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Analysis of the Strength Parameters of Worsted and Component Spun Yarns after the Rewinding Process

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Abstract
The notion of yarn is understood as a continuous textile product of theoretically endless length and circle-like cross-section, made of staple or continuous fibres. A yarn leaves the spinning mill in a raw state and is used to produce some fabrics, but mostly it is subjected to the process of finishing. The yarn undergoes preparatory processes, such as winding, doubling, twisting, paraffin treatment, singeing and dyeing, depending of the final fabric type. Yarns are rewound on winding frames, and computers control operation of the rewinding frames and systematically monitor the yarn parameters. An electronic cleaner removes yarn defects, whose size has been saved in the computer memory. The purification of yarn improves its quality, resulting in a decrease in the number of breaks in further technological processes. A lower number of yarn breaks contribute to an increase in machine efficiency (weaving and knitting machines). The experimental section of the study is divided into two parts. The first includes tests of yarn strength parameters before and after the rewinding process. It was established in the process of cleaning that the yarn during rewinding affects the strength of wool and blended yarns. In the second part, the strength parameters of yarn doubling points after the rewinding process for various variants of the splicer setting were tested. The blowing time in the doubling chamber was changed and the importance of using the thermosplicer for the yarn joint strength was established.

Key words: *worsted yarn, component yarn, winding process, yarn tenacity, joining knotless method, splicer.*

Aim and scope of the study

The aim of the study was to test the strength parameters of worsted and component yarns before and after the rewinding process and the determination of the strength of yarn splicing [5, 7, 9, 11]. The coefficient of using the tenacity of the yarn joining points in relation to the tenacity of the rewound yarn has to be determined. The tests were carried out for two classic yarns with various raw material compositions and various linear densities, one rewinding speed, four splicer settings and Thermosplicer turned on and off.

Objects, investigation methods and variant characteristics

Materials

- Classic yarn, 100% wool with a linear density of 18 tex, fibre diameter – 21.3 micrometers,
- Classic wool-polyester blended yarn (W/PES) with percentage content = 45/55, liner density of 12 tex x 1, wool fibre diameter – 21.7 micrometers, polyester fibre linear density – 2.4 dtex.

Characteristics of yarn variants

Classic worsted wool and blended yarns were rewound using the single-point test stand of an Autoconer 338 rewinding frame (Schlafhorst Saurer Group, Germany) [11, 12]. The tests were performed at the Department of Material and Commodity Sciences and Textile Metrology, Lodz University of Technology.

Constant parameters in the tests:
Rewinding speed – 250 m/min,

- Pressure in the chamber of the doubling frame during yarn end opening-up – 4 Bar.
- Pressure in the doubling chamber during yarn end splicing – 5 Bar.
- Air temperature during wool yarn doubling – 117 °C (turned on Thermosplicer).
- Air temperature during blended yarn doubling – 92 °C (turned on Thermosplicer).
- Parameters of yarn cleaning (standard settings recommended by the Manufacturer).

Variable parameters in the tests:

- Raw material composition of yarn (wool 100%, wool – polyester 45/55).
- Splicer – 4 settings.
- Thermosplicer (turned on, turned off).

  A Thermosplicer is a device supporting yarn doubling. As a result of hot air action, fibres can be formed more easily and one can obtain a doubling with a set structure [13, 14].

Variants of testing the rewinding process are presented in ***Table 1***.

Variants of splicer setting in the rewinding process are presented in ***Table 2***.

Determination of yarn strength parameters

An automatic Zwick 1120 tensile strength tester (Zwick Testing Machines, Germany) was used to determine the breaking force and elongation at break of yarns according to the standard PN-EN ISO

2062:2010. Yarn sections with a length of 500 mm were unidirectionally tensioned with a preliminary load of 0.5 cN/tex and jaw travel speed of 500 m/min. For each type of non-rewound yarn, 5 measurements were taken from 10 randomly selected cops and 30 measurements for each variant of rewound yarn.

The following parameters were determined [1]:

- Yarn tenacity from ***Equation (1)***:

$$Ww = \frac{F_{śr}}{Tt}, \quad \text{cN/tex} \quad (1)$$

$F_{śr}$ – average maximal force, cN,
Tt – linear density of yarn, tex.

- The coefficient of utilising the tenacity of the splicing joint in that of yarn after rewinding can be obtained from the ***Equation (2)***:

$$W = \frac{W_{W_s}}{W_{W_{pp}}} * 100\%, \quad \% \quad (2)$$

W_{W_s} – tenacity of the splicing joint, cN/tex,
$W_{W_{pp}}$ – tenacity of yarn after rewinding, cN/tex.

Table 1. *Variants of the rewinding process.* ***Denotation:*** *„+" – Thermosplicer turned on, „ –" – Thermosplicer turned off.*

Rewinding variant	Raw material composition	Linear density of yarn Tt, tex	Rewinding speed	Variant of splicer setting	Thermosplicer
W1	Wool 100%	18.3	250	1	+
W2	W-PES 45/55	12.1	250	1	+
W3	Wool 100%	18.3	250	1	–
W4	W-PES 45/55	12.1	250	1	–
W5	Wool 100%	18.3	250	2	+
W6	W-PES 45/55	12.1	250	2	+
W7	Wool 100%	18.3	250	3	+
W8	W-PES 45/55	12.1	250	3	+
W9	Wool 100%	18.3	250	4	+
W10	W-PES 45/55	12.1	250	4	+

Table 2. *Variant of splicer setting.* ***Denotations:*** *Opening-up code – the doubling frame performs a knotless joint of two thread ends. This happens first by opening up the thread ends, and consequently doubling is prepared. The operation duration depends on the set turn on time. For code 4, this time is 400 ms. Thermosplicer code: 5 – code for blended W/PES yarns, air temperature – 92 °C, 8 – code for wool yarns, temperature – 117 °C. Code of doubling frame – thread end splicing occurs directly after opening up. The sum of the data entered for impulse 1 + break + impulse 2 must not exceed the value of a doubling time of 440 ms.*

Variant number	Splicer settings				
	Opening-up code	Doubling frame code	Doubling time, ms	Thermosplicer code	
				Wool	W-PES 45/55
1	4	5, 3, 5	260	8	5
2	4	5, 3, 7	300	8	5
3	4	5, 3, 9	340	8	5
4	4	3, 3, 5	220	8	5

Results of investigation of strength parameters of wool and blended yarns and discussion

Tables 3 and ***4*** present measurement results of the strength parameters of wool and blended yarns before and after rewinding.

Table 3. *Results of measuring the strength parameters of wool yarn before and after rewinding.* ***Denotations:*** *W_w – average tenacity, cN/tex; s_{Ww} – standard deviation of tenacity, cN/tex; Cv_{Ww} – variation coefficient of tenacity, %; ε – average relative elongation at break, %; $s^ε$ – standard deviation of relative elongation, %; $Cv^ε$ – variation coefficient of relative elongation, %.*

Parameter	Wool 100%	W1	W3	W5	W7	W9
W_w, cN/tex	7.93	8.17	7.68	7.95	8.13	7.52
Uster statistics	< 5 %	< 5 %	< 5 %	< 5 %	< 5 %	< 5 %
s_{Ww}, cN/tex	1.07	1.16	1.11	1.19	1.07	1.08
Cv_{Ww}, %	13.49	14.2	14.45	14.97	13.16	14.36
Uster statistics	< 25%	25%	25-50%	25-50%	< 25%	< 25 %
ε, %	7.92	9.67	8.13	9.32	8.94	8.40
Uster statistics	< 75%	50%	< 75%	> 50%	50-75%	50-75 %
$S^ε$, %	2.90	3.44	3.03	3.68	3.74	3.34
$Cv^ε$, %	36.60	35.61	38.50	39.48	41.82	39.74
Uster statistics	50%	50 %	50-75%	75%	75-95%	75 %

The results obtained were compared with Uster 2013 statistics. On their basis one can state that the tenacity of worsted yarn (100% wool) before and after rewinding is below 5% of world production of this type of yarn and indicates its very good quality.

The variation coefficient of the tenacity of worsted yarn (100% wool) before and after rewinding for variants W7 and W9 is below 25% of world production, indicating very good quality. For variants W1, W3 and W5, the variation coefficient of tenacity is below 50% of world production, indicating the good quality of these yarns.

The average relative elongation of worsted yarn (wool – 100%) at break before and after rewinding is below 75% of world production of this type of yarn, indicating its satisfactory quality.

The variation coefficient of the relative elongation of worsted yarn is mostly below 75% of world production, which indicates the satisfactory quality of this yarn. Only in the case of variant W7 is the yarn quality adequate.

The results obtained were compared with Uster 2013 statistics [1]. On their basis one can state that the tenacity of blended (W/PES 45/55%) yarn before and after rewinding for variants W2 and W10 is below 75% of world production of this type of yarn, indicating its satisfactory quality. On the other hand, for variants W4, W6 and W8, the tenacity is below 50% of world production, which indicates good quality.

The variation coefficient of the tenacity of blended yarn (W/PES – 45/55%) be-

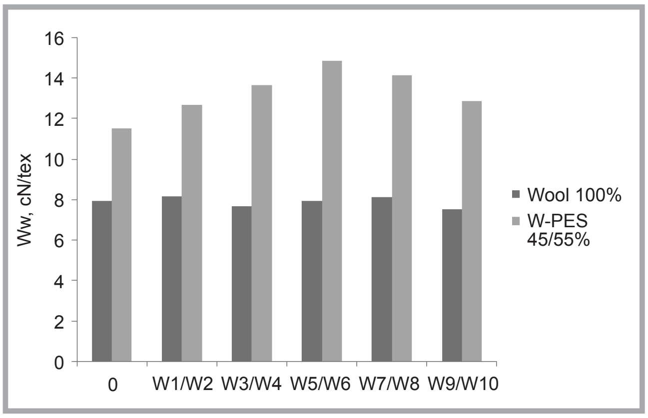

***Figure 1**. Dependence of the tenacity of yarns tested on the splicer setting.*

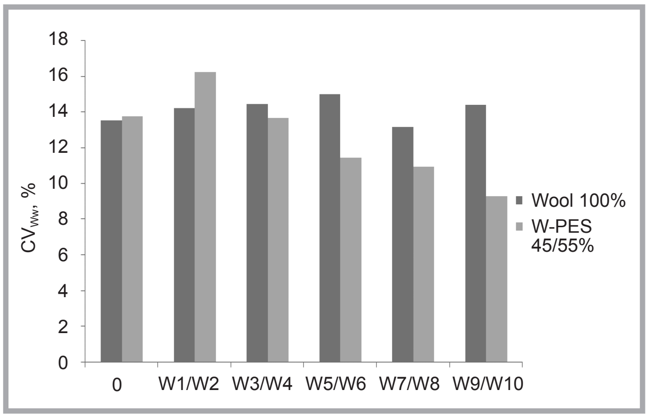

***Figure 2.** Dependence of the variation coefficient of yarn tenacity Cv_{Ww} on the splicer setting.*

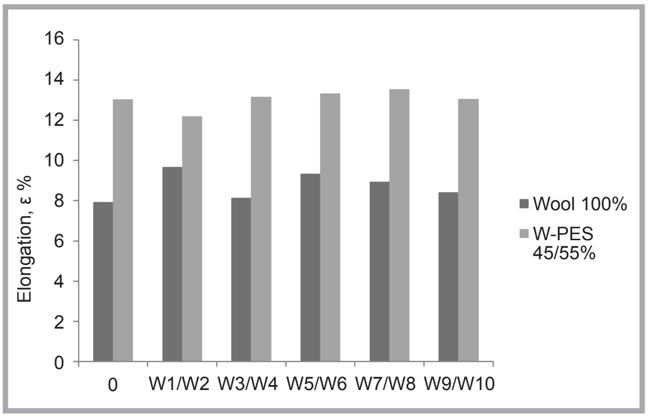

***Figure 3.** Dependence of the relative elongation at break ε of the yarns tested on the splicer setting.*

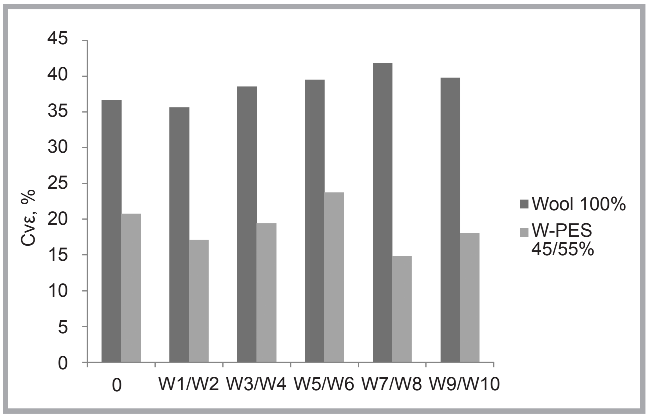

***Figure 4.** Dependence of the variation coefficient of the yarn relative elongation at break Cvε on the splicer setting.*

fore and after rewinding is below 25% of world production, which indicates very good quality.

The average relative elongation at break of blended yarn (W/PES – 45/55 %) before and after rewinding for most variants is above 50 % of world production of that type of yarn, its quality being satisfactory. Only the average relative elongation of variant W2 is below 95% of world production, indicating the adequate quality of this yarn.

The variation coefficient of the relative elongation of blended yarn in most cases is below 75% of world production, which indicates the satisfactory quality of this yarn. Only in the case of variant W8 is the quality of yarn very good, while in the case of variant W6 yarn quality is insufficient.

Figure 1 shows the dependence of tenacity W_w on the splicer setting for worsted and blended yarns.

Figure 2 presents the dependence of the variation coefficient of tenacity Cv_{W_w} on the splicer setting for worsted and blended yarns.

Figure 3 presents the dependence of the relative elongation at break *ε* on the splicer setting for worsted and blended yarns.

Figure 4 presents the dependence of the variation coefficient of relative elongation at break *Cvε* on the splicer setting for worsted and blended yarns.

Based on the test results obtained, it was found that the rewinding process, especially cleaning yarns during rewinding, causes an increase in yarn tenacity [11], while greater changes are observed in the

***Table 4.** Measurement results of strength parameters of blended yarn before and after rewinding. **Denotations:** W_w – average tenacity, cN/tex; s_{Ww} – standard deviation of tenacity, cN/tex; Cv_{Ww} – variation coefficient of tenacity, %; ε – average relative elongation at break, %; $s^ε$ – standard deviation of relative elongation, %; $Cv^ε$ – variation coefficient of relative elongation, %.*

Parameter	W-PES 45/55%	W2	W4	W6	W8	W10
W_w, cN/tex	11.51	12.65	13.64	14.83	14.13	12.87
Uster statistics	> 50%	50%	< 50%	< 50%	< 50%	50 %
s_{Ww}, cN/tex	1.58	2.51	1.86	1.69	1.54	1.19
Cv_{Ww}, %	13.73	16.2	13.63	11.4	10.9	9.25
User statistics	< 5%	> 5%	< 5%	< 5%	< 5%	< 5 %
ε, %	13.04	12.19	13.17	13.33	13.55	13.05
Uster statistics	> 50%	< 95%	> 50%	> 50%	> 50%	> 50 %
$S^ε$, %	2.70	2.08	2.56	3.16	2.00	2.36
$Cv^ε$, %	20.72	17.07	19.42	23.71	14.79	18.06
Uster statistics	< 95%	50%	> 50%	> 95%	> 5%	> 50 %

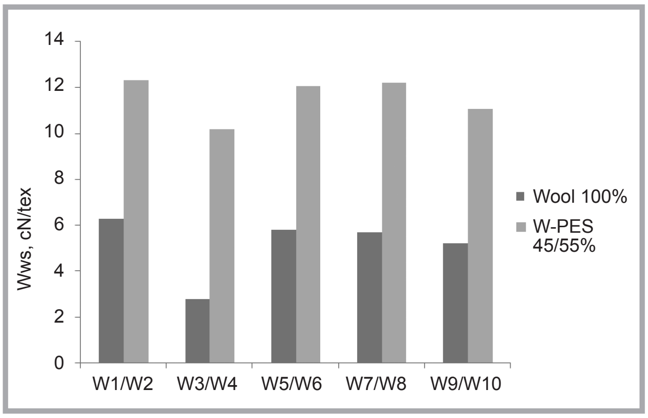

***Figure 5.** Dependence of the yarn joint tenacity on the splicer setting for worsted and blended yarns.*

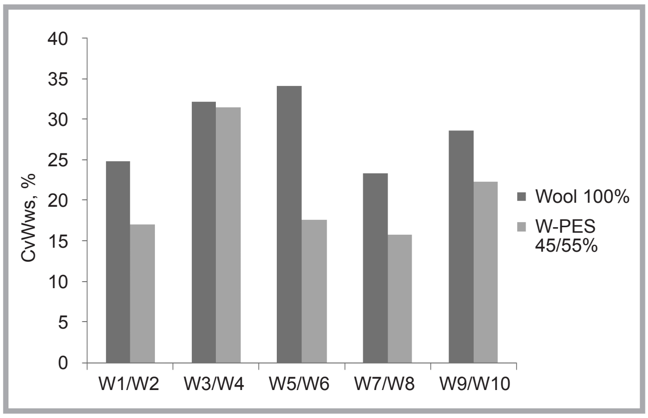

***Figure 6.** Dependence of the variation coefficient of the yarn joint tenacity Cv_{Wws} on the splicer setting.*

case of blended yarns. The highest values of worsted yarn tenacity are observed for variant W1 (wool – 100%, 18 tex, splicer setting – 5,3,5, thermosplicer turned off), while the lowest value is shown by variant W9 (wool – 100% ,18 tex, splicer setting – 3,3,5, thermosplicer turned off). The highest value of blended yarn tenacity is observed in the case of variant W6 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,7, thermosplicer turned off), while the lowest value is for variant W2 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,5, Thermosplicer turned off).

The variation coefficient of yarn tenacity after the rewinding process is usually higher than that recorded before rewinding. A decrease in the coefficient is observed in the case of blended yarn of the following variants: W6 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,7, thermosplicer turned on), W8 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,9, thermosplicer turned on) and W10 (W/PES – 45/55%, 12 tex, splicer setting – 3,3,5, thermosplicer turned on). The highest value of the coefficient occurs in the case of variant W2 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,5, thermosplicer turned on), while the lowest value is shown by variant W10 (W/PES – 45/55%, 12 tex, splicer setting – 3,3,5, thermosplicer turned on). For worsted yarn the highest value of the variation coefficient of tenacity is observed for variant W5 (wool – 100%, 18 tex, splicer setting – 5,3,7, thermosplicer turned on), while the lowest value is for variant W7 (wool – 100%, 18 tex, splicer setting – 5,3,9, thermosplicer turned on).

The yarn after rewinding shows a higher elongation at break than the non-rewound yarn. The highest increase in relative elongation is shown by variant W1 (wool – 100%, 18 tex, splicer setting – 5,3,5, thermosplicer turned on), while the lowest increase is presented by variant W3 (wool – 100%, 18 tex, splicer setting – 5,3,5,). The highest increase in the relative elongation of blended yarn is observed in the case of variant W8 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,9, thermosplicer turned on), while the lowest is presented by variant W2 (W/PES – 45/55% , 12 tex, splicer setting – 5,3,5, thermosplicer turned on).

The variation coefficient of relative elongation at break of blended yarn after rewinding is lower than that of non-wound yarn. Only for variant W6 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,7, thermosplicer turned on) is an increase in the value of this coefficient observed. The lowest value of the coefficient is shown by variant W8 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,9, thermosplicer turned on). The rewound worsted yarn shows an increase in the variation coefficient of the relative elongation at break. The highest value of this coefficient is shown by variant W7 (wool – 100%, 18 tex, splicer setting – 5,3,9, thermosplicer turned on), and the lowest by variant W1 (wool – 100%, 18 tex, splicer setting – 5,3,5, thermosplicer turned on).

Analysis and discussion of the strength parameters of yarn end joints

Tables 5 and ***6*** present measurement results of the joint strength parameters of worsted and blended yarns.

***Table 5.** Measurement results of the strength parameters of wool yarn joints.*

Parametr	W1	W3	W5	W7	W9
W_{ws}, cN/tex	6.28	2.76	5.79	5.69	5.21
s_{Wws}, cN/tex	1.56	0.89	1.98	1.33	1.49
Cv_{Ww}, %	24.84	32.25	34.2	23.37	28.6
ε_s, %	6.05	2.55	5.98	5.22	4.52
S^{ε}_s, %	3.61	1.11	4.04	2.55	2.05
Cv^{ε}_s, %	59.71	43.56	67.68	48.93	45.33

***Table 6**. Measurement results of the strength parameters of blended yarn joints. **Denotations:** W_{ws} – average tenacity of yarn joints, cN/tex; s_{Wws} – standard deviation of yarn joint tenacity, cN/tex; Cv_{Wws} – variation coefficient of yarn joint tenacity, %; ε_s – average relative elongation at break of yarn joint, %; S^{ε}_s – standard deviations of yarn joint relative elongation, %; Cv^{ε}_s – variation coefficient of joint relative elongation, %.*

Parameter	W2	W4	W6	W8	W10
W_{ws}, cN/tex	12.32	10.2	12.09	12.23	11.1
s_{Wws}, cN/tex	2.11	3.22	2.13	1.94	2.48
Cv_{Wws}, %	17.13	31.57	17.62	15.86	22.34
ε_s, %	12.67	9.08	11.51	11.93	9.39
S^{ε}_s, %	3.22	4.73	3.03	3.05	4. 50
Cv^{ε}_s, %	25.37	52.14	26.32	25.33	47.90

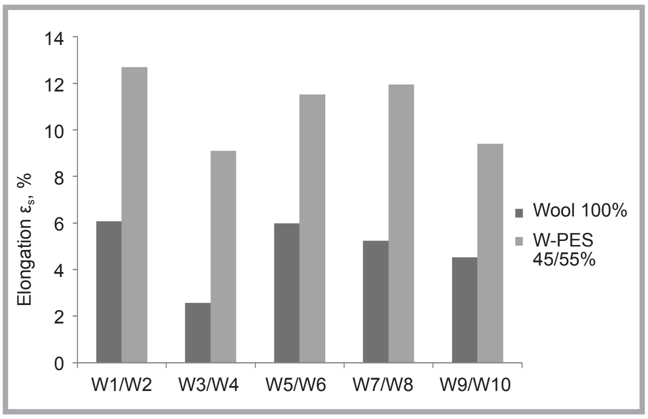

Figure 7. Dependence of the yarn joint relative elongation at break ε_s *on the splicer setting.*

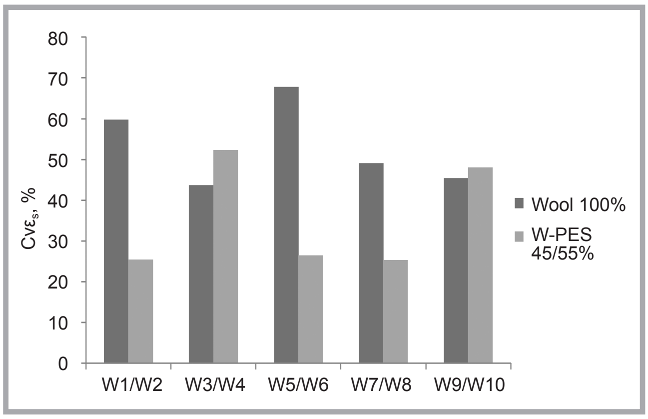

Figure 8. Dependence of the variation coefficient of the yarn joint relative elongation at break $Cv\varepsilon_s$ *on the splicer setting.*

Figure 5 presents the dependence of the yarn joint tenacity W_{ws} on the splicer setting for worsted and blended yarns

Figure 6 presents the dependence of the variation coefficient of the yarn joint tenacity $Cv_{W_{ws}}$ on the splicer setting for worsted and blended yarns.

Figure 7 presents the dependence of the yarn joint relative elongation at break ε_s on the splicer setting for worsted and blended yarns.

Figure 8 presents the dependence of the variation coefficient of the yarn joint relative elongation at break on the splicer setting for worsted and blended yarns.

On the basis of the test results obtained, one can find that yarn joints made by the use of a thermosplicer have a higher tenacity than those made by means of a standard splicer [13,14]. The highest tenacity of the wool yarn joint is noted for variant W1 (wool – 100%, 18 tex, splicer setting – 5,3,5, thermosplicer turned on), while the lowest is for variant W9 (wool – 100%, 18 tex, splicer setting – 3,3,5, thermosplicer turned on). The highest tenacity of the blended yarn joint is noted for variant W2 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,5, thermosplicer turned on), while the lowest is for variant W4 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,5,).

The variability coefficient of the tenacity of a yarn joint made by means of a thermosplicer is usually lower than that made by a standard splicer. Only in the case of worsted yarn for variant W5 (wool – 100%, 18 tex, splicer setting – 5,3,7, thermosplicer turned on) is an increase in this coefficient noted.

Yarn joints made by means of a thermosplicer have a higher relative elongation at break than those made with the use of a standard splicer.

The elongation variation coefficient of a wool yarn joint made with the use of a thermosplicer is higher than that made by a standard splicer. In the case of blended yarn, the relative elongation coefficient of a yarn joint made by means of a thermosplicer is decreased.

Table 7. Measurement results of strength parameters for wool yarn joints.

Parameter	W1	W3	W5	W7	W9
W_{Ws}, cN/tex	6.28	2.76	5.79	5.69	5.21
W_{Wpp}, cN/tex	8.17	7.68	7.95	8.13	7.52
W, %	76.87	35.94	72.83	69.99	69.28

Table 8. Measurement results of the strength parameters of blended yarn joints.

Parameter	W2	W4	W6	W8	W10
W_{Ws}, cN/tex	12.32	10.20	12.09	12.23	11.10
W_{Wpp}, cN/tex	12.65	13.64	14.3	14.13	12.87
W, %	97.39	74.78	81.52	86.55	86.25

For the yarn variants analysed, the coefficient of utilizing the knotless joint strength in the tenacity of yarn after rewinding was calculated. The results obtained are listed in ***Tables 7*** and ***8***.

The coefficient of utilising the splicer joint tenacity in the tenacity of yarn after rewinding in the case of joints made by a standard splicer has lower values than that of joints made by means of a thermosplicer. In the case of worsted yarn, once the thermosplicer is turned on, this coefficient increases twice. The maximal value of the worsted yarn coefficient is observed for variant W1 (wool – 100%, 18 tex, splicer setting – 5,3,5, thermosplicer turned on), and the minimal value for variant W9 (wool – 100%, 18 tex, splicer setting – 3,3,5, thermosplicer turned on). In the case of blended yarn, the maximal coefficient is shown by variant W2 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,5, thermosplicer turned on), and the minimal coefficient by variant W6 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,7, thermosplicer turned on).

Coefficient W reaches higher values for blended yarns and in the case of variant W2 (W/PES – 45/55%, 12 tex, splicer setting – 5,3,5, thermosplicer turned on) the joint tenacity almost reaches the tenacity of the yarn.

Conslusions

Based on the tests performed and their analysis, it was found that the rewinding process improves the strength parameters of yarn. In the case of worsted yarn, changes in this parameter are lower, indicating that wool yarn, according to rewinding reports, is characterised by a low number of defects and does not require frequent interference of the cleaning device nor considerable improvement in its quality. In the case of blended yarn, an increased number of neps and thin places required a higher number of cleaning cuts to improve its quality [6, 12].

The use of a thermosplicer does not translate into an increase in yarn strength after rewinding. The yarn strength depends of the number of defects, joint frequency and settings of the rewinding process [16].

Yarn joints made by the use of a thermosplicer have a higher tenacity, lower variability coefficient of the tenacity and higher relative elongation at break than those made with the use of a standard splicer.

The highest tenacity of the wool yarn joint is noted for variant W1 and of the blended yarn for variant W2. Variants W1 and W2 are yarns rewound at the standard settings recommended by the manufacturer of the winding frame (joining time – 260 ms). This indicates that these settings are optimal for worsted and blended yarns. For cotton yarns, the setting of a longer joining time (300 ms) is more advantageous, as confirmed during previous tests [11]. It was the manufacturer's recommendation to set 260 ms as the joining time, which means that for yarns made of various types of fibres with different structures, the settings in the rewinding frame chamber should be established individually on the basis of one's own production experience.

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