002	0.1	0.981
rotor-spun by R1, combed cotton	0.082	5.6	0.48	0.002	0.1	0.987

Table 4. Values of coefficients a_2, and a_1 of the function (2), standard deviation S_{CV} of the variable CV_y, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficients r.

Yarn	a_1	a_0	S_{CV}	S_{a1}	S_{a0}	r
ring-spun, carded cotton	-0.045	17.3	0.48	0.002	0.10	-0.960
ring-spun, combed cotton	-0.017	15.1	0.55	0.002	0.10	-0.755
rotor-spun by BD 200 S, carded cotton	0.003	13.4	0.71	0.002	0.10	0.178
rotor-spun by BD 200 S, combed cotton	0.003	13.3	0.49	0.002	0.10	0.231
rotor-spun by R1, carded cotton	0.019	12.9	0.54	0.002	0.10	0.794
rotor-spun by R1, combed cotton	0.016	12.9	0.37	0.001	0.08	0.845

Table 5. Values of coefficients a_1, and a_0, the estimators of standard deviation S_P of the variable p, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficient r.

Yarn	a_1	a_0	S_p	S_{a1}	S_{a0}	r
ring-spun, carded cotton	-0.899	72.2	19.1	0.066	3.9	-0.865
ring-spun, combed cotton	-0.251	22.5	4.0	0.014	0.8	-0.917
Rotor-spun by BD 200 S, carded cotton	-0.017	5.6	5.4	0.018	1.1	-0.118
Rotor-spun by BD 200 S, combed cotton	0.044	0.6	1.7	0.006	0.3	0.695
Rotor-spun by R1, carded cotton	0.149	-0.2	2.6	0.009	0.5	0.901
Rotor-spun by R1, combed cotton	0.133	2.2	2.0	0.007	0.4	0.925

Table 6. Values of coefficients a_1, and a_0, the standard deviation S_z of the variable z, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficient r.

Yarn	a_1	a_0	S_z	S_{a1}	S_{a0}	r
ring-spun, carded cotton	-2.29	230	25	0.08	5	-0.960
ring-spun, combed cotton	-0.55	72	13	0.04	3	-0.850
Rotor-spun by BD 200 S, carded cotton	0.56	8	18	0.06	4	0.760
Rotor-spun by BD 200 S, combed cotton	0.53	-3	17	0.06	4	0.745
Rotor-spun by R1, carded cotton	0.43	12	10	0.04	2	0.840
Rotor-spun by R1, combed cotton	0.36	14	12	0.04	2	0.743

spun yarns, we obtained insignificantly higher elongations at break.

Modelling the unevenness of linear density of yarns

The dependency of the coefficient of variation of the yarn's linear density CV_t on the percentage share U_P of polyester fibres was modelled with the use of linear regression (2). The values of coefficients a_2, and a_1 for the various yarn variants and different machines, the estimators of standard deviation S_{CV} of the variable CV_y, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficients r are listed in Table 4. Figure 3 (see page 36) presents the measurement results and dependencies determined for the PO ring spinning frame, and BD 200 s & R1 ring spinning frames, for yarn blends manufactured of carded (C_{car}) and combed (C_{com}) cotton.

On the basis of the coefficient r values determined, we could conclude that a strong correlation dependency exists between the coefficient of variation of the yarn's linear density and the percentage share of polyester yarn for the ring spinning frame and the R1 rotor spinning frame, whereas no such dependency exists for the BD 200 S rotor spinning frame. The unevenness of the rotor yarns' linear density is at a similar level for all the variants of carded and combed yarn blends, and is lower than that of ring-spun yarns. Carded ring-spun yarns have a higher unevenness than those which were combed.

Modelling the thin places

The dependency of the number p of thin places per 1000 metres of yarn on the percentage share U_P of polyester fibres for various kinds of yarn blends and different machine types was modelled with the use of linear regression (2). The values of coefficients a_1, and a_0, the estimators of standard deviation S_P of the variable p, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficients r are listed in Table 5. The results of experimental tests and the dependencies of the number of thin places on the percentage share of polyester fibres in the yarn blends are presented in Figure 4 (see page 36) .

On the basis of the coefficient r values determined, we could conclude that a correlation dependency exists between the number of thin places and the percentage share of polyester fibres for all the kinds of yarns, with the exception of rotor yarn manufactured of carded cotton with the use of the BD 200 S spinning frame.

The number of thin places of the yarns analysed differs to an insignificant degree. Only the carded yarn with a small content of polyester fibres manufactured with use of the ring spinning frame was characterised by a higher number of thin places.

Modelling the thick places

The dependency of the number z of thick places per 1000 metres of yarn on the percentage share U_P of polyester fibres for various kinds of yarn blends and different machine types was modelled with the use of linear regression (2). The values of coefficients a_1, and a_0, the estimators of standard deviation S_z of the variable z, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficients r are listed in Table 6. The results of experimental tests and the dependencies of the number of thick places on the percentage share of polyester fibres in the yarn blends are presented in Figure 5 (see page 36) .

On the basis of the coefficient r-values determined, we could conclude that a strong correlation dependency exists between the number of thick places and the percentage share of polyester fibres for all the kinds of yarns tested. The dependency has a linearly decreasing character for yarns spun with the use of the ring spinning frame, and a slightly increasing character for rotor yarns.

The dependencies obtained have a similar character to the dependencies determined for thin places, but the number of thick places per 1000 metres of yarn is higher than that of thin places for all the yarn variants tested.

Modelling the number of neps

The dependency of the number n of thick places per 1000 metres of yarn on the percentage share U_P of polyester fibres was modelled with the use of linear regression (2). The values of coefficients a_1, and a_0, for the various yarn variants and different machine types, the estimators of standard deviation S_n of the variable n, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficients r are listed in Table 7. The results of experimental tests and the dependencies of the number of thick places on the percentage share of polyester fibres in the yarn blends are presented in Figure 6 (see page 36).

On the basis of the coefficient r-values determined, we could conclude that a strong correlation dependency exists between the number of neps and the percentage share of polyester fibres for ring-spun yarns, a mean correlation dependency for yarns spun with the use of the BD 200 S spinning frame, and a lack of any dependency for yarns spun with the R1 rotor spinning machine. This dependency has a linearly decreasing character for the ring spinning frame, and a linearly increasing character for yarns spun with use of the BD 200 S spinning frame; however, for the R1 rotor spinning frame, the number of neps in practice does not depend on the percentage share of the polyester fibres.

The number of neps of rotor yarns is maintained at a very low level independently of the percentage share of polyester fibres in the blend. This is caused by the opening rollers, with which the rotor spinning frames are equipped, and which divide the fibre clusters. Combed yarn has significantly lower numbers of thin & thick places and neps than those of the carded yarn.

Modelling the yarn hairiness

Yarn hairiness H has great practical significance for further yarn processing, as well as for the end-user of final products. Hairiness is one of the parameters which are decisive for yarn quality, and significantly influences the properties and usage comfort of woven and knitted fabrics. Yarn hairiness should be constant, without periodical changes, at a level required for the given product type [1, 5].

The yarn hairiness H on the percentage share U_P of polyester fibres for various kinds of yarn blends and different machine types was modelled with the use of the linear regression (2). The values of coefficients a_1, and a_0, for the various yarn variants and different machine types, the estimators of standard deviation S_H of the variable H, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficients r are listed in Table 8. The results of experimental tests and the dependencies of the number of thick places on the percentage share of polyester fibres in the yarn blends are presented in Figure 7 (see page 36).

Table 7. *Values of coefficients a_1, and a_0, the standard deviation S_n of the variable n, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficient r.*

Yarn	a_1	a_0	S_n	S_{a1}	S_{a0}	r
ring-spun, carded cotton	-1,270	166	18.0	0,06	4	-0,932
ring-spun, combed cotton	-0,640	88	11.0	0,04	2	-0,899
Rotor-spun by BD 200 S, carded cotton	0,200	2	11.0	0,04	2	0,562
Rotor-spun by BD 200 S, combed cotton	0,110	2	6,4	0,02	1	0,527
Rotor-spun by R1, carded cotton	-0,010	13	6,9	0,02	1	-0,035
Rotor-spun by R1, combed cotton	0,004	8	4,1	0,01	1	0,036

Table 8. *Values of coefficients a_1, and a_0, the standard deviation S_H of the variable H, the standard deviations S_{a1} and S_{a0} of the coefficients determined, and the linear correlation coefficient r.*

Yarn	a_1	a_0	S_H	S_{a1}	S_{a0}	r
ring-spun, carded cotton	0,0004	5,39	0,54	0,0019	0,11	0,024
ring-spun, combed cotton	0,0028	5,15	0,66	0,0023	0,14	0,150
Rotor-spun by BD 200 S, carded cotton	0,0124	3,84	0,15	0,0005	0,03	0,948
Rotor-spun by BD 200 S, combed cotton	0,0148	3,69	0,26	0,0009	0,05	0,898
Rotor-spun by R1, carded cotton	0,0199	3,83	0,41	0,0014	0,08	0,871
Rotor-spun by R1, combed cotton	0,0258	3,67	0,75	0,0026	0,15	0,782

On the basis of the coefficient r-values calculated, we could conclude that a strong correlation dependency exists between the hairiness of yarns manufactured by rotor spinning frames and the percentage share of polyester yarn ($r > 0.78$), whereas there is no correlation for the ring spinning frame ($r \le 0.15$).

The hairiness of yarns manufactured with the use of rotor spinning frames increases with the increase in the content of polyester fibres.

Conclusions

The dependency of the tenacity of all yarns tested on the percentage share of polyester fibres in the blend has a parabolic character.

The tenacity of cotton/polyester fibre blend yarns increases with the increase in the content of polyester fibres in the fibre blend. Yarns with a content of combed cotton manufactured with the use of ring spinning frames are characterised by the highest tenacity.

The dependencies of the yarn parameters tested, such as elongation at break, unevenness of linear density, the number of faults, and hairiness on the percentage share of polyester fibres in the yarn blend have a linear character.

The number of thin & thick places and neps of classical yarns is higher than that for rotor yarns, and decreases with the increase in the percentage share of polyester fibres in the yarn blends.

The number of faults of rotor yarns is maintained at a constant low level, independently of the content of polyester fibres.

The hairiness of rotor spun yarns increases with the increase in the content of polyester fibres in the yarn blend.

The quality of yarns manufactured with the use of ring spinning frames is significantly positively influenced by the combing process. Ring-spun, combed yarns are characterised by higher tenacity and lower unevenness of linear density.

Acknowledgment

This research work was financially sponsored from the resources of the Polish State Committee for Scientific Research during the years 2004 – 2006 as part of research project Nr. 3 T08E 035 26.

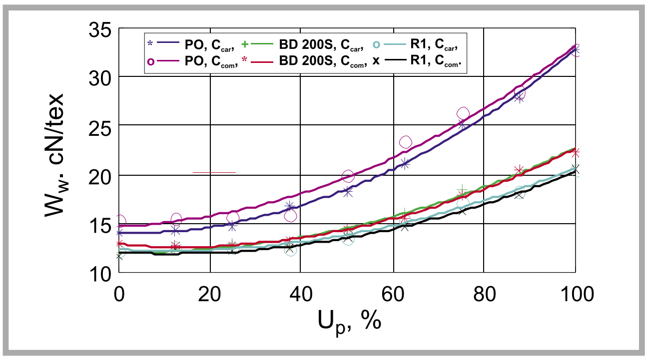

Figure 1. *Dependency of tenacity W_W on the percentage share of polyester fibres U_P in the fibre blend for various yarn blends and spinning frame types.*

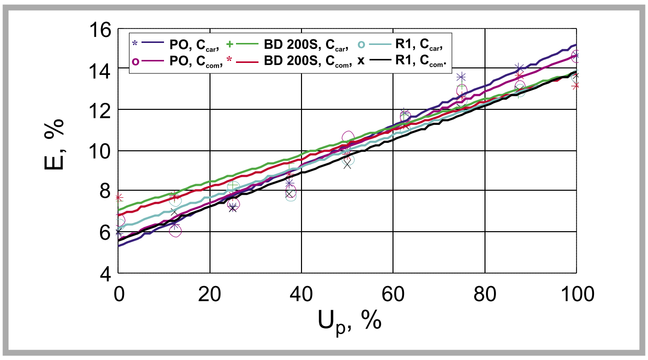

Figure 2. *Dependency of elongation at break E on the percentage share of polyester fibres U_P in the fibre blend for various yarn blends and spinning frame types.*

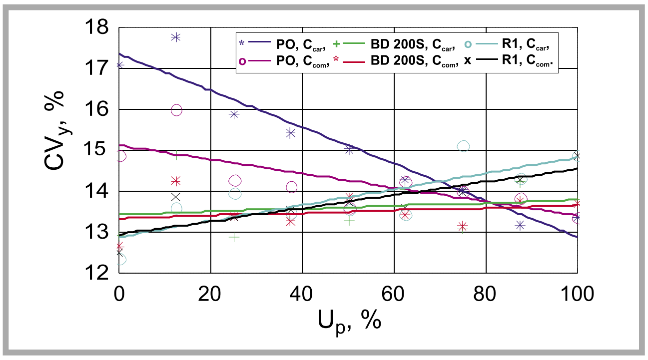

Figure 3. *Dependency of the coefficient of variation of the yarn's linear density CV_y on the percentage share of polyester fibres U_P in the fibre blend for various yarn blends and spinning frame types.*

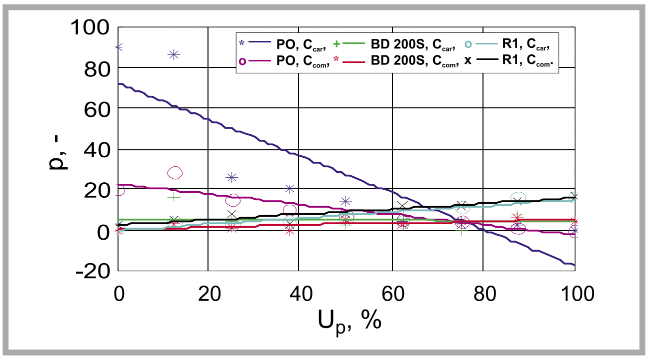

Figure 4. *Dependency of the number of thin places p on the percentage share of polyester fibres U_P in the fibre blend for various yarn blends and spinning frame types.*

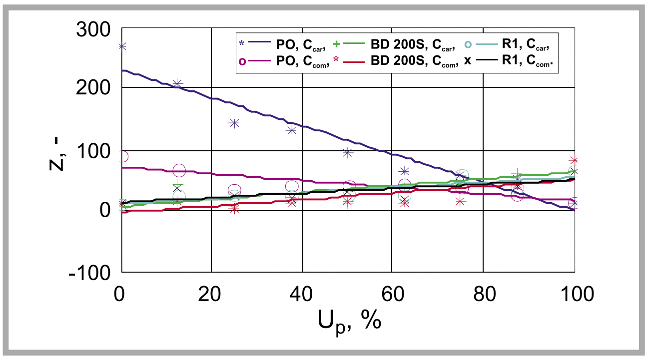

Figure 5. *Dependency of the number of thick places z on the percentage share of polyester fibres U_P in the fibre blend for various yarn blends and spinning frame types.*

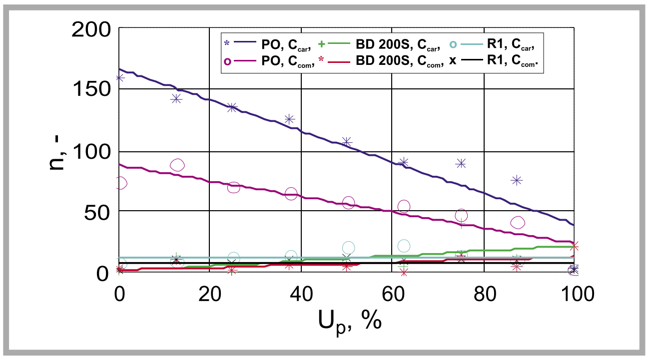

Figure 6. *Dependency of the number of neps n on the percentage share of polyester fibres U_P in the fibre blend for various yarn blends and spinning frame types.*

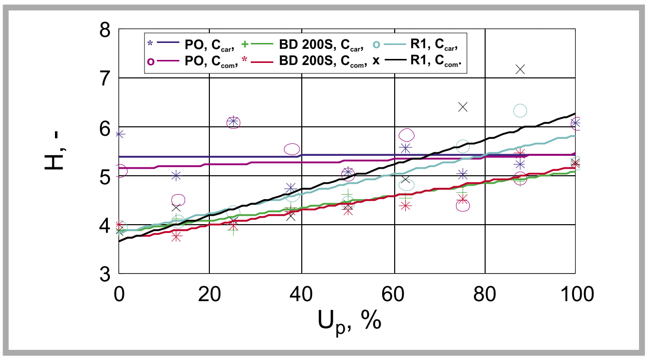

Figure 7. *Dependency of yarn hairiness H on the percentage share of polyester fibres U_P in the fibre blend for various yarn blends and spinning frame types.*

Denotations used in figures:

PO, C_{car} – ring spinning frame, carded cotton
PO, C_{com} - ring spinning frame, combed cotton
BD 200 S, C_{car} – rotor spinning frame, carded cotton
BD 200 S, C_{com} – rotor spinning frame, combed cotton
R1, C_{car} – rotor spinning frame, carded cotton
R1, C_{com} - rotor spinning frame, combed cotton

References

1. Barella A., 'Yarn Hairiness', The Textile Institute, Vol. 13, p. 61, 1983.
2. Baykal P. D., Babaarlson D., Erol R., 'Prediction of Strength and Elongation Properties of Cotton-Polyester-Blended OE Rotor Yarns'. Fibres and Textiles in Eastern Europe, vol. 14, 2006, No.1, p.18-21.
3. Cyniak D., Czekalski J., Jackowski T., Popin Ł. 'Quality Analysis of Cotton/ Polyester Yarn Blends Spun with the Use of a Rotor Spinning Frame', Fibres & Textiles in Eastern Europe, vol. 14, No. 3, (57) 2006, pp. 33-37.
4. Cyniak D., Czekalski J., Jackowski T. 'Influence of Selected Parameters of the Spinning Process on the State of Mixing of Fibres of a Cotton/Polyester-Fibre Blend Yarn', Fibres & Textiles in Eastern Europe, vol. [14], No. 4, 2006, pp. 36-40
5. Das D., Ishiaque S.M., Veit D., Gmes T. 'Application of artificial neural network to predict rotor spun yarn properties'. Melliand International 2004, No. 3, p. 183.
6. 'Global chemical fibre production 38 million tons'. Chemical Fibres International, vol. 55, 2005, No. 2, p. 6.
7. Göktepe E., Lawrance C.A. 'Deformation of Yarn Cross-Section in Relation to Yarn Structure.' Fibres & Textiles in Eastern Europe, 2001, vol. 9, No. 2. pp. 18-22.
8. Jabłoński W., Jackowski T.: Nowoczesne systemy przędzenia Bielsko-Biała 2001.
9. Jackowski T., Cyniak D Czekalski J., 'Influence of selected fibre parameters decisive on the quality of spun yarns' (in Polish), Przegląd Włókienniczy, 2006, No. 2, p. 53.
10. Jackowski T., Chylewska B., Cyniak D., Czekalski J., Jackowska-Strumiłło L., 'Modelling the relationship between feeding sliver structures and parameters of cotton/linen blended yarns', Fibres & Textiles in Eastern Europe, 2003. vol. 11, No. 2, pp. 12-17.
11. Jackowski T., Chylewska B., Cyniak D., Jackowska-Strumiłło L. 'Investigating and Modelling Yarn Parameters for Different Feeding Slivers'. Fibres &Textiles in Eastern Europe, 2002. vol. 10, No.1, pp. 49-51.
12. Jiang Y.,Chen X. 'Geometric and algebraic algorithms for modelling yarn in woven fabrics.' Textile Research Journal, vol. 96, 2005, No 4, pp. 237-245.
13. Neckar B., Soni M.K., Das D. 'Modelling of Radial Fiber Migration in Yarns,' Textile Research Journal, vol. 76, 2006, No. 6, pp. 486-491.
14. Oxenham W. 'Innovations in spun yarn technologies – present and future'. Indian Journal of Fibre & Research, vol. 31, 2006, pp.116-124.
15. Szydłowski H.: Teoria pomiarów, WNT, Warsaw, 1981.
16. Tyagi G. K., Chatterjee K. N.: 'Contribution of doubling to the characteristics of polyester-cotton ring- and rotor-spun yarns', Indian Journal of Fibre & Research, 1992.

Received 20.01.2006 Reviewed 18.11.2006