Luminita Ciobanu,
Florin Filipescu

Experimental Study on the Mechanic Behaviour of Weft Knitted Fabrics

"Gheorghe Asachi" Technical University of Iasi
Department of Knitting and Ready-Made Clothing
Str. Prof. Dimitrie Mangeron, no. 29, corp TEX1,
Iasi, 700050, Romania
e-mail: lciobanu@easynet.ro

Abstract

The paper presents the results of an extensive investigation regarding the tensile behaviour of knitted fabrics with basic evolutions, made of two types of yarns: classic acrylic yarn (used for garments) and PES HT yarn (used for technical applications). Samples were produced according to an experimental matrix containing technological variables considered significant. The fabrics were tested for tensile strain in both the weft and warp directions, and the values were compared and discussed. Conclusions regarding the tensile behaviour of weft knitted fabrics are drawn based on the experimental data.

Key words: *knitted fabrics, tensile behaviour, raw material, structure, technological parameters.*

Introduction

The functional design of textile fabrics and products considers the direct link between the functions of the product, the fabric/product properties and specific behaviour.

Knitted fabrics are known as hyperelastic materials, with high deformations at small forces. Their mechanical behaviour is important, especially in technical applications where the strain level is higher and there is a need to control the fabric strength. It is, therefore, essential to know how these fabrics behave when subjected to mechanical strain. Experimental data also represent the base for any model concerning the mechanical behaviour of knitted fabrics.

The factors affecting the way knitted fabrics respond to strain are different in nature and influence. From the micro to macro level, they refer to the characteristics of the raw material – fibre and yarn, the fabric structure and structural parameters. Their diversity and complex interactions make it difficult to model the fabric response to strain. Therefore, an initial requirement is an experimental study of the mechanical behaviour that highlights the most significant influence factors and their degree of significance.

All models concerning the mechanical behaviour of both weft and warp knitted fabrics with different structures are based on experimental data for definition of the fabric geometry, as well as for the accuracy of the model response under a certain type of strain [1 - 10].

Experimental work

Experimental matrix

In order to determine the mechanic behaviour of the knitted fabrics, the experimental matrix took into consideration the most important factors affecting the fabrics: yarn, fabric structure and technological parameters (reflected in the structural parameters).

The study included three types of **structures**: jersey, rib 1×1 and purl 1×1, representing the basic evolutions. The selection of these structures was justified by their distinct stitch geometry.

For the **raw material**, two types of yarns were selected, considered to have different characteristics and applications:

1. A plied 100% acrylic yarn, count Nm 28/2, used for garments.
2. A polifilament PES high tenacity yarn, count 1110/100 dtex, used for technical applications.

The two yarns have different mechanical behaviour (tensile strength, elongation, and bending rigidity). The knitted samples were produced with similar yarn counts (Nm 28/2/3 ↔ 2×110 tex).

The second set of variables was considered at the knitting process level. The following technological parameters were selected: the **position of the stitch quality cam** and the **yarn tension.** These two technological parameters are indicated in the literature as among the most important factors of influence for the knitted fabrics.

The position of the quality cam was determined within intervals specific to the fabric evolution and yarn knittability. The yarn rigidity of the PES HT yarns proved to have a strong influence, limiting the technological intervals, due to the non-uniform aspect of the stitches produced with a higher value of the quality cam position.

The adjustment intervals for the yarn tension were determined according to machine possibilities and yarn characteristics. The tension was adjusted using yarn control units set at two distinct levels – a low level and one close to the maximum value. An interval of 2 cN was considered for each tension level in order to compensate for the tension variation existing in the bobbins. The tension values indicated were determined before the cam carrier track, due to the fact that the alternative displacement of the carrier made it impossible to choose a closer measuring point.

Table 1 illustrates the resulting experimental matrix, with the values selected for each variable. For each type of structure made of acrylic yarns there are four fabric variants, while for PES HT yarns

Table 1. *Experimental matrix.*

Structure	Initial variables					
	Raw material x1	Quality cam position NP x2			Yarn tension T_a, cN x3	
		Minim	Medium	Maxim	Minim	Maxim
Jersey (G)	PNA	11.5	-	12.5	11 - 13	22 - 24
	PES HT	11.5	12.0	12.5	12 - 14	32 - 34
1×1 Rib (P)	PNA	9.5	-	10.5	11 - 13	22 - 24
	PES HT	9.5	10.0	10.5	12 - 14	32 - 34
1×1 Purl (L)	PNA	11.5	-	12.5	11 - 13	22 - 24
	PES HT	11.5	12.0	12.5	12 - 14	32 - 34

Ciobanu L, Filipescu F. Experimental Study on the Mechanic Behaviour of Weft Knitted Fabrics.
FIBRES & TEXTILES in Eastern Europe 2012; 20, 2(91): 34-39.

Table 2. Physical characteristics of the yarns.

Yarn	Yarn count			Torsion				Diameter, mm
	Nominal	Real	Cv, %	T, t/m	Cv, %	α_m	α_{tex}	
PNA 100%	Nm 28/2	28.45	2.56	246.6 zs	5.77	45.5	1437.2	0.400
PES HT	1110 dtex	1084.33	1.16	-	-	-	-	0.308

Table 3. Tensile characteristics of the yarns.

Yarn	Yarn strength			Loop strength		
	F, N	ε, %	Tenacity, cN/tex	F, N	ε, %	Tenacity, cN/tex
PNA 100%	7.42	22.2	10.39	12.98	19.72	18.17
PES HT	72.64	11.08	66.98	101.85	8.76	112.03

there are six initial variants. The medium value for the quality stitch cam appeared for reasons related to fabric aspect and quality. Due to the quality of the samples, the maximum value of the stitch quality cam position for the PES fabrics was replaced with the medium one.

Raw materials

The following physical and mechanical characteristics of the yarns were determined: yarn count, torsion and tensile strength (Mesdan tensile machine). The tensile strength was determined according to ASTM 2256 [11]. All experimental values are presented in ***Tables 2*** and ***3***. The yarn-yarn friction coefficient was determined according to ASTM 3412 [12], on a ROTHSCHILD F- METERS tester: $\mu_{PNA} = 0.7$ and $\mu_{PES} = 0.33$.

Fabric production

The fabrics were programmed on a M1 programming station, and samples were produced on a CMS 330 TC machine (Stoll), gauge 5E. The technological parameters used for knitting are presented in the experimental matrix from ***Table 1***. The take-down was constant, with a medium value (WM = 7.0), thereby avoiding fabric overstraining. The knitting speed was adjusted to the fabric structure and raw material in order to ensure fabric quality - MSEC = 0.7 m/min for most of the samples and MSEC = 0.5 m/min for those produced on a small number of needles (longitudinal testing). After knitting, the fabrics were relaxed in a dry environment until there were no dimensional changes.

Tensile testing

The tensile behaviour of the fabrics was determined using a Tinius Olsen testing machine, model HK5, according to ISO 1421 [13]. A 5 kN load cell was used for the tests. The following settings were used:

- Test speed – 100 mm/min
- Distance between jaws – 100 mm
- No pretension

The fabrics were tested in both directions (courses and wales) five times for each variant. The force and elongation were determined for the proportional limit, yield limit and breaking.

The specific strength is used in order to be able to compare the fabric variants with different stitch densities, regardless of their structure. The specific strength is determined by dividing the force by the number of rows or wales in the sample

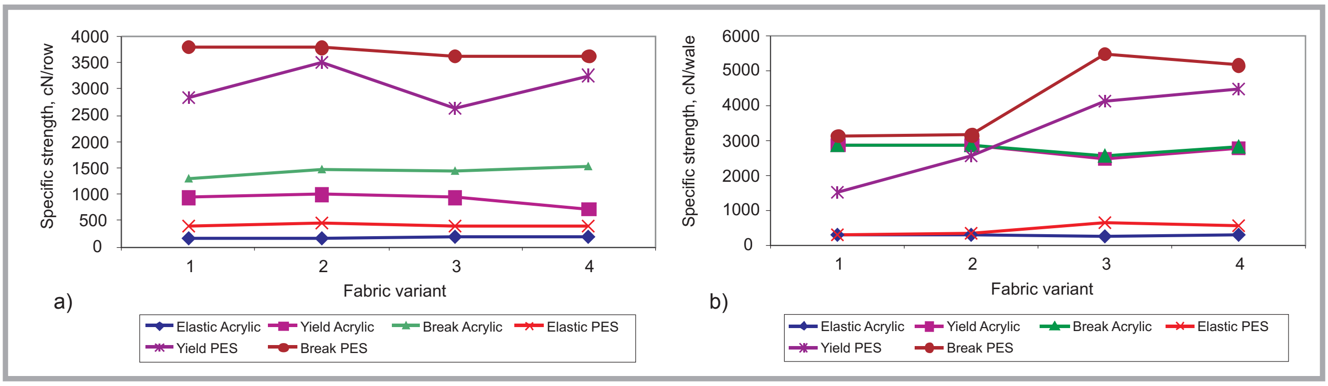

Figure 1. *Variation in the transversal (a) and longitudinal (b) tensile specific strength for acrylic and PES jersey fabrics.*

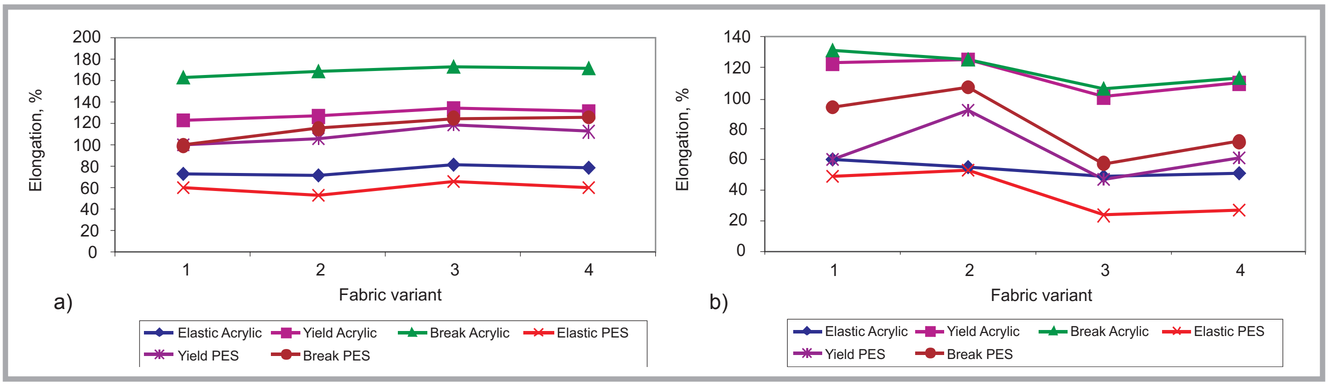

Figure 2. *Variation in the transversal (a) and longitudinal (b) tensile elongation for acrylic and PES jersey fabrics.*

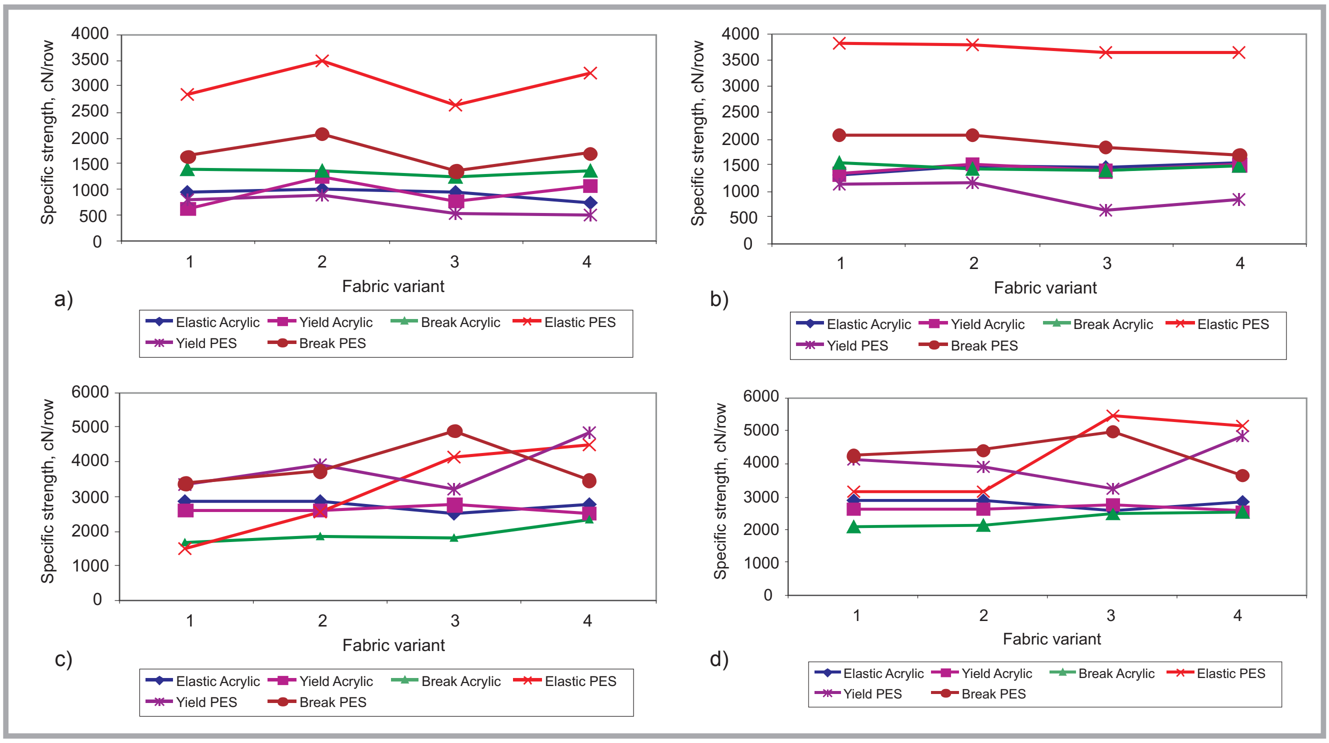

Figure 3. *Comparison the transversal (a, b) and longitudinal (c, d) tensile elongation of the specific strength for the knitted structures at the yield (a, c) and breaking points (b, d) for acrylic and PES jersey fabrics.*

considered perpendicular to the testing direction:

$$S_W = F/\ N_W,\ cN/wale \qquad (1)$$

where: S_W - specific strength per wale; F - measured tensile force; N_W - number of wales in the sample.

$$S_r = F/\ N_r,\ cN/row \qquad (2)$$

where: S_r - specific strength per row; F - measured tensile force; N_r - number of rows in the sample.

Results and discussions

The following observations regarding the tensile behaviour of the samples could be drawn from the experimental data.

Acrylic fabrics

For a significant amount of variants there is an important difference between yield and breaking, caused by the fact that there is a point where a decrease in force appears due to the breaking of a yarn or yarn slippage in the edge stitches. After that point, the force continues to increase until fabric breaking. The yield limit coincides with the breaking point only for longitudinal testing of jersey and rib fabrics. For the transversal testing, the differences between yield and breaking are bigger - 25% to 53% for jersey fabrics, 18% to 54% for rib fabrics and only 6 to 10% for purl fabrics.

The proportional limit is very low for all fabrics, around 10% of the breaking force, indicating that the samples have an elastic behaviour only under small forces. Such a small interval for elastic behaviour would normally lead to breaking in a short interval of time, but the high amount of yarns in the sample cross section, as well as the yarn migration at low forces extend the test duration.

Figures 1** & **2 exemplify the variation in specific strength and elongation for the jersey fabrics. The variants code is made of the following: a letter indicating the fabric structure (G – jersey, in this case), the value of the stitch quality cam position, the yarn tension level (T3 being the lower value and T6 the higher one, see ***Table 1***), and the test direction (Transversal or Longitudinal).

The graphics illustrate the variation in specific strength in three stages - for the proportional limit (elastic), yield and breaking (maximum force). The very low values of specific strength for the proportional limit are obvious, as well as the fact that their variation interval is reduced. In contrast, the elongation for the proportional limit is about half the total value, for both transversal and longitudinal testing. At the yield point the transversal elongation is about 75% of the total value.

When comparing the transversal specific strength for the three structures, the values and hierarchy are different at the yield and maximum stages (***Figure 3***). At the yield point, the purl fabrics have the best specific strength, while for the maximum point (breaking) the values are similar for most of the variants. For the longitudinal tensile testing, the jersey fabrics present the best specific strength, followed closely by the rib fabrics and then the purl structure. These graphics show that the structure has a stronger influence on the transversal tensile behaviour and a diminished effect on the longitudinal tensile behaviour.

The influence of the second variable from the experimental matrix (position of the quality stitch cam) is significant especially for the transversal direction. The stitch density increases the transversal fabric strength for all types of structure. In the case of the longitudinal direction, this influence is not so strong due to the fact that the influence of the quality cam is more important when

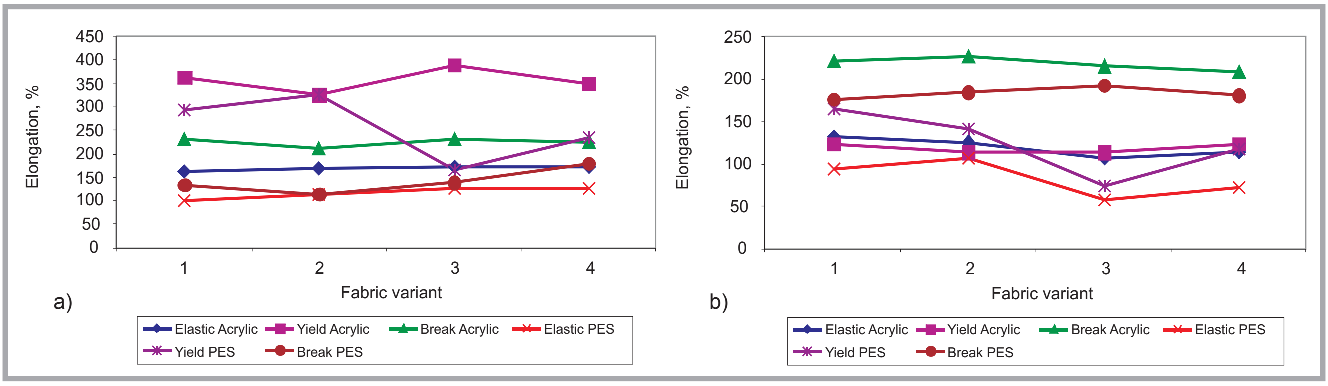

Figure 4. *Influence the transversal (a) and longitudinal (b) of fabric structure on the elongation of acrylic and PES fabrics.*

considering the stitch height and vertical stitch density.

With regard to the third variable from the experimental matrix (yarn tension), there is a certain influence on the transversal direction. For the longitudinal direction, the differences are too small to be taken into consideration, indicating that even if the third variable was not significant at the structural parameter level, the variation in yarn tension modified the internal stress within the acrylic yarns sufficiently to affect the transversal fabric strength.

The variation in technological parameters shows less influence, the most important factor being the **fabric structure** and **raw material**.

The structure also has a clear influence on elongation due to the specific geometry of each evolution (***Figure 4***). Transversal elongation is smaller for the structures with rows produced on a single bed (jersey and purl). The specific geometry of the basic evolutions also influences the longitudinal elongation. In this case purl fabrics present the highest values, while jersey and rib fabrics are characterised by around 50% less elongation. The other two variables influence the elongation to a lesser degree – the stitch density shows an influence on the transversal elongation of rib fabrics, while the yarn feeding tension brings about a decrease in transversal elongation; with respect to longitudinal elongation the variation intervals are less significant.

PES HT fabrics

There were significant problems with regard to PES sample behaviour during the tensile test, especially for the wale direction. There was a rapid laddering of the samples at lower forces, causing the destruction of the samples, as illustrated in ***Figure 5***. The sample destruction affected the final results, but it also indicated certain behaviour.

The problem was solved by knitting PES samples at the test dimensions, thus avoiding sample cutting (as instructed in the standard procedure). Even so, the laddering tendency remained in a smaller proportion, especially for the rib fabrics, and it affected the tensile strength results. This behaviour is explained by the low friction coefficient value, specific to such technical yarns, as mentioned in literature [14, 15]. Its low value means that the friction forces in the contact areas are insignificant and the stitches unravel easily along the testing direction.

The breaking forces are higher than in the case of fabrics made of classic acrylic yarns, emphasising the influence of the mechanical characteristics of the raw material. The tensile strength varies in a larger interval.

Figures 1 & ***2*** also illustrate the variation in specific strength and elongation at the yield and breaking points for the PES jersey fabrics. The differences between the transversal specific strength values are clearer for the yield point and less significant for the breaking point. Differences between the yield and breaking are significantly smaller for the fabric variants made with a higher yarn tension. The fabrics produced with a lower yarn tension exhibit a lower strength.

The elongation presents a similar variation in comparison with acrylic fabrics – around 50% of the transversal maximum elongation represents the elongation corresponding to the proportional limit, while for the longitudinal elongation the proportion is less. In this case the elongations for the yield and breaking point are very close (within a 10% range).

When comparing the specific strength at the yield and breaking points for all structures (***Figure 3***), the graphics show that jersey fabrics have the highest transversal specific strength, while rib fabric presents the lowest values, as explained before, due to their tendency to unravel easily. The differences between the transversal strength at the yield and breaking points are significant for all types of fabrics. The influence of the third variable (yarn tension) is more evident at the yield point and less important at the breaking point, where the variation interval is much smaller. The first two graphics from ***Figure 3*** also show a diminished degree of influence for the second variable (position of the quality stitch cam), especially for the purl and rib fabrics.

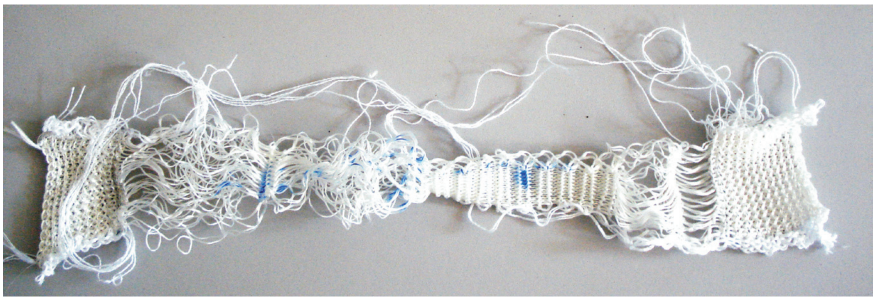

Figure 5. *Aspect of a destroyed rib PES sample tested.*

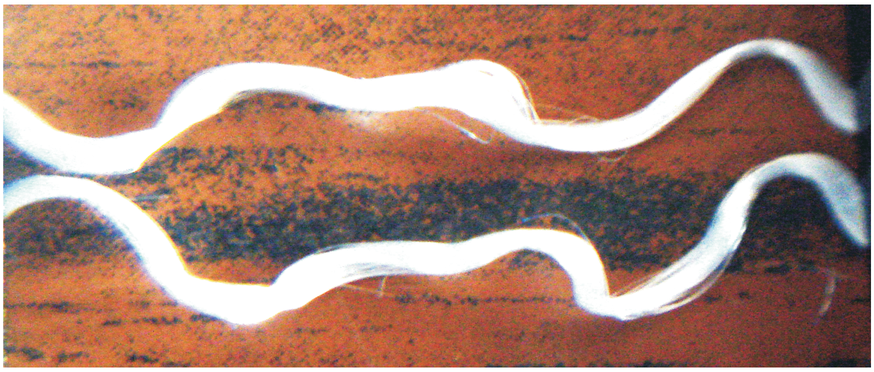

Figure 6. *Aspect of PES HT yarns after deknitting.*

Table 4. *Tensile behaviour of deknitted PES yarns.*

Yarn		**Breaking force** P_{max}**, N**	**Elongation** ε_{max}**, %**	**Tenacity** T_{max}**, cN/tex**
Witness yarn		72.64	11.08	66.98
Deknitted	G_11.5_T3	76.25	11.61	70.30
	G_11.5_T6	80.30	12.02	74.04

Values for the longitudinal specific strength are within a smaller variation interval, and the hierarchy based on fabric structure is not maintained, showing less influence. The last two graphics also show that the longitudinal strength is less influenced by the yarn feeding tension and more by the stitch density (quality cam position). There are differences between the yield and breaking points only for jersey fabrics, while for rib and purl fabrics these points coincide for most of the variants, especially those made with a higher yarn tension.

Structure remains the main influence factor for elongation (in both directions); the hierarchy is maintained, but the values are closer than those for acrylic fabrics (***Figure 4***). An interesting aspect is that compared to acrylic fabrics, the PES samples have lower elongation: the differences are significant for transversal elongation and less important, but not negligible, for longitudinal elongation. One explanation is the lower extensibility of PES yarns, suggesting the influence of the raw material.

What must be underlined is the **significant influence of the yarn feeding tension on the tensile behaviour** of the knitted fabrics made of PES HT yarns. The fabric variants produced with a higher yarn tension consistently present better tensile strength, regardless of the testing direction, the explanation for which lies with what happens to the PES yarns during knitting. There is a redistribution of the filaments in the yarn cross section until it flattens, as shown in ***Figure 6.*** This modification of the filament distribution, as well as the increase in the contact surface between filaments lead to the improved strength of yarns and, subsequently, of the fabrics.

In order to verify this hypothesis, yarns taken from fabric samples were tested. Yarns were taken from two jersey samples produced with the same position of the quality stitch cam, but with the two yarn tension levels. The values were compared to normal ones for the witness yarn, as presented in ***Table 4***.

The experimental values from Table 4 allow to state the following conclusions:

- There is an increase in yarn strength of 4.7% in the case of the fabric with a lower yarn tension level and of 9.5% for that with a higher tension level. This situation is justified by the fact that the PES yarns present a much higher initial modulus than the rest of the fibres, proving beneficial for higher yarn tension during the knitting process, with no increase in elongation.
- The elasticity modulus recommends PES HT yarns for applications where the strain level is lower. Due to the high initial modulus, the fibres recover from tensile, compression, bending and shear strain.
- The knitted yarns present a slightly higher elongation at breaking, but the differences are not significant enough to draw some conclusions.

Conclusions

The mechanical behaviour of the knitted fabrics is an important aspect, especially when considering technical applications. The present study took into consideration the tensile behaviour of knitted fabrics with basic evolutions, made of two types of yarns: acrylic yarns and PES HT yarns. The tensile behaviour was studied based on an experimental matrix that included the fabric structure, raw materials and two technological parameters (the quality stitch cam position and yarn tension).

Based on the experimental results, the following conclusions can be drawn:

1. The raw material, fabric structure and technological parameters represent factors with a significant influence on the tensile strength. The fabric structure presents a stronger influence in the case of transversal strength.
2. The fabric behaviour depends on the testing direction. The experimental values vary more widely in the case of transversal testing, and less so for longitudinal testing, which can be explained by the fact that the jamming phenomenon followed by the transfer of strain to the yarn level appears in a shorter time for the longitudinal strain due to the smaller yarn amount used in yarn migration within the stitch.
3. The friction coefficient influences the deformation mechanism because yarns with lower coefficients present an increased laddering tendency, which is stronger for longitudinal testing and for rib fabrics. Therefore, further studies are recommended in the case of yarns with a low friction coefficient, such as the PES HT used in the present work or glass fibre.
4. In the case of classic yarns, yarn tension presents a limited influence on the tensile behaviour. For the longitudinal tensile strength, this influence can be considered insignificant. In the case of technical yarns, yarn tension is an important factor. The study shows that higher yarn tension during the knitting process improves the mechanical behaviour.

Acknowledgments

This paper is published within the framework of research project PN II ID no. 376/2007, financed by the Romanian Government, through CNCSIS.

References

1. Karimi, H. R.; Jeddi, A.A.A.; Rastgoo, A. Theoretical Analysis of Load-Extension Behaviour of Plain Knitted Fabric, *J. Text. Inst.,* 2009, 1(100), 18-27.
2. Postle, R. Structural Mechanics of Knitted Fabrics for Apparel and Composite Materials, *J. Text. Inst.*, 2001, 3(92), 80-90.
3. Postle, R.; Munden, D.L. Analysis of the Dry Relaxed Knited-Loop Configuration, part I: Two-Dimensional Analysis; *Text. Res. J.*, 1967, Dec(58), 329-351.
4. Postle, R.; Munden, D. L. Analysis of the Dry Relaxed Knited-Loop Configuration, part II: Three-Dimensional Analysis, *Text. Res. J.*, 1967, Dec(58), 352-365.
5. Shanahan, W. J.; Postle, R. A Theoretical Analysis of the Plain Knitted Structure, *Text. Res. J.*, 1970, July(67), 656-665.
6. Xu-Hong Miao, Wu Xi, Ge Ming-Qiao; The Compression Behaviour of Warp Knitted Spacer Fabric*, Fibres & Textiles in Eastern Europe*, 2008, 16, 1(66), 90-92.
7. Supeł B., Mikołajczyk Z., Model of the Compressing Process of a One- and Two-Side Fastened Connector of a 3D Distance Knitted Fabric, *Fibres & Textiles in Eastern Europe*, 2008, 16, 6(71), 44-48.
8. Taheri Otaghsara Mir Reza; Jeddi Ali A. A.; Mohandesi Jamshid Aghazedeh, Tensile Property and Fatigue Behaviour of Warp Knitted Fabrics, *Fibres & Textiles in Eastern Europe*, 2009, 17, 3(74), 70-75.
9. Sherburn, M. Geometrical and Mechanical Modelling of Textiles; PhD thesis, University of Nottingham, UK, 2007.
10. Loghin, C.; Nicolaiov, P.; Ionescu, I.; Hoblea, Z. Functional Design of Equipments for Individual Protection, 6th International Conference Management of Technological Changes, September, 2009, 2, 3-5, 693-696.
11. ASTM D2256 Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method; ASTM Standards on Disc, section 7 Textiles (I), 2008.
12. ASTM D3412-07 Standard Test Method for Coefficient of Friction, Yarn to Yarn, ASTM Standards on Disc, section 7 Textiles (I), 2008.
13. ISO 1421 Rubber-or plastics-coated fabrics - Determination of tensile strength and elongation at break.
14. Lau, K.W.; Dias, T. Knittability of High-modulus Yarns, *J. Text. Inst.*, 1994, 2(85), 173.
15. Ciobanu, L. Development and Production of Knitted Fabrics for Technical Use, PhD Thesis, „Gheorghe Asachi" Technical University of Iasi, Iasi, 2003.

Received 26.08.2010 Reviewed 14.09.2011

Technical University of Lodz
Faculty of Material Technologies
and Textile Design

Department
of Material and Commodity Sciences
and Textile Metrology

Activity profile: The Department conducts scientific research and educational activities in a wide range of fields:

- Material science and textile metrology
- Structure and technology of nonwovens
- Structure and technology of yarns
- The physics of fibres
- Surface engineering of polymer materials
- Product innovations
- Commodity science and textile marketing

Fields of cooperation: innovative technologies for producing nonwovens, yarns and films, including nanotechnologies, composites, biomaterials and personal protection products, including sensory textronic systems, humanoecology, biodegradable textiles, analysis of product innovation markets, including aspects concerning corporate social responsibility (CSR), intellectual capital, and electronic commerce.

Research offer: A wide range of research services is provided for the needs of analyses, expert reports, seeking innovative solutions and products, as well as consultation on the following areas: textile metrology, the physics of fibres, nonwovens, fibrous composites, the structure and technology of yarns, marketing strategies and market research. A high quality of the services provided is guaranteed by gathering a team of specialists in the fields mentioned, as well as by the wide range of research laboratories equipped with modern, high-tech, and often unique research equipment. Special attention should be paid to the unique, on a European scale, laboratory, which is able to research the biophysical properties of textile products, ranging from medtextiles and to clothing, especially items of special use and personal protection equipment. The laboratory is equipped with normalised measurement stations for estimating the physiological comfort generated by textiles: a model of skin and a moving thermal manikin with the options of 'sweating' and 'breathing'. Moreover, the laboratory also has two systems for estimating sensory comfort – the Kawabata Evaluation System (KES) and FAST.

Educational profile: Educational activity is directed by educating engineers, technologists, production managers, specialists in creating innovative textile products and introducing them to the market, specialists in quality control and estimation, as well as specialists in procurement and marketing. The graduates of our specialisations find employment in many textile and clothing companies in Poland and abroad. The interdisciplinary character of the Department allows to gain an extraordinarily comprehensive education, necessary for the following:

- Independent management of a business;
- Working in the public sector, for example in departments of control and government administration, departments of self-government administration, non-government institutions and customs services;
- Professional development in R&D units, scientific centres and laboratories.

For more information please contact:

Department of Material and Commodity Sciences and Textile Metrology
Technical Universiy of Lodz
ul. Żeromskiego 116, 90-924 Łódź, Poland
tel.: (48) 42-631-33-17 e-mail: nonwovens@p.lodz.pl web site: http://www.k48.p.lodz.pl/