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Influence of Knitting Process Conditions and Washing on Tensile Characteristics of Knitted Ribbon Yarns

Abstract
An investigation was carried out on fabrics knitted from a new kind of fancy yarns, namely ribbon-type knitted yarns. The influence of the knitting process and the tightness factor of the knits on the tensile behaviour of knitted ribbon yarns was estimated. It is maintained that the tensile properties of ribbon yarns depend on the tightness of the knits. A high value of tightness factor of knits means small changes in the tensile properties of the ribbon yarns tested, and vice versa. We compared the stress-strain properties of initial yarns and the yarns obtained after deknitting knitted and washed fabrics. It has been determined that the processes of knitting and washing ribbon yarns influences the tensile properties of the ribbon yarns tested.

Key words: *knitted fabrics, knitted ribbon yarns, structure, tensile properties.*

Introduction

To make fabrics more attractive to the purchaser, their appearance is enhanced by various materials, structures, colour, patterns, finishes and textures. For fashionable knitted underwear, fancy yarns are used to produce a natural and attractive product. New looks, structures and raw materials of fancy yarns are constantly in demand. There are many different types of fancy yarns. The methods of manufacturing and designing of a wide range of fancy yarns may be grouped into two large classes: direct and indirect [1]. Most fancy yarns are produced by the direct system, using spinning and twisting machinery that is modified or specially developed for this purpose. With indirect methods, the yarns are produced by modifying the conventional processing techniques (spinning, carding, drawing, etc.). Some fancy yarns produced by in direct methods are obtained by weaving or knitting on specialised equipment. Fancy yarns knitted on weft or warp knitting machines have a typical yarn structure. One type is the yarn knitted by forming pillar stitch and tricot inlay, and is known as ladder-knit [2]. Another type of knitted fancy yarn has a ribbon structure. This fancy yarn is manufactured on a small-diameter circular knitting machine. Either yarn type may be manufactured from filament or staple yarns.

In the literature, papers discussing fancy yarns have predominantly described the techniques used to achieve various effects, the problems of designing fancy yarns, or the assortment of such yarns [3-5]. However, there are few studies of the fundamental parameters that characterise various fancy yarn types and the fabrics knitted from them. In spite of the wide use of fancy yarns, no attempt has yet been made to investigate the structure and tensile behaviour of fancy ribbon yarns during knitting. The problems of producing knitted fabrics from ribbon yarns has been almost entirely overlooked.

The aim of this study is to define the main structure parameters of knitted fabrics manufactured on a flat V-bed knitting machine (gauge 3 E) from knitted ribbon yarns, and to estimate the tensile behaviour of ribbon yarns as a function of tightness factor of knits, knitting and washing processes.

The material investigated

The investigations were carried out on ribbon-type yarns. We analysed plain knitted fabrics manufactured on a flat V-bed Shima Seiki 122 CS knitting machine at a gauge of 3 E. These fabrics were knitted from yarns with three different linear densities (330 tex, 450 tex and 550 tex) PAN and 450 tex PAN/PA ribbon yarns (Table 1).

The main principle used in these experiments was the comparison of the tensile properties of initial and deknitted yarns, i.e. the yarns obtained after deknitting the fabrics.

A diagram of the experimental material is presented in Figure 1. The samples were knitted at the same nominal course density (3.0 cm^{-1}); the knitting speed was 0.84 m/s; the number of working needles was 65. After knitting, the samples were washed in a domestic washing-machine and dried by being spread them on a horizontal surface. The washing procedure for the knitted samples was as follows:
- program for wool fabrics;
- gentle machine cycle;
- rotation frequency of hydro-extraction 600 min^{-1} (intermediate 100 min^{-1});
- water temperature - 30°C;
- washing time – 29 min;
- rising time – 18 min;
- hydro-extraction time – 3 min;

Total time was 50 min.
The consumption of detergent was 45 ml.

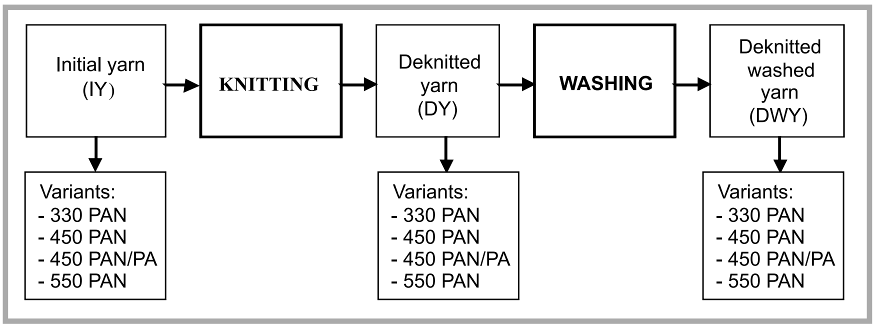

Figure 1. *Diagram of the experimental material.*

Table 1. *Ribbon yarns (IY) for knitted samples.*

Yarn code	Composition	Nominal yarn count Nm, m/g	Nominal linear density T, tex	Factual linear density T_f, tex
330 PAN	100 % PAN	3.0	333.0	324.0
450 PAN	100 % PAN	2.2	454.5	431.0
450 PAN/PA	70 % PAN/30 % PA	2.2	454.5	479.0
550 PAN	100 % PAN	1.8	555.0	540.0

Table 2. *Structure parameters of knitted fabrics.*

Yarn code*		Actual linear density, tex	Actual course density, cm^{-1}	Actual wale density, cm^{-1}	Stitch length, cm	Tightness factor	Area density, g/m^2
330 PAN	IY	324 ± 4	-	-	-	-	-
	DY	327 ± 4	2.55 ± 0.05	1.85 ± 0.05	2.10 ± 0.07	8.6	330
	DWY	328 ± 8	2.75 ± 0.05	1.85 ± 0.05	2.11 ± 0.08	8.6	350
450 PAN	IY	431 ± 9	-	-	-	-	-
	DY	429 ± 10	2.90 ± 0.05	1.95 ± 0.05	2.11 ± 0.06	9.8	510
	DWY	446 ± 8	2.95 ± 0.05	1.95 ± 0.05	2.07 ± 0.07	10.2	535
450 PAN/ PA	IY	479 ± 9	-	-	-	-	-
	DY	479 ± 8	3.05 ± 0.05	1.95 ± 0.05	2.06 ± 0.05	10.6	585
	DWY	491 ± 8	3.15 ± 0.05	2.00 ± 0.05	2.01 ± 0.05	11.0	620
550 PAN	IY	540 ± 10	-	-	-	-	-
	DY	561 ± 8	2.85 ± 0.05	1,95 ± 0.05	2.08 ± 0.05	11.4	655
	DWY	561 ± 7	3.00 ± 0.05	2.00 ± 0.05	2.06 ± 0.05	11.5	695

* *IY – initial yarn, DY – de-knitted yarn, DWY – de-knitted washed yarn.*

Experimental methods

All experiments were carried out in standard atmosphere for testing, according to ISO standard 139.

The actual linear density of the initial and deknitted ribbon yarns was measured by inserting the specimen in the clamps of the testing machine with a pre-tension of 0.02 cN/tex. This value was established by the experimental method. It removes the crimp of the deknitted yarn but does not stretch the ribbon yarn. The gauge length was 500 mm. Then specimen was cut and weighed.

Structure parameters of knits. The structure parameters of the plain knitted samples were analysed according to British Standard BS 5441 [6]. The course and wale density of the samples were counted in the direction of the length and across the knits at 10 cm distance, and evaluated per cm. The stitch length of the samples were measured by the method of ravelling the loops. The pre-tension was the same as during the measurement of the yarns' actual linear density – 0.02 cN/tex.

The tightness of the knits was characterised by the tightness factor [7]:

$$TF = \sqrt{T} / l, \qquad (1)$$

where T – the factual linear density of the yarn in tex, l – the stitch length in cm.

The area density of the samples was obtained from an average of three measurements of 20×20 samples, and is reported in g/m^2.

Knitted fabrics are prone to shrink during finishing processes and customer usage. Changes in the structural parameters that occur in the fabrics after washing were determined.

Tensile properties of yarns. In this paper, the tensile properties of initial yarns and yarns obtained after de-knitting knitted and washed samples were compared. The tensile stress-strain characteristics of the ribbon yarns were studied. The tensile properties of the yarns were determined with a Zwick/Z005 universal testing machine. The stress-strain characteristics of the yarns studied were obtained by following standard ISO 2062 [8] apart from the pre-tension value, which was the same as while measuring the structural parameters of the samples.

The tensile strength of yarn is an important criterion in assessing the yarn's quality. In knitting, yarn strength is not such an important parameter. In this process,the yarn is not subjected to very great loads. However, the knitting yarn must have sufficient elongation and elasticity. For knitting technologists, the initial modulus values of the new kinds of knitted ribbon yarns are very relevant. The initial modulus of the yarns tested was estimated from stress-strain curves in cN/tex.

Results and discussion

The new type of fancy yarns (knitted ribbon yarns) may be characterised by relatively stable construction in comparison with normal single or folded yarns structure as applied for manufacturing knitted outwear on a flat V-bed knitting machine. The data of the factual linear density of tested yarns is presented in Table 2. Student's test shows insignificant changes in the linear density of the yarns tested after knitting (DY) and washing (DWY) in regard to the value of the linear density of initial yarns' (*IY*).

The key to understanding a knitted structure lies within its basic element, the single knitted loop. The length of yarn knitted into a single loop will determine such overall fabric qualities as hand, comfort, weight, extensibility, finished size, tightness factor, and most importantly the fabric's dimensional stability.

Although yarn length per loop is the paramount factor in determining relaxed fabric dimensions, the finished product will not necessarily be saleable as outwear unless it has other desirables properties such as opacity. This is especially important for the summer assortment of knitwear from ribbon knitted yarns. It is knownthat the opacity of the knitted fabric is also characterised by the factor of tightness (*TF*).

The structure parameters of knitted and washed fabrics from ribbon yarns are presented in Table 2.

It is known that knitted fabrics tend to change dimensions in width and length after being taken off the machine. After knitting, the samples were allowed to relax from their strained and distorted state. The data presented in Table 2 shows that after knitting, the samples changed their actual course density from 3.05 cm^{-1} to 2.85 cm^{-1}, having been knitted at a nominal course density of 3.00 cm^{-1}. The data also indicates a change in loop shape rather than loop length. The tightness factor *TF* indicates the relative looseness or tightness of the plain weft knitted structure. From the data presented in Table 2, it is evident that the samples knitted in the same nominal course density from 330 PAN ribbon yarns have the lowest *TF* value 8.6, and the samples knitted from 550 PAN yarns have a maximum of value 11.4. In our case, it was impossible to knit the samples from 550 tex ribbon yarns at a greater course density than 3.0 cm^{-1} on a flat V-bed knitting machine at a gauge of 3 E. It may be noted that for most plain fabrics knitted from worsted yarns, the *TF* ranges between 14 and 15. According to our experiments, knitted fabrics with a maximum cover manufactured on a flat V-bed knitting machine, at a gauge of 3 E from 550 tex PAN ribbon yarns, must have the values of *TF* lower than 14.

When the knitted structure is allowed to relax from its strained state during manufacture, the more favourable conditions for fabric relaxation are provided during washing. The data from Table 2 shows the insignificant changes in stitch length and tightness factor of all the knitted fabrics after washing. Structure images for the knitted and washed knitted fabrics are given in Figure 2.

Considering that the stress which the yarns receive during knitting could change their tensile behaviour, the main tensile properties of initial yarns were studied. The tensile behaviour of ribbon yarns was revealed by means of stress-strain curves. The tensile characteristics of initial and de-knitted ribbon yarns were compared. The experimental data is presented in Table 3.

It was mentioned above (data in Table 2) that the samples were knitted at various tightnesses (loose, medium and tight).

The samples knitted from comparatively thin (from a 3E gauge knitting machine) 330 tex PAN ribbon yarns had the lowest tightness values (data in Table 2). It may be considered that the stress which the 330 tex ribbon yarn received during knitting was too great , and so the yarn was stretched. The tested de-knitted 330 tex PAN ribbon yarns showed significantly greater values of breaking force (6.8 %), elongation at break (9.4 %) and initial modulus (8.8 %) in regard to the values of corresponding indices of initial yarns. Student's test of 330 tex PAN ribbon yarns: for breaking force t_F = 4.27; for elongation at break $t_ε$ = 4.88; for initial modulus t_E = 5.39; t_{99} = 3.25; t_{95} = 2.26; i.e. $t_F > t_{99}$; $t_ε > t_{99}$; $t_E > t_{99}$. After the washing procedure, the yarn could relax, and showed smaller values of the indices mentioned.

The knitted samples from 450 tex PAN ribbon yarns were knitted at medium tightness. In this case it may be seen from the data presented in Table 3 that the breaking tenacity of initial and deknitted yarn had not significantly changed. The elongation at break of tested yarns after knitting show ~6.3 % higher values than before knitting. After washing, the 450 tex PAN yarns tested could relax, and their tensile characteristics proved to be similar to the initial yarn.

The tensile behaviour of 450 tex PAN/PA ribbon yarns did not changed after knitting and washing. The representative stress-strain curves of initial 450 tex PAN and 450 tex PAN/PA yarns are presented in Figure 2. It can be seen that the curves different in their type. The PAN/PA yarns are characterised by higher breaking

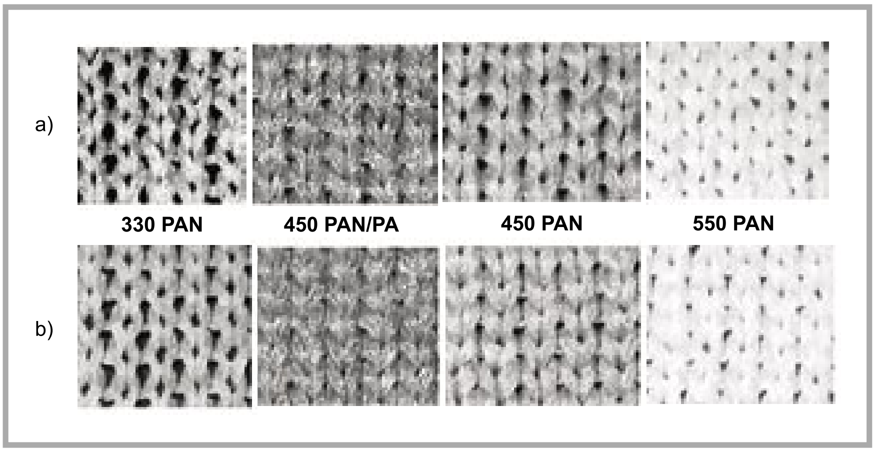

***Figure 2.** Structure images of knitted (a) and washed knitted (b) samples.*

***Table 3.** Tensile characteristics of ribbon yarns.*

Yarn code*		Indices			
		Breaking force F, N	Breaking tenacity f, cN/tex	Elongation at break ε, %	Initial modulus E, cN/tex
330 PAN	IY	34.7 ± 0.9	10.6	31.8 ± 0.9	0.574
	DY	37.0 ± 0.9	11.3	34.8 ± 1.0	0.620
	DWY	36.0 ± 0.5	11.0	33.5 ± 1.0	0.690
450 PAN	IY	45.2 ± 0.7	10.5	35.0 ± 0.7	0,560
	DY	46.3 ± 1.4	10.8	37.2 ± 0.9	0.560
	DWY	44.1 ± 1.2	9.9	34.6 ± 1.0	0.520
450 PAN/ PA	IY	59.6 ± 0.9	12.4	37.9 ± 0.6	0.400
	DY	60.6 ± 1.1	12.7	40.1 ± 0.6	0.425
	DWY	60.7 ± 0.7	12.4	41.1 ± 0.7	0.410
550 PAN	IY	58.6 ± 0.9	10.9	36.0 ± 0.5	0.536
	DY	55.0 ± 1.2	9.8	35.5 ± 0.6	0.474
	DWY	48.7 ± 0.9	8.7	29.4 ± 0.9	0.520

* *IY – initial yarn, DY – deknitted yarn, DWY – deknitted washed yarn.*

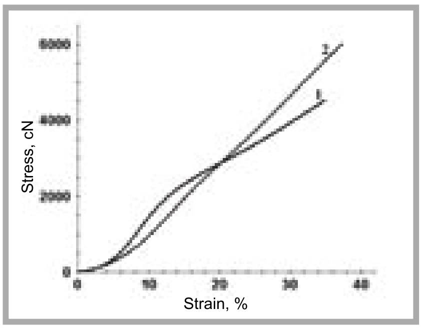

Figure 3. *Representative stress-strain curves of 450 tex ribbon yarns: 1 – PAN yarn, 2 – PAN/PA yarn .*

strength and a lower initial modulus in regard to the same indices of 450 PAN ribbon yarns.

The influence of the knitting conditions on the tensile characteristics of 550 tex PAN ribbon yarns is evident from the data presented in Table 3. The samples from 550 tex ribbon yarns are tight. The data show that in this case the yarn could not relax, and after knitting it lost its breaking strength and initial modulus. These ribbon yarns were manufactured into knit under difficult conditions. test of 550 tex PAN yarns: for breaking strength t_F = 5.43; for elongation at break t_ε = 1.48; for initial modulus t_E = 4.42; t_{99} = 3.27; t_{95} = 2.26; i.e. $t_F > t_{99}$; $t_\varepsilon < t_{99}$; $t_E > t_{99}$.

The influence of washing conditions on the tensile characteristics of de-knitted 550 tex PAN ribbon yarns is evident from the data presented in Table 3. The data show that the process of washing the knitted samples causes some changes in the tensile characteristics of the yarns tested. After washing, the tested 550 tex PAN ribbon yarns lost their breaking force F (11.4 %) and elongation at break ε (11.4 %) in regard to the F and ε values of the de-knitted yarns. The values of the initial modulus E of 550 tex PAN ribbon yarns after washing reached approximately the E value of initial yarns. The samples knitted from 550 tex PAN ribbon yarns was very tight and had no opportunity to relax.

Conclusions

The influence of the tightness factor of knitted fabrics and the knitting process on the tensile characteristics of knitted ribbon yarns were studied. We compared the tensile behaviour of initial yarns and yarns obtained after de-knitting knitted and washed knitted fabrics.

The main conclusions from the experiment are as follows:

1. The knitted PAN and PAN/PA ribbon yarns tested were characterised by relatively stable construction, great breaking tenacity and elongation at break, and low initial modulus values.
2. After the knitting process, the tensile properties of ribbon yarns depend on the tightness factor of knits. High values of tightness factor of knits mean small changes in the structural and tensile characteristics of the ribbon yarns tested, and vice versa.
3. The knitting process on 3E gauge flat V-bed knitting machine influences the stress-strain characteristics of ribbon knitted yarns. After knitting, the breaking force and breaking tenacity of tested yarns did not change significantly. In contrast to the breaking strength, de-knitted ribbon yarns showed a greater elongation at break in regard to the value ε for initial yarns, apart from 550 tex PAN ribbon yarns.
4. The process of washing knitted fabrics influences the changes in the structure and tensile properties of the PAN and PAN/PA ribbon yarns tested. The PAN/PA yarns are characterised by higher breaking strength and lower initial modulus in regard to the same indices of 450 PAN ribbon yarns.

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