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Modern Yarns and Knitted Fabrics for Underwear and Lightweight

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ABSTRACT
In the total world production, the share of cotton fibres is gradually decreasing, so that new fibres are needed to replace or supplement them. A double bed circular knitting machine with a machine gauge of E17 was used to knit five samples of knitted fabrics in plain double jersey weft knitted structure made of 20 tex yarns. The samples were knitted of cotton, Lyocell (Tencel), micromodal and viscose yarns. The ring spinning method was used to spin cotton and Lyocell yarns, micromodal yarns were spun by using the air-jet and rotor spinning method, viscose yarns were spun by employing the SIRO spinning method. Half of each knitted fabric samples was finished. The structure parameters and the tensile properties were determined for the unfinished and finished knitted fabrics, with emphasis on the percentage of elasticity when the knitted fabric was elongated in the course and wale direction. The mass per unit area of the finished knitted fabrics ranged from 138 ± 3 do 169 ± 4 g/m2, while the volume mass ranged from 0.27 to 0.40 g/cm3. All the manufactured and analysed knitted fabrics were compared with cotton knitted fabrics.

Key words: knitted fabric, cotton, Lyocell, micromodal, viscose, SIRO

INTRODUCTION

For a number of reasons, the share of cotton fibres in the total world production gradually decreases, although the population number grows each year. In 2019, the per capita fibre consumption was about 13 kg. For the first time, in 2017 the total world production of 100 million tons of fibres was exceeded, with cotton accounting for around 28%, or 28 million tons [1]. This is why the research in the production of man-made fibres of plant origin is increasingly being conducted in the world. These fibres have some properties similar to cotton fibres and are suitable for making knitted fabrics in different structures that adhere to the skin of the human body. The products are comfortable to use, easy to take care of, not significantly expensive and environmentally friendly [2,3]. For these purposes, viscose, Lyocell, modal, micromodal and other fibres are used in addition to cotton fibres [4,5]. Such fibres and various spinning processes such as: ring-, rotor-, air-jet, compact and other spinning processes are used for making yarns with some properties better than classic cotton yarns made by employing the ring spinning process [6,7].

Single yarns in the count range of 14, 17, 20, 22 and 25 tex are mostly used to make cotton knitted fabric for underwear or more lightweight knitted fabric which adheres to the body or knitted fabrics with mass per unit area to 250 g/m^2. Classic single jersey weft knitted, double jersey weft knitted fabrics and interlock plain structures are mostly used to make classic cotton knitted underwear. One part of the women's lingerie is made of polyamide warp knitted fabrics. For the production of classical women's lingerie, single cotton yarns with counts of 14, 17 and 20 tex are mostly used. For the production of knitted fabrics single bed circular knitting machines with gauges of E18, E20, E24 or E28 are used to make knitted fabrics with mass per unit area from 80 to 140 g/m^2, Fig. 1. Men's classic underwear is made of knitted fabrics with mass per unit area from 140 to 200 g/m^2. For its manufacture, cotton yarns of 17, 20, 22 or 25 tex are also used, as well as single or double bed circular knitting machines of the mentioned gauges. Quality winter men's underwear has a mass per unit area from 180 to 250 g/m^2 and is made of single cotton yarns of 17 or 20 tex, most commonly on interlock knitting machines of the specified gauge. Pyjamas and nightgowns are also made of these knitted fabrics. However, ply yarns of 10 tex x 2, 14 tex x 2 or 17 tex x 2 are sometimes used for their manufacture. Men's winter, bulky pyjamas are made of cotton plush knitted fabric with a mass per unit area from 200 to 350 g/m^2, [3,4]. One group of knitted fabrics is made on single and double bed circular knitting machines E28 by using PA or PES yarns with counts of 76, 110 or 156 dtex, and knitted fabrics are used to make various women's and recreational clothing [8,9].

a)

b)

Fig. 1 Underwear and lightweight clothing; a) women's, b) men's

Structures of weft knitted fabrics

To make simpler knitted fabrics intended for classic underwear, single jersey, double jersey and plain interlock structures are mostly used. All the yarns used for knitted fabrics have the same raw material composition, structure, fineness and colour. In addition to the use of cotton yarns, modern yarns, which are interlooped independently or in combination with other yarns, are commonly used in the production of modern underwear. Modern knitted fabrics for underwear, recreational clothing and general clothing that adheres to the skin of the body are made in a variety of plated structures whereby a course is formed by two yarns, Fig. 2.

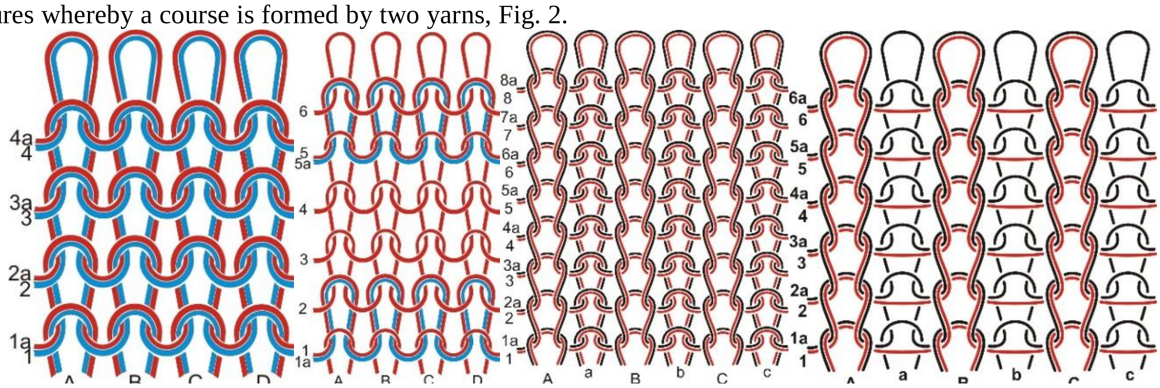
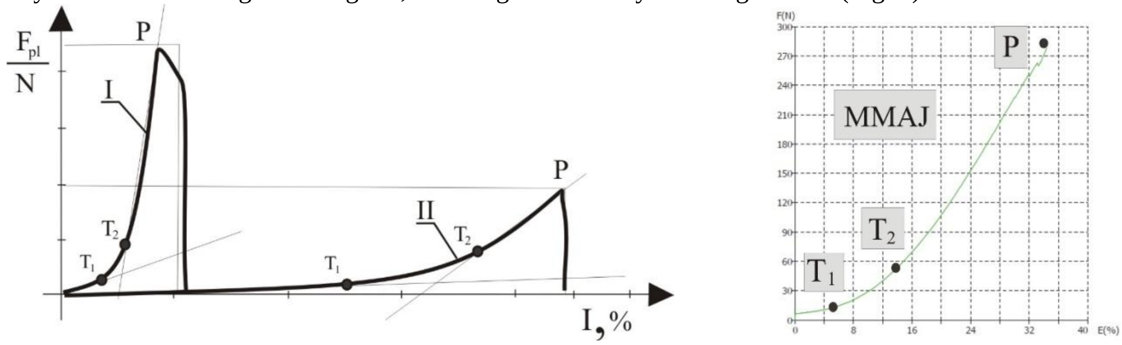


Fig. 2 Single jersey weft knitted and double jersey weft knitted plated structures, which are most commonly used to make elastic knitted fabrics for underwear and recreational clothing

The base yarn is one of the mentioned ones, and the other yarn, which is plated, is mostly PA, PES or elastane yarn with counts of 22, 23 or 44 dtex. The base yarn had elongation at break 3 to 15%, and elastane yarn had elongation at break 200 to 400%. The elastane yarn is fed to the needles in the stretched state, and after stitches are formed and removed from the needles, then the elastane yarn contracts and shrinks the fabric in the course direction or in width. Its task is to allow the stretching of the knitted fabric in use or to shrink it to fit the body comfortably. If more pressure is to be exerted by the knitted fabric on the body, then an elastane coarser yarn will be knitted into each course, e.g. elastane yarn with a count of 44 dtex. If a knitted fabric with less pressure on the body is to be made, an elastane yarn with a specified count is to be knitted into every second, third or fourth course. When making double jersey and interlock knitted fabrics, the elastane yarn can be interlooped only into one fabric surface. For some sporting activities plated knitted fabrics are used whereby the base substrate is made of PA or PES yarns, and the elastane yarn is plated [8,6].

Tensile properties of weft knitted fabrics

Plain single jersey weft knitted fabrics stretch about two times more in the course direction than in the wale direction, and double jersey weft knitted fabrics stretch up to five times more [10]. When making knitted fabric for contemporary underwear, length contraction of the stretched knitted fabric is significant so that the knitted fabric fits the body comfortably. In the force/elongation diagram, three regions are very often significant (Fig. 3).



a) b)

Fig. 3 Force/elongation diagrams for double jersey weft knitted fabric: a) elongation diagrams of the knitted fabric in the wale direction (I) and in the course direction (II); T_1 - end of the elastic region, T_2 – point of the onset of plastic deformation, P – point of knitted fabric breakage, b) elongation diagram of the knitted fabric in the course direction, knitted fabric made of a 20 tex micromodal yarn spun by employing the air-jet spinning method

It is assumed that the first, linear part of the diagram to point T1 represents the elastic region. The second part of the diagram from point T1 to point T2 encompasses the possibly elongated elastic region. These two regions can also be analysed as an entire region to the onset of permanent deformation. The part of the diagram from point T1 to point T2 represents the elastic limit or the part connecting the elastic region with the region of permanent deformation. The fourth part of the diagram ranges from point T2 to the point of knitted fabric breakage (P) and represents permanent or plastic deformation. During elongation and at the moment of breaking the knitted fabric, the tensile testing device records the elongation length at break and this information is often not debatable. However, it is not always easy and precise to determine, estimate or calculate the elastic region, i.e. point T1 or the onset of permanent deformation, i.e. point T2. If these points are determined, it is quite a question whether they include the mentioned regions. These regions have not been sufficiently studied for knitted fabrics made of yarns of different raw materials, yarn counts and structures [11,12]. The elastic limit and the onset of permanent deformation are particularly interesting, as they are very important for the production of high-quality recreational, especially compression recreational clothing. Yarns made of new fibres and by using modern spinning methods have a significantly different structure, and thus have properties compared to cotton yarns made by employing the ring spinning method. [13,14]. Due to different tensile properties of the yarn, different tensile properties of the knitted fabric are also expected, where it is desirable to find out the percentages in the indicated regions of the force/extension diagram. First of all, the elasticity of the knitted fabric or the extension of the fabric to point T1 is significant. In the manufacture of compression garments, the region between the edge of elasticity and the onset of permanent deformation is very significant, i.e., between points T1 and T2, while the percentage of permanent deformation is often not so significant in the garment manufacture. Due to the above, five types of yarn were made according to plan which were used to knit samples of knitted fabrics which can be used for making underwear, lightweight outerwear or recreational clothing. The structure parameters and tensile properties were determined for knitted fabrics, with particular emphasis on the individual percentages of knitted fabric elongation.

Manufacturing and finishing of knitted fabric samples

Four fibre types were used to make yarns: cotton, Lyocell, micromodal and viscose fibres. The ring spinning method was used to spin cotton (PKK) and Lyocell (TR) fibres into single yarns. Micromodal fibres were used to spin them into yarns by employing the air-jet spinning method (MMAJ) and the rotor spinning method (MMOE). The SIRO method was used to spin viscose fibres into the fifth yarn group (SP) [13,15]. All the yarn groups were made with a nominal count of 20 tex. Table 1 lists the basic parameters of tensile properties of the manufactured and analysed yarns at p =0.05.

Table -1 Tensile properties of the yarns with a nominal count of 20 tex spun of different fibres and by employing different spinning methods

Yarn	Breaking force, *cN*	Breaking elongation, *%*	Breaking strength, *cN/tex*	Work to break, *cN·cm*
PKK	302 ± 5	3.7 ± 0.1	15.1 ± 0.3	301 ± 10
TR	532 ± 13	9.6 ± 0.2	26.6 ± 0.7	1515 ± 68
MMAJ	365 ± 11	8.2 ± 0.2	18.2 ± 0.5	886 ± 46
MMOE	344 ± 10	7.3 ± 0.2	17.2 ± 0.5	777 ± 42
SP	393 ± 7	13.6 ± 0.3	19.7 ± 0.4	1700 ± 59

where: PKK – cotton yarn spun on the ring spinning machine, TR – Lyocell (Tencel) yarn spun on the ring spinning machine, MMAJ - micromodal yarn spun on the air-jet spinning machine, MMOE – micromodal yarn spun on the rotor spinning machine, SP – viscose yarn spun on the SIRO spinning machine

The lowest breaking force of the yarn amounted to 302 ± 5 cN and was measured for the cotton yarn, and the highest one amounted to 523 ± 13 cN and was measured for the Lyocell yarn spun on the ring spinning machine. The lowest elongation at break amounted to 3.7 ± 0.1% and was measured for the cotton yarn and the highest one amounted to 13.6 ± 0.3% and was measured for the viscose SIRO spun yarn. The smallest amount of work to break was also measured for the cotton yarn and the greatest amount of work of was measured for the viscose SIRO spun yarn. Based on the data obtained from measurements, it can be concluded that the analysed yarns differed significantly in their tensile properties and that all the measured values of tensile properties for the cotton yarn were the lowest. Since 20 tex yarns were used, double-bed circular knitting machine E17 was chosen to knit plain double jersey weft structure [15].

Each yarn was used to make 100 m of each knitted fabric. Half of the knitted fabrics was finished so that 50 m of the unfinished and 50 m of the finished fabrics were available for the analysis of structure parameters and tensile properties. The finishing of knitted fabrics was done in industrial plants. After the knitting process, the knitted fabrics were first relaxed for ten days. During the finishing process, the knitted fabrics were washed at an initial temperature of 40°C. Washing, bleaching and stabilizing agents were added and the temperature rose to 98°C. After rinsing, a cold wash was performed with neutralization and softening of knitted fabrics. After washing the knitted fabrics were dried at a temperature of 150°C, while the material passed through the dryer at a speed of 0.15 m/s. The knitted fabrics were folded and thus stored for further investigations.

Results and discussion of the parameters of knitted fabric structure

Appropriate standards and methods were used to analyse basic or technological parameters of the structure of knitted fabrics as they are measured and analysed several times in daily production [16]. Some performance parameters relevant to these investigations were also calculated [17]. Measurements were made in a logical sequence, first those for which no material destruction was required, and then the knitted fabric was unknit and cut. When determining the average stitch length to form a stitch, it was necessary to cut the knitted fabric and to unravel the yarn. From among the performance parameters, the following were analysed: knitted fabric shrinkage in the course direction after removal of the fabric from the knitting machine, number of stitches per unit area, coefficient of stitch density and volume mass of the knitted fabric (Table 2).

Width of the unfinished knitted fabric (S_p) ranged from 36 to 49 cm and of the finished fabric from 38 to 47 cm. The smallest width of the knitted fabric was 36 cm and was measured for the unfinished fabric knitted of the viscose yarn spun by employing the SIRO spinning method (SP).

The greatest width of the knitted fabric was also measured for the unfinished fabric knitted of the micromodal yarn spun by employing the air-jet spinning process (MMAJ). This width was 26.5% greater than the smallest one. It is important for knitting technologists to know that at the lowest width of the knitted fabric the greatest fabric shrinkage was observed, and thus the highest mass per unit area and in the case of the greatest width the fabric shrinkage was the smallest as well as mass per unit area. Based on these six mutually connected data, it can be concluded that different yarn structures are obtained by employing the ring, air-jet, rotor and SIRO spinning process. The yarn spun on the rotor and air-jet spinning machine was stiffer. During the stitch formation, it forms a larger stitch skeleton than the stitch made on ring or SIRO spinning machines. This is the reason why wale spacing was larger; consequently, the knitted fabric was wider. Knitted fabric finishing substantially changes fabric structure. After the finishing process, the knitted fabrics made of Lyocell yarns spun by employing the ring spinning method (TR) were 17.5% wider, those made of SIRO yarns 16.7% and those made of cotton yarns 10.3% wider.

In contrast to these samples, the knitted fabrics made of micromodal yarns and spun by employing the rotor spinning system (MMOE) were 20.8% narrower after the finishing process, and the knitted fabrics made of micromodal yarns and spun by employing the air-jet spinning process (MMAJ) were 12.2% narrower. The cause of this different behaviour of the knitted fabrics after the finishing process should be sought in the structure of fibres, yarns and finishing process, i.e. it is necessary to investigate the optimal parameters of the finishing process for individual raw material compositions and yarn structures.

Table -2 Structure parameters of unfinished and finished knitted fabrics

Sample		S_p,cm	s,%	ℓ,mm	D_o, stitches/cm^2	C	m, g/m^2	m_z, g/cm^3
PKK	S	39	39	3.15 ± 0.02	253	0.97	157	0.25
	D	43	32	3.08 ± 0.01	258	0.85	162	0.27
	R. %	-10.3	17.9	2.2	-2.0	12.4	-3.2	-8.0
TR	S	40	36	3.13 ± 0.02	255	0.92	152	0.24
	D	47	26	3.09 ± 0.01	220	0.80	139	0.32
	R. %	-17.5	27.8	1.3	13.7	13.0	8.6	-33.3

MMAJ	S	49	23	3.12 ± 0.02	215	0.72	129	0.21
	D	43	31	3.08 ± 0.02	231	0.90	138	0.35
	R. %	12.2	-34.8	1.3	-7.4	-25.0	-7.0	-66.7
MMOE	S	48	25	3.14 ± 0.02	218	0.75	129	0.22
	D	38	40	3.08 ± 0.02	273	0.87	169	0.33
	R. %	20.8	-60.0	1.9	-25.2	-16.0	-31.0	-50.0
SP	S	36	44	3.13 ± 0.01	282	0.89	180	0.25
	D	42	34	3.05 ± 0.00	231	0.82	147	0.40
	R. %	-16.7	22.7	2.6	18.1	7.9	18.3	-60.0

where: S – Unfinished fabric, D – finished fabric, R – difference between the unfinished and finished fabric, %, S_p – fabric width, cm, s – fabric shrinkage in the course direction after removal from the machine, %, ℓ - stitch length, mm, D_o – number of stitches on the surface, stitches/cm^2, C – coefficient of stitch density, m – mass per unit area of the fabric, g/m^2, m_z – fabric volume mass, g/cm^3

Stitch length (ℓ) is one of the basic parameters, especially for plain knitted fabric structures. For the unfinished and finished knitted fabrics it ranged from 3.05 ± 0.00 mm to 3.15 ± 0.02 mm with a difference of 3.2%, which is significantly less than 5%, so for practical considerations it can be concluded that stitch length does not differ significantly for all analysed knitted fabrics. The difference between the finished and unfinished knitted fabrics was also small, amounting to 2.6%. This is also one of the data that indicates that the samples were knitted under the same knitting conditions.

A change in the structure of unfinished and finished knitted fabrics and their comparison can be qualitatively analysed by the number of stitches per unit area (Do). In the case of unfinished knitted fabrics, the number of stitches was 215 to 282 stitches/cm^2, and for the finished ones 220 to 273 stitches/cm^2. A change in the number of stitches is associated with a change in the width and length of the knitted fabric, especially after finishing the knitted fabric.

Coefficient of stitch density (C) describes the general stitch density of the knitted fabric (C = Dh/Dv = B/A). For the analysed knitted fabrics, it ranged from 0.72 to 0.97, which mainly corresponds to the commercial usage of such knitted fabrics for various purposes.

Mass per square meter of the knitted fabric or **mass per unit area (m)** is the most significant structure parameter, especially for plain knitted structures [10,18]. It determines the purpose and price of the product. For the analysed unfinished samples, the mass per square meter of the knitted fabric ranged from 129 ± 3 to 180 ± 5 g/m^2, and for the finished ones from 138 ± 3 to 169 ± 4 g/m^2.

The micromodal yarns spun by employing the air-jet method (MMAJ) and the rotor spinning method (MMOE) were stiffer, and the made knitted fabric was wider with a lower mass per unit area. Other yarns were more flexible, so knitted fabrics were narrower with a higher mass per unit area.

After the finishing process, the wider knitted fabrics shrank and the narrower knitted fabrics widened with a considerable change in the mass per unit area. In the case of the finished cotton knitted fabrics (PKK) the mass per unit area was 3.2% higher than for the unfinished ones. In the case of the micromodal knitted fabrics made of the yarns spun by employing the air-jet spinning method (MMAJ) was 7% higher, and in the case of the micromodal knitted fabrics made of the yarns spun by employing the rotor spinning method (MMOE) it was higher even 31%. For the other two knitted fabrics, i.e. for the Lyocell fabric (TR), mass per unit area was 8.6% lower, and for the viscose fabric made of the yarns spun by employing the SIRO method (SP) it was 18.3% lower. These results are very important for batch and commercial production as they suggest the practical conclusion that it is very complex to make knitted fabrics of one mass per unit area using yarns with the same yarn count, which have different raw material compositions and are spun by employing different spinning methods.

Knitted fabric volume mass (m_z) mass per unit area and fabric thickness, being therefore a very significant parameter, especially when thermophysiological fabric properties are determined. For all analysed finished fabric samples it was 8 to 66.7% higher than for the unfinished ones. For the unfinished fabrics it ranged from 0.21 to 0.25 g/cm^3, and for the finished ones it ranged from 0.27 to 0.40 g/cm^3. Knitted fabrics with an increased volume mass can be used for garments worn at lower temperatures [8,19].

RESULTS AND DISCUSSION

To measure tensile properties of knitted fabrics, 50 mm wide and 200 mm long samples were cut out. The distance between the grips of the tensile tester was 100 mm. The STATIMAT M tensile tester was used to measure unfinished and finished knitted fabric samples cut out in course and wale direction. While tensile force acts, the sample is elongated with continuous measurement of force/elongation data. In case of break of the knitted fabric the last measurement is recorded which represents the force/elongation value of the knitted fabric. After the measurements were

performed, the tensile properties of knitted fabrics in course direction or transversally and in wale direction or longitudinally were studied separately, Table 3.
The breaking force of knitted fabric stretched in the wale direction was 2.8 to 5.4 times higher than in the course direction. Theoretically, the breaking elongation of this plain double jersey weft knitted fabric in the course direction was 4 times higher than in the wale direction, and in this study it ranged from 5.4 to 7.6 times. The amount of work of rupture of the knitted fabric in the course or wale direction was always smaller for the finished than for the unfinished knitted fabrics. It was 15.9% greater only for the cotton knitted fabric (PPK) elongated in the course direction. The work of rupture of the unfinished and finished knitted fabrics does not change regularly and varies within the range from -52 to +36%. These three parameters depend on the structure and tensile properties of the yarn and the knitted fabric structure. In these investigations, the results of the breaking elongation of the fabric will be used to determine individual percentages of elongation in the analysis of the force/elongation diagram.

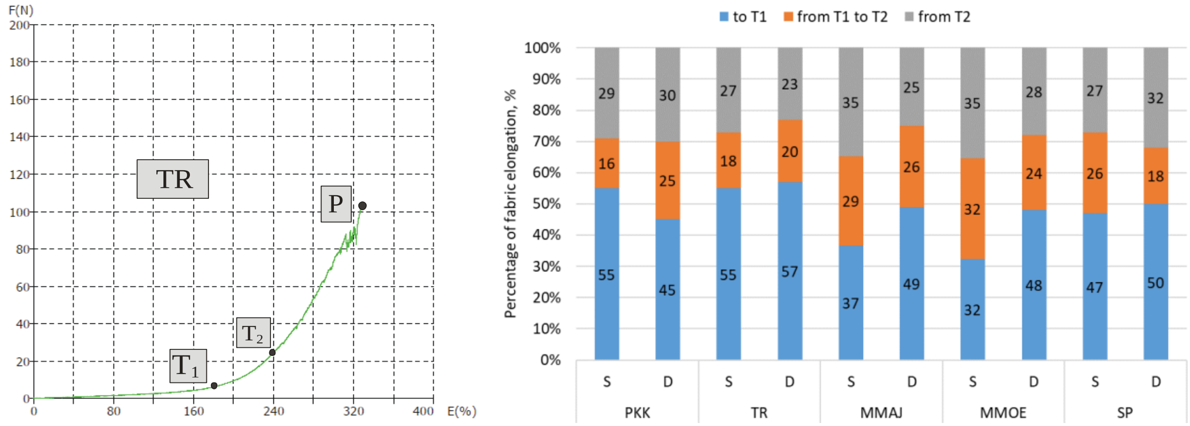
Table -3 Tensile properties of the unfinished and finished knitted fabrics measured in the course and wale direction

Sample		**Breaking force, *N***		**Breaking elongation, *%***		**Work of rupture, *N·cm***	
		P	**U**	**P**	**U**	**P**	**U**
PKK	S	88	472	364	51	488	742
	D	97	336	354	62	580	576
	R, %	9.3	-40.5	-2.8	17.7	15.9	-28.8
TR	S	104	492	328	49	634	772
	D	114	319	247	45	502	414
	R, %	8.8	-54.2	-32.8	-8.9	-26.3	-86.5
MMAJ	S	85	278	245	34	554	355
	D	76	279	265	40	319	341
	R, %	-11.8	0.4	7.5	15.0	-73.7	-4.1
MMOE	S	72	286	247	45	441	419
	D	70	265	292	54	423	393
	R, %	-2.9	-7.9	15.4	16.7	-4.3	-6.6
SP	S	81	345	382	64	573	603
	D	78	236	325	43	494	323
	R, %	-3.8	-46.2	-17.5	-48.8	-16.0	-86.7

where: S – unfinished knitted fabric , D – finished knitted fabric , R –difference between the unfinished and finished knitted fabric, P – in the course direction, transversally, U – in the wale direction, longitudinally
Figure 4 shows the force/elongation diagram of the Lyocell (Tencel) knitted fabric (TR) whose breaking elongation in the course direction amounted to 328%. Figure 4b shows the percentages of the mentioned regions for all analysed knitted fabrics. The data were sorted according to the raw material composition of the knitted fabric.
The diagram in Fig. 4a shows that the first assumed linear region to point T_1 amounts to around 180% or 55% of the total elongation. This elongation region is interesting when making classic clothing that does not fit snugly on the body. The second region of the diagram from point T_1 to T_2 is the shortest, accounting to 18% of the total elongation. This region is interesting when making the clothing, which fits more tightly on the body. The third part of the diagram, amounting to 27%, belongs to the region of permanent deformation of the knitted fabric, which is not so interesting for making clothing.
The total measurements of the unfinished knitted fabrics have shown that the highest percentage of elasticity of knitted fabrics is found for the cotton (PKK) and Lyocell knitted fabric (TR), amounting to 55% of the total elongation. The lowest percentage was recorded for the micromodal knitted fabric made of the yarns spun by employing the rotor spinning method (MMOE), amounting to 32%. A slightly higher percentage of elasticity, amounting to 37%, was also recorded for the micromodal knitted fabric which was made of the yarns spun by employing the air-jet spinning method (MMAJ). The finishing process changes the fabric structure as well as tensile properties. It is important to note that only in the cotton finished knitted fabric (PKK) the percentage of the elasticity was lower than in the unfinished knitted fabric. In all other knitted fabrics, the percentage of elasticity increased after finishing. The highest increase in the percentage of elasticity was observed in the micromodal knitted fabric made of the yarns spun by employing the rotor spinning method (MMOE). This percentage increased from 32 to 48%. In the micromodal knitted fabric made of the yarns spun by employing the air-jet spinning method (MMAJ) the increase was similar and grew from 37 to 49%, meaning that the spinning method affected tensile fabric properties. The percentage of elasticity in the total elongation was the highest, ranging from 32 to 57%. The percentage between the elastic limit and the onset of plastic deformation, i.e. the part of the diagram between point T1 and T2 is the lowest, ranging from 16 to 32%. It is the lowest for the cotton unfinished knitted fabric (PKK-S) and the highest for the micromodal, also unfinished knitted fabric made of the yarns spun by employing the rotor spinning method (MMOE-S). The percentage of permanent deformation of the knitted fabric ranges from 23 to 35%. The research results reveal that the considered three elongation percentages for

the knitted fabric are approximately the same for the unfinished micromodal knitted fabric made of the yarns spun by employing the rotor spinning method (MMOE), amounting to 32%+33%+35%.

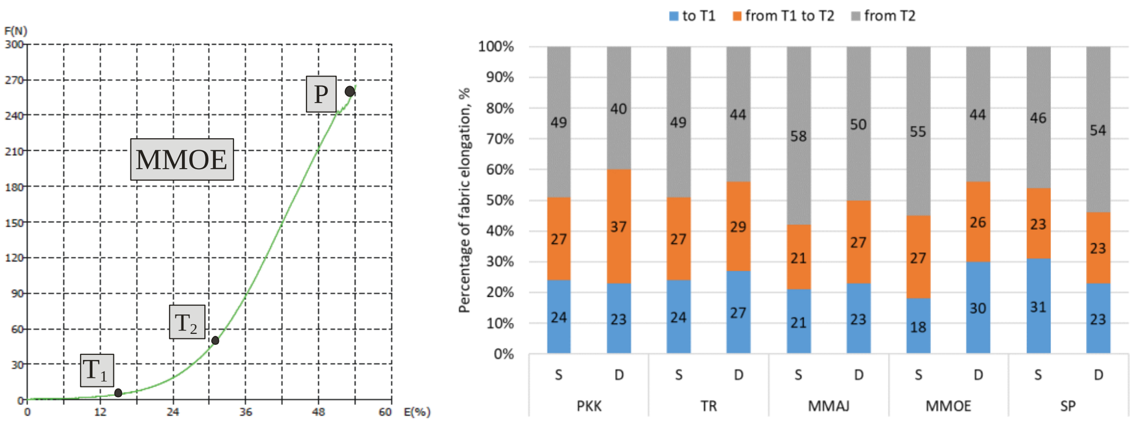
On the basis of the analysis of the tensile properties of the knitted fabric in the course direction it can be recommended that the cotton knitted fabrics can be replaced successfully with Lyocell knitted fabrics whose yarns were spun by employing the same spinning method as the cotton ones or with the viscose knitted fabrics whose yarns were spun by employing the SIRO spinning method (SP).



a) b)

Fig. 4 Elongation of the knitted fabric in the course direction – transversally; a) force/elongation diagram for the unfinished knitted fabric knitted of Lyocell (Tencel) yarns spun by employing the ring spinning method (TR), b) percentages per individual elongation regions; S – unfinished fabric, D – finished fabric

The breaking elongation of the knitted fabric in the wale direction or longitudinally ranges from 34 to 64% and is significantly lower than the breaking elongation of the knitted fabric in the course direction. This fact is significant because of the quality construction of the garment cut (style) and thus its functionality. Underwear and light garments are cut according to the principle that a series of knitted fabrics are laid longitudinally. In the manufactured and analysed knitted fabric samples, the percentage of the elastic region in the wale direction is also lower than in the course direction, ranging from 21 to 31%, Fig. 5b. The lowest percentage of elasticity was recorded for the unfinished knitted fabric made of the micromodal yarns spun by employing the rotor spinning method (MMOE-S), and the highest one was recorded for the viscose knitted fabrics made of the yarns spun by employing the SIRO spinning method (SP). In the case of cotton (PKK), Lyocell (TR) and micromodal knitted fabrics made of the yarns spun by employing the air-jet spinning method (MMAJ), the difference between the percentage of elasticity of the unfinished and finished knitted fabrics was small, and for the other two samples (MMOE) and (SP) the difference was significantly greater. The percentage between the end of the elastic region and the onset of plastic deformation ranged from 21 to 37% and was the lowest for the unfinished knitted fabric made of the micromodal yarns spun by employing the air-jet spinning process (MMAJ-S), and the highest in the finished cotton knitted fabrics (PKK-D). When elongating the knitted fabrics in the wale direction the percentage of permanent deformation was high, ranging from 40 to 58% or the percentage of fabric elongation to the onset of permanent deformation ranged from 42 to 60%. If the tensile properties of the knitted fabric are primary in the wale direction, then it may be recommended to replace the cotton knitted fabrics with Lyocell (TR) or micromodal fabrics whose yarns were spun by employing the air-jet spinning method (MMAJ).



a) b)

Fig. 5 Elongation of the knitted fabric in the wale direction – longitudinally; a) force/elongation diagram of the finished knitted fabric knitted of the micromodal yarns spun by employing the rotor spinning method (MMOE), b) percentages per individual regions of elongation; S – unfinished fabric, D – finished fabric.

For the production of classic knitted fabrics for men's and women's underwear, cotton single yarns with counts of 14, 17, 20 or 22 tex are used. Instead of cotton Lyocell or viscose yarns spun by employing the SIRO spinning process can be used. For the production of outer lightweight knitwear, micromodal knitted fabrics made of yarns spun by employing the air-jet or rotor spinning method can be used. Such yarns are suitable for making plated knitted fabric in which the second thread will be elastane one, and knitted fabrics are suitable for making recreational clothing.

CONCLUSION

Using cotton, Lyocell, micromodal and viscose fibres and employing the ring, air-jet, rotor and SIRO spinning method five types of yarns with a count of 20 tex were spun. Five knitted fabric samples, which were also finished, were knitted in plain double jersey weft knitted structure. Based on the performed tests the following conclusions can be drawn:

a) Yarns for making samples have the same nominal yarn count; however, the tensile properties of the yarns differed significantly. The breaking force ranged from 302 to 532 cN, the breaking elongation ranged from 3.7 to 13.6%, the breaking strength ranged from 15.1 to 26.6 cN/tex, and work of rupture ranged from 301 to 1700 cNcm.
b) All the knitted fabric samples were made on one machine under the same knitting conditions. The mass per unit area of the finished fabrics ranged from 138±3 to 169±4 g/m^2, volume mass ranged from 0.27 to 0.40 g/cm^3. The finishing process significantly changed the structure.
c) Fabric elongation in the course direction was 5.4 to 7.6 times higher than the elongation in the wale direction. The percentage of elasticity in the total elongation of the knitted fabrics elongated in the course direction ranged from 32 to 55%, and in the wale direction from 18 to 31%.
d) Raw material composition, yarn structure and tensile properties of the knitted fabric as well as fabric finishing caused all other differences. Particular attention should be paid to the finishing of knitted fabrics, which will be adapted to the yarns of certain structures. The research results suggest that it is relatively difficult to obtain the same knitted fabric structure with the mentioned yarns that will be used for the manufacture of one product.

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