Manufacturing Technology and Physical Properties of Yarn Blends Containing Broken Polyester Fibres with Decreased Susceptibility to Pilling

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Abstract

The aim of the investigation presented in this article was to verify the possibility of manufacturing polyester/wool blended yarn (of type PET55/Wo45) which would contain a fraction of polyester fibres with decreased susceptibility to pilling, obtained from a spinning cable prepared by the uncontrolled breaking method. This investigation demonstrated that it is possible to manufacture the above-mentioned yarns on condition that the technological process is modified. The physical properties of single and doubled yarns were tested. An analysis of the results obtained indicated that the majority of quality parameters of the 21 tex 550Z single yarn comply with standard requirements, as well as with the values described by Uster Statistics at the 50% line. A decrease in the twist number of the 21 tex x 2 doubled yarn from 560 rev./m to the value of 520 rev./m, i.e. almost 8%, does not in principle influence the decrease in quality of this yarn.

Key words: *yarn blends, polyester, wool, broken fibres, pilling, yarn quality.*

Introduction

Textile slivers and wool-type yarns from a polyester (PET) fibre cable have been manufactured with the use of cutting converters. However, this technology has a variety of disadvantages, such as formation of fibre bunches with 'stuck ends', deformation of fibre ends, and low machine productivity. As a result, the slivers and yarns obtained are of relatively low quality.

The fundamental obstruction to using the method of uncontrolled breaking (which allows higher productivity to be achieved) for processing a polyester cable is its high breaking strength, which causes difficulties in mechanical processing. The application of chemically modified polyester fibres, which display both decreased susceptibility to pilling and also decreased breaking strength as raw material, created a possibility of using the technology of uncontrolled breaking for the process of textile sliver formation. Considering this situation, research works were carried out [1] with the aim of developing a manufacturing technology for PET55/Wo45 blended yarn which should include polyester fibres from the ELANA WK-2LP polyester cable with decreased susceptibility to pilling. This cable has been produced by the ELANA Company in Toruń, Poland (Zakłady Włókien Chemicznych ELANA).

The main aim of our research carried out was to answer the following questions:

1. Is it possible to manufacture PET55/Wo45 blended weaving yarn with a content of polyester fibres of decreased susceptibility to pilling obtained from a spinning cable divided by the method of uncontrolled breaking, which could fulfil the quality criteria provided for such yarn?
2. Do the physical properties of the single yarns comply with the values described by the particular subject standards and by the Uster Statistics (of the 50% line)

Table 1. *Physical properties of the ELANA WK-2LP spinning cable of polyester fibres with decreased susceptibility to pilling.*

Parameter analysed	Unit	Value
Linear density of cable	ktex	50
Linear density of filaments	dtex	2.84
Tenacity of 10-mm length segments in air-conditioned state	cN/tex	31.5
Average breaking force of 10-mm length segments in air-conditioned state	cN	8.94 ± 0.12
Coefficient of variation of breaking force	%	6.7
Average relative elongation at break of 10-mm length segments in air-conditioned state	%	48.0 ± 2.4
Number of crimps	1/cm	4.7
Degree of crimp	%	73.5
Linear contraction at temperature of 175°C	%	1.98
Electrical resistivity of fibres	Ω	0.49×10^9

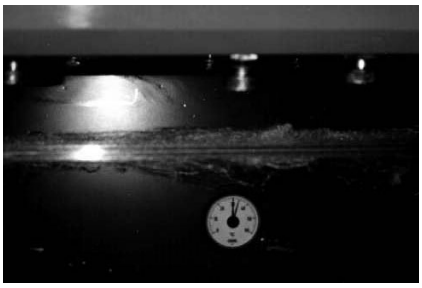

Figure 1. Fibre breaking in the first zone (B) of preliminary breaking; breaking by whole fibre bundles can be distinctly seen.

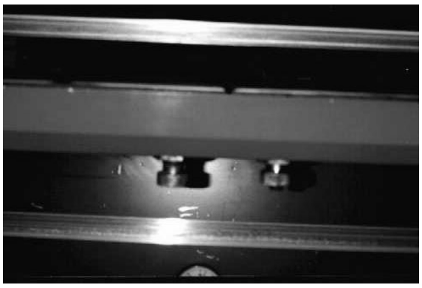

Figure 2. Fibre breaking in the first zone (B) of preliminary breaking; breaking by fibre bundles occurs only to a minimal degree.

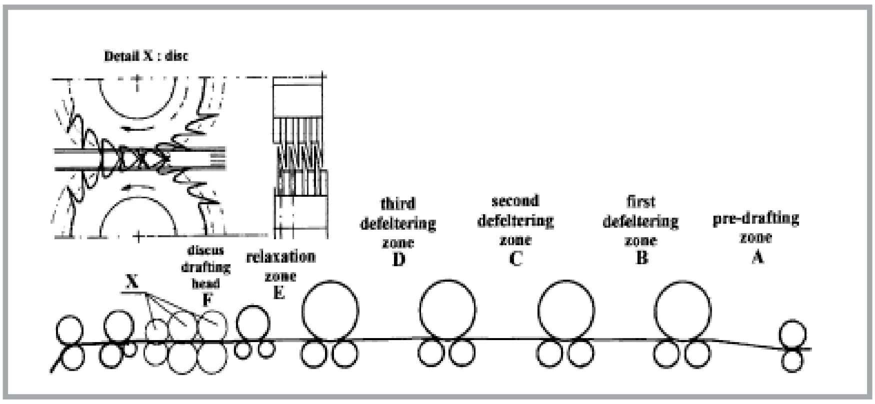

Figure 3. Technological arrangement of the RSN/D integrated drawing frame from the SAN company.

Table 2. Working parameters of 860-Compact cable breaking machine used for breaking the ELANA WK-2LP polyester cable with decreased susceptibility to pilling; A - heating zone, B - 1st pre-breaking zone, C - 2nd pre-breaking zone, D - breaking zone, E - rebreaking zone, F - crimping zone.

Zone lengths, mm		Partial draft ratio, (-)					
L_D	L_E	D_A	D_B	D_C	D_D	D_E	D_F
195	165	1.00	1.16	1.38	1.25	1.86	1.07
Total draft 4.00, delivery linear density 12.50 ktex, delivery speed 120 m/min							

Table 3. Working parameters of RSN/D integrated drawing frame from the SAN company for re-breaking the sliver obtained from the polyester cable; A, B, C, D, E, F - as in Table 2.

Zone lengths, mm					Partial draft ratio, (-)					
L_A	L_B	L_C	L_D	L_E	D_A	D_B	D_C	D_D	D_E	D_F
-	176	160	157	-	0.950	1.354	1.354	1.444	0.880	7.389

published by Zellweger; and if the physical yarn properties do not comply, how great are the differences?

3. Does the application of polyester fibres with decreased susceptibility of pilling allow for a decrease in the number of twists of the yarn obtained without a reduction of its quality?

Object of Investigation

A WK-2LP spinning cable (wool-type cable - low pilling) with decreased susceptibility to pilling, with 50 ktex linear density, and with 2.7 dtex linear density of the polyester fibres which formed the cable, was used as initial raw material. The cable has been manufactured by the ELANA company in Toruń. Its main physical properties are listed in Table 1.

A theoretical analysis based on the Michajlov & Sevostianov dependencies [2] preceded the optimisation of the cable breaking process. On the basis of this optimisation, a set of theoretical cumulative diagrams of fibre lengths was formed, and the theoretical basic length parameters and the fibre length distribution were calculated. Next, the theoretically calculated distributions were verified with data obtained from experiments. The technological process of uncontrolled cable breaking was developed for those slivers which fulfilled best the optimisation criteria. This process was conducted with the use of the 860-Compact cable-breaking machine. Then, the sliver obtained from the cable was additionally broken with the use of the RSN/D integrated drawing frame from the SAN company [4].

Manufacturing Technology of PET55/Wo45 Blended Weaving Yarn Including Polyester Fibres with Decreased Susceptibility to Pilling

The yarn manufacturing technology developed comprises intermediate spinning products as follows:
- sliver from the cable and tops,
- roving, and
- single and doubled yarn.

Manufacturing technology of slivers from cable and blended tops

The leading operation in the process of manufacturing sliver from cable is uncontrolled breaking. It was performed with the use of the 860-Compact cable-breaking machine of SEYDEL [3] at the 'Argopol' Wool Textile Enterprise (Zakłady Przemysłu Wełnianego) in Głuszyca. The working parameters of the cable-breaking machine are listed in Table 2. Emphasis should be placed on the necessity of unloading the pressure roller in the Ω roller system located in the zone of cable thermal drawing (A). The roller should be unloaded because in a normal run breaking in the first zone of preliminary breaking (B) occurs in the form of whole bundles, even at the smallest values of the partial draft ratio (drawing ratio), as can be seen in Figure 1.

Unloading the roller system almost entirely suppressed the undesirable phenomenon of fibre breaking in zone B (as shown in Figure 2), whereas the second zone (C) of preliminary breaking was fed by a layer of almost unbroken, matted fibres.

The remaining working zones of the breaking machine, i.e. the breaking zone (D) and the zone (E) of additional breaking

Table 4. Fibre lengths and fibre length distributions of fibres in the sliver from the cable and in the sliver from the integrated drawing frame, determined by means of the method of fibre segregation into length classes.

Parameter analysed	Unit	Parameter values for:	
		860-Compact cable breaking machine	RSN/D integrated drawing frame
Average fibre length (l)	mm	136.0	133.0
Maximum fibre length	mm	239.0	237.0
Percentage of fibres longer than 180 mm	%	9.4	11.6
Percentage of fibres shorter than 40 mm	%	4.7	3.3

Table 5. Fibre lengths and fibre length distributions of fibres in the sliver from the integrated drawing frame determined by means of the electro-capacitive method.

Parameter analysed		Unit	Value
Weight fibre length B		mm	95.3
Fibre length of percentage content of:	0.5%	mm	203.0
	1.0%	mm	190.0
Percentage of fibres longer than:	180 mm	%	1.3
	160 mm	%	2.6
Percentage of fibres shorter than 40 mm		%	

Table 6. Working parameters of WL-2 re-breaking machine applied for additional re-breaking the sliver from ELANA WK-2LP PET low pilling fibre cable; A - pre-drafting zone, B - drafting zone, C - breaking zone, D - re-breaking zone.

Zone lengths, mm				Partial draft ratio, (-)			
L_A	L_B	L_C	L_D	D_A	D_B	D_C	D_D
Not adjusted	195	185	160	1.03	1.46	2.20	3.50
delivery linear density 11.0 ktex							

Table 7. Physical properties of wool tops used for yarn manufacture.

Parameter analysed	Unit	Value
Mean linear density of sliver	ktex	21.0
Coefficient of variation of sliver CV_{1m}	%	1.50
Number of neps in sliver	pieces/100 g	30
Number of vegetable impurities in sliver	pieces/100 g	9
Coefficient of variation of linear density CV_{20mm}	%	3.9
Preparation content deposited	%	0.80
Tops humidity φ	%	14.14
Mean value of Hauteur - H [13]	mm	77.3
Coefficient of variation of Hauteur CV_H [13]	%	42.0
Percentage of fibres shorter than 40 mm	%	17
Mean diameter of fibres	µm	23.0

(the re-breaking zone), were not sufficient to break the fibres at the appropriate, assumed length. Thus, a process of additional breaking (re-breaking) of the sliver obtained from the cable-breaking machine was applied, and the RSN/D integrated drawing frame from the Italian SAN company was used for this purpose. The technological arrangement of the RSN/D integrated drawing frame is presented in Figure 3. The best quality results of the re-breaking process were achieved using the working parameters listed in Table 3.

It should be stressed that the process of re-breaking sliver obtained from the cable with use of the RSN/D integrated drawing frame was unfortunately not completely effective. The test results of fibre length parameters obtained for fibres of the sliver from the 860-COMPACT breaking machine and from the RSN/D integrated drawing frame are listed in Tables 4 and 5.

The data presented in Table 5 prove that the content (in per cent) of fibres which belong to the ranges qualified as 'long' and as 'the longest' fibres still remains high. A fibre length distribution similar to that of wool fibres, i.e. of a percentage content of fibres longer than 180 mm in the range of 0.5-1.0% and fibres shorter than 40 mm in the range of 21-30%, could not be achieved.

However, it should be stressed that the sliver samples taken from the cable and from the sliver after the integrated drawing frame to perform measurements of fibre length, included fibres of a maximum length longer than 300 mm, which exceeds the measuring range of the apparatus used [5]. In such a case, the electro-capacitive measuring method which was characteristic for the apparatus used for fibre length measurements distorted the results obtained. In this case, the only possible method of fibre length assessment in the sliver is the organoleptic method of segregating fibres into length classes [6].

From the analysis of the results listed in Table 4, it can be seen that the length of the longest fibres reaches 239 mm, and the content of fibres longer than 180 mm is 11.6.

Considering the phenomenon of fibre matting which appears in the second zone of preliminary breaking of the cable breaking machine (C), which could not really have been eliminated (notwithstanding the operation of re-breaking the sliver from the cable obtained after the RSN/D drawing frame applied in the process) and the disadvantageous fibre length distribution, the necessity arose of integrating an operation of repeated fibre breaking with the use of a classical WL-2 breaking machine. The working parameters of the WL-2 breaking machine are presented in Table 6.

The process of re-breaking the sliver with the WL-2 breaking machine proceeded without greater disturbances. However, when testing the sliver drawing process on the first GN-6 intersecting gillbox from the NSC Schlumberger company, some disturbances could be observed. Repeated fibre wrapping around the bottom and the upper feeding rollers (with a cot) could often be observed, as well as the interruption of the layer's continuity at the output of the faller bed. The process of sliver drawing with the use of the second GN-6 intersecting gillbox from the NSC Schlumberger company proceeded without disturbances.

Considering the excessive number of neps in the sliver after the RSN/D integrated drawing frame and the disadvantageous fibre length distribution, a process of combing polyester fibres with wool was introduced. The characteristic of the wool tops (including selected physical parameters) destined for processing with the sliver from the cable of PET fibres is demonstrated in Table 7.

The processes of sliver drawing, and also combing (with exception of the first drawing passage before combing), proceeded without disturbances. The interferences of the process at this stage, which were caused by the very high cohesion of polyester fibres, consisted in fibre displacement through the faller bed in strands. This in turn caused difficulties in mixing the polyester fibres with wool. The situation described above was the reason for our decision to apply three drawing passages before combing. The final plan of spinning sliver from the WK-2LP polyester cable from the ELANA company and the PET55/Wo45 blended top is listed in Table 8.

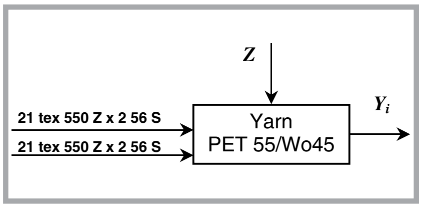

Figure 4. *Plan of tests for clarifying the possibility of influence of an 8% decrease in the doubled yarn twist number on the yarn physical properties; Y_i - basic physical yarn parameters, Z - unmeasurable disturbances of the yarn manufacturing process and of measuring devices.*

Table 8. *Plan for sliver spinning from cable and PET55/Wo45 blended tops with a content of ELANA WK-2LP polyester fibres of reduced susceptibility to pilling.*

Name of machine	Type of machine	Sliver count at feeding ktex	Doubling	Total draft	Sliver count at delivery ktex	Total of ends at delivery	Delivery speed m/min	Theoretical production, kg/h	Efficiency	Practical production kg/h
Preparation of sliver from cable										
Breaking machine	860	50	1	4.00	12.5	1	120	90	0.70	63
Integrated drawing frame	RSN/D	12.5	20	16.35	15.3	1	150	138	0.70	97
Re-breaking machine	WL-2	15.3	8	11.58	10.6	1	140	89	0.70	62
Intersector	GN 6	10.6	8	6.47	13.1	1	165	130	0.75	97
Intersector with autoleveller	GN 6 15R	13.1	11	7.20	20.0	1	165	198	0.80	158
Preparation of PET55/Wo45 blended tops										
Intersector	GN 5	20 PET 21 Wo	5 4	7.6	24.2	1	90	130	0.70	
Intersector	GN 5	24.2	6	6.3	23.0	1	130	179	0.70	125
Intersector	GN 5	23.0	6	7.3	18.9	1	150	170	0.70	119
Comber	PB 31	18.9	22	-	28.6	1	220 cycles/min		0.82	
Intersector	GN 5	28.6	7	6.60	30.3	1	110	199	0.75	149
Intersector with autoleveller	GN 5 24R	30.3	6	9.10	20.0	1	150	180	0.75	135

Table 9. *Plan for spinning PET55/Wo45 blended roving with content of ELANA WK-2LP polyester fibres with reduced susceptibility to pilling.*

Name of machine	Type of machine	Sliver count at feeding ktex	Doubling	Total draft	Sliver count at delivery ktex	Total of ends at delivery	Delivery speed m/min	Theoretical production, kg/h	Efficiency	Practical production kg/h
Preparation of PET55/Wo45 blended roving										
Chain gill with autoleveller	CSNS +ARM	20.0	9	7.4	24.3	1	190	277	0.60	166
Chain gill	CSN S UV12	24.3	3	7.4	9.9	2	210	249	0.65	162
Plurihead drawframe	SH 24	9.9	4	7.5	5.3	4	190	242	0.65	157
Horizontal rub apron finisher	FM 7A	5.3	1	11.8	0.450	20 × 2	180	194	0.40	77.5 × 2 m

Table 10. *Plan for spinning PET55/Wo45 - 21 tex 550Z x 2 560S and 21 tex 550Z x 2 560S blended single and doubled yarn with content of ELANA WK-2LP polyester fibres with reduced susceptibility to pilling.*

Name of machine	Type of machine	Roving count at feeding tex	Total draft	Yarn count tex	Spindle speed rpm	Twist T/m	Delivery speed m/min	Theoretical capacity kg/h/point	Efficiency	Practical capacity kg/h/point
Ring spinning frame	PH-11	450	21.4	21	8900	554	16.06	0.0202	0.87	0.0176
Automatic winder	RAS-15L	21	-	21	-	-	850	1.0710	0.84	0.8996
Two-for-one twister	TDS-9	21 × 2	-	21 × 2	8710 × 2	525	33.18	0.0836	0.87	0.0727
Two-for-one twister	TDS-9	21 × 2	-	21 × 2	8710 × 2	561	31.05	0.0782	0.87	0.0680

Technology of manufacturing blended roving, single and doubled yarn

The plan of roving spinning is listed in Table 9, and the plan of single yarn manufacturing in Table 10. The process of manufacturing PET55/Wo45 blended roving with a content of WK-2LP polyester fibres with decreased susceptibility to pilling comprises operations of sliver thinning and roving formation. No fibre breaks or fibre wrapping around the rollers (in the case of drawing frames as well as rowing frames) were observed during roving manufacturing. The process of 21 tex 550Z single yarn manufacturing run correctly with a small number of breakages; only 46 breakages/1000 spindle hours were noted. No technological disturbances were observed during manufacturing 21 tex 550Z x 2 560S and 21 tex 550Z x 2 520S doubled yarn with the use of an RAS-15L automatic winder and a TDS-9 two-for-one twister from SAVIO.

Table 11. *Physical properties of 21 tex 550Z single yarn; test results.*

Analysed parameter		Unit	Value of parameter	USTER Statistics 50% line	1st quality according to BN-89/7541-02
Coefficient of variation of yarn count		%	1.37	2.00	3.20
Coefficient of variation of yarn twist		%	12.32	-	-
Work to break A_r		cN×m	1192.0	1363.1	-
Coefficient of variation $V(A_r)$		%	16.23	21.90	-
Breaking force F_r		cN	288.6	-	-
Coefficient of variation $V(F_r)$		%	11.22	-	-
Breaking tenacity W_t		cN/tex	13.47	13.10	9.00
Coefficient of variation $V(W_t)$		%	11.22	12.80	-
Elongation at break E_r		%	13.61	15.60	-
Coefficient of variation $V(E_r)$		%	8.85	13.00	-
Coefficient of mass variation CV_{8mm}		%	19.48	18.70	21.50
Index of irregularity - Huberty		-	1.330	-	-
Neps $z_{N,1000}$		pieces/ 1000 m	30.0	33.7	-
Thick places $z_{T,1000}$		pieces/ 1000 m	75.0	85.1	-
Thin places $z_{L,1000}$		pieces/ 1000 m	200.0	222.7	-
Purity of yarn determined by organoleptic method:	neps	pieces/ 1000 m	2.63	-	4.00
	thick places	pieces/ 1000 m	0.66	-	0.60
	vegetable impurities	pieces/ 1000 m	0.22	-	0.00

Table 12. *Abrasion resistance and hairiness of 21 tex 550Z single yarn; test results.*

Parameter		Unit	Value
Abrasion resistance		number of cycles	610
Yarn hairiness:	measurement zone 3 mm	pieces /50 m	1232
	measurement zone 5 mm	pieces /50 m	230

Table 13. *Calculated values t_{comp} and critical values t_{crit} of the t-Student test between the mean value from test and the assumed value (related to 50% line according to Uster Statistics).*

Parameter analysed	t_{comp}	t_{crit}	Parameter differs significantly
Coefficient of variation of yarn count	9.28	2.093	yes
Work to break	6.19	2.010	yes
Tenacity	1.73	2.010	no
Coefficient of variation of tenacity	7.33	2.010	yes
Elongation at break	11.59	2.010	yes
Coefficient of variation of linear density CV_{8mm}	1.67	2.262	no
Number of neps	9.12	2.262	yes
Number of thick places	18.36	2.262	yes
Number of thin places	24.33	2.262	yes

Physical Properties of Fibres Manufactured by the Elaborated Technology

Test plan

It was assumed that the basic physical properties to qualify the yarn obtained by the developed technology should comply with the parameters described in the Uster Statistics from the Zellweger company [7,8] and the parameters required by BN-89/7542-01 standard, which is generally applied in Poland (though not obligatory). The tests which should identify the influence of decreasing the twist number of yarn down to 8% on the selected physical yarn properties were preceded by estimation of physical properties of the single yarn. Independent of any assessment of the basic physical properties, additional tests were carried out with the aim of estimating yarn hairiness and abrasion resistance. The tests of physical properties of the doubled yarns were planned according to the scheme presented in Figure 4.

Test methods

The tests of the physical parameters of the single and doubled yarns were carried out according to obligatory standards. In addition, the following non-standard physical properties were estimated:

- hairiness of yarn, and
- abrasion resistance assessed with the use of the 5-27 apparatus from the Metrimpex company.

Hairiness

Hairiness of yarn (crewel, worsted) is defined as the number of fibre ends and fibre fragments which stick out from the yarn core along a selected yarn length, and related to 1 m of yarn. This parameter was assessed by the photo-electric method with the use of an SDL 84 Shirley Yarn Hairiness Meter according to Standard PN-91/P-04685. Measuring zones of 3 mm, 5 mm, and 9 mm were selected. The yarn was conducted at a constant velocity through the measuring head of the apparatus which recorded the fibre ends and fragments sticking out from the yarn core. All fibre ends and fragments of a length longer than the selected zone were counted over the measurement time. The apparatus was equipped with a pneumatic take-up device for the tested yarn. After the time of measurement, which lasted 50 s, the take-up device was shut off and counting was interrupted. Next, the number of ends and fragmentssticking out from the core-and recorded by the apparatus was noted.

Table 14. Physical properties of doubled yarns; test results.

Parameter analysed		Unit	21 tex × 2 550Z/520S	21 tex × 2 550Z/560S
Coefficient of variation of yarn count		%	2.587	2.306
Coefficient of variation of yarn twist		%	4.733	4.341
Work to break A_r		cN×m	2894.9	2904.8
Coefficient of variation of work to break $V(A_r)$		%	13.67	15.07
Breaking force F_r		cN	645.5	637.0
Coefficient of variation of breaking force $V(F_r)$		%	8.65	9.78
Tenacity W_t		cN/tex	16.00	15.33
Coefficient of variation of tenacity $V(W_t)$		%	8.65	9.78
Elongation at break E_r		%	15.12	15.27
Coefficient of variation $V(E_r)$		%	7.64	8.39
Coefficient of variation of linear density CV_{8mm}		%	12.58	13.06
Index of irregularity - Huberty		-	1.179	1.242
Number of neps $z_{N,500}$		pieces/500 m	2.0	1.6
Number of thick places $z_{T,500}$		pieces/500 m	1.2	1.4
Number of thin places $z_{L,500}$		pieces/500 m	0.7	1.4
Organoleptic method:	number of thick places	pieces/500 m	0.00	0.63
	number of neps	pieces/500 m	0.00	0.00
Number of seldom occurring yarn faults (USTER CLASSIMAT II):	number of thick places	pieces/500 m	0.02	1.01
	number of neps	pieces/500 m	0.26	0.23
	abrasion resistance	number of cycles	1810	2925
Yarn hairiness:	measurement zone 3 mm	pieces/50 m	661	666
	measurement zone 5 mm	pieces/50 m	137	130
	measurement zone 9 mm	pieces/50 m	5.8	8.4

Table 15. Calculated values F_{comp} and critical values F_{crit} of the F-Snedocor test for two variances, and calculated values t_{comp} and critical values t_{crit} of the t-Student test for two mean values determined for physical parameters of doubled yarns.

Parameter analysed		Test F - Snedecora		Test t-Studenta	
		F_{comp}	F_{crit}	t_{comp}	t_{crit}
Coefficient of variation of yarn count		1.08	2.22	3.38	2.03
Coefficient of variation of yarn twist		1.06	1.62	5.54	1.98
Work to break		1.23	1.62	0.12	1.98
Breaking force		1.23	1.62	0.72	1.98
Tenacity		1.16	1.62	2.31	1.98
Elongation at break		1.23	1.62	0.64	1.98
Coefficient of linear density variation CV_{8mm}		2.22	3.44	5.81	2.12
Number of neps (USTER)		1.25	3.44	0.27	2.12
Number of thick places (USTER)		1.58	3.44	0.52	2.12
Number of thin places (USTER)		1.44	3.44	1.28	2.12
Abrasion resistance		2.32	2.31	Not computed because $F_{comp}>F_{crit}$	
Yarn hairiness:	measurement zone 3 mm	1.22	2.17	0.20	2.02
		1.22	2.17	0.91	2.02
		1.98	2.17	3.11	2.02

Ten measurements were carried out for each selected measuring zone. The average yarn hairiness was calculated from the equation:

$$\overline{H} = \frac{\sum_{i=1}^{n} H_i}{50 \cdot n}, \ \mathrm{m}^{-1} \qquad (1)$$

where:

n - number of measurements, and

H_i - number of fibre ends and fragments which stack up from the yarn core along 50 m of yarn.

Abrasion resistance

The abrasion resistance was tested with the use of the 5-27 apparatus from the Hungarian METRIMPEX company [10]; 20 measurements were carried out for each type of yarn.

Methods of data analysis

The t-Student test [11,12] was applied to ascertain if the physical properties of the single yarns essentially differ from the values described by Uster Statistics from the Zellweger company at the 50% line [7,8]. The methodology recommended by ISO Standards PN-ISO 2602, and PN-ISO 3534-2, and by Greń [11] and Stanisz [12], were applied for discussion of the consequences of the decrease in twist number in doubled yarn.

Estimation of physical yarn properties

The basic and additional physical properties of single yarn are listed in Tables 11 and 12. The t-Student test [11,12] was applied to ascertain whether the values of the particular parameters of the single yarns differ essentially from the values described by the Uster Zellweger company at the 50% line [7,8]. The values calculated and their estimation are shown in Table 13.

By analysing the data listed in Tables 11, 12, and 13, we can state that the PET55/Wo45 21tex 550Z blended single yarn with a content of ELANA WK-2LP polyester yarn with decreased susceptibility to pilling is characterised by:

- a very low coefficient of variation of yarn count (of the true and legal values) which significantly differs from the values given by the Uster Statistics,
- small work of break, which significantly differs from the value given by the Uster Statistics,
- a low coefficient of variation of tenacity, also significantly different from the value given by the Uster Statistics,
- small relative elongation at break,
- low number of yarn faults, such as neps, thin and thick places which differ essentially from the values given by the Uster Statistics,
- tenacity and the coefficient of variation of the linear density CV_{8mm} do not differ essentially from the values given by the Uster Statistics, and
- all parameters with exception of the number of thick places and vegetable impurities determined by the organoleptic method comply with the requirements of the branch standard BN-89/7541-01.

The estimated yarn can be qualified to the quality class designated as '**very good**' when considering the variations of yarn count and tenacity, as well as the number of neps, thick, and thin places. Considering tenacity and the variation coefficient of linear density, the estimated yarn can be qualified as '**good**', and as '**satisfactory**' regarding the work of break and the elongation to break.

The test results of physical parameters of 21 tex 550Z x 2 560S and 21 tex 550Z x 2 520S doubled yarns with a content of ELANA WK-2LP polyester fibres with decreased susceptibility to pilling are presented in Table 14.

It was not possible to compare the values of physical parameters obtained for the doubled yarns with the Uster Zellweger Statistics [7,8] because the latter does not collect such data for doubled yarn. The physical parameters of doubled yarns assessed in tests comply with the requirements of branch standard BN-89/7541-02.

The data from Table 14 demonstrates that all the physical parameters of the PET55/Wo45 21 tex 550Z x 2 560S and 21 tex 550Z x 2 520S blended doubled yarns meet the requirements of the branch standard mentioned above.

The t-Student test for two means preceded by the F-Snedocore variance analysis test were applied in order to ascertain whether the decrease of the doubled yarn twist numbers from 560 rev./m down to 520 rev./m fundamentally influences the physical properties of yarn (Table 15).

From the data presented, it can be seen that the decrease in twist number of the doubled yarn from 560 rev./m to 520 rev./m does not essentially influence the following physical parameters:
- coefficient of variation of yarn count,
- coefficient of variation of twist,
- work of breaking,
- breaking strength,
- relative elongation at break,
- number of neps, thick, and thin places, and
- yarn hairiness determined for the measurement zones 3 mm and 5 mm.

As a result of the influence of the decrease in twist number, a decrease followed in:
- coefficient of variation of the linear density CV_{8mm},
- abrasion resistance, and
- yarn hairiness determined for the measuring zone 9 mm.

Summary

The investigations carried out allow us to draw the following conclusions:
- The WK-2LP polyester cable manufactured by the ELANA Company (Zakłady Włókien Chemicznych ELANA), Toruń, Poland is not unreservedly suitable for division into staple fibres by means of the uncontrolled breaking method.
- The electro-capacity method of length fibre measurement proposed for our research was not suitable. The estimation of fibre lengths in the sliver was accomplished by means of the organoleptic method, which consisted in the segregation of fibres into length classes.
- The polyester sliver obtained from the ELANA WK-2PL polyester cable by means of the method of uncontrolled breaking with use of the 860-COMPACT breaking machine cannot be directly applied to the manufacturing yarns under consideration. The decisive factors were the unsatisfactory length fibre distribution in the sliver after the RSN/D integrated drawing frame and an excessive number of neps.
- For the polyester sliver from the ELANA WK-2LP cable, the application of a classical rebreaker or a rebreaker of reinforced construction would be more advisable than additional breaking with the use of a RSN/D integrated drawing frame. Such a rebreaker, for example the Wl-2 rebreaker from the FALUBAZ company, would more effectively improve the distribution of fibre length.
- It is necessary to insert the operation of fibre combing (with the use of a wool combing machine working periodical) into the technological process in order to achieve a decrease in the nep number of the sliver obtained from the polyester cable with decreased susceptibility to pilling. Good quality results can be achieved when using the combing process for a blend with wool, for example the PET55/Wo45 blend.
- The polyester sliver from the ELANA WK-2LP polyester cable can be used for manufacturing blended tops with wool destined for yarns and flat textile products, such as woven fabrics and knittings, which should be characterised by high resistance to pilling formation.
- During manufacturing of the PET55/Wo45 blended polyester/wool worsted weaving yarns with linear density 21 tex x 2, it could be observed that:
  - the majority of quality parameters of the single yarn fulfil the requirements of the relevant standards, and also comply with the values described by the Uster Statistics at the 50% line.
  - a decrease in the doubled yarn twist number from 560 rev./m down to 520 rev./m (near 8%) does not essentially decrease the yarn quality, because the physical parameters such as abrasion resistance still are high.

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