STUDY OF RIB KNITS COURSEWISE TENSILE PROCESS

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Abstract: *Stretchability of knitwear is one of the most important factors of wearing comfort. Elasticity of knitted structures in course wise direction is usually higher than along wales and often characterized by crosswise shrinkage. Existing methods of knitting program development do not consider the real rate of wale wise shrinkage of rib knitted structure under the course wise extension. During the study experimental research has been carried out to fulfill empirical data on the relationship between samples' length and width under uniaxial course wise elongation. A range of samples of rib 1×1, 2×2, 3×3, 4×4 and 5×5 knits, made of cotton, bamboo, polyacrylonitrile (PAN), wool/acrylic blend and wool yarn, were stretched with a tensile machine WDW-05M. In the process of stretching the width of each specimen was defined in the moments of extension by 50, 100, 150, 200, 250 and 300 per cent. It has been found that linear approximation can be applied to describe the dependence of specimen's width on its relative course wise elongation. It was found that the stitch height/width ratio changes unevenly. In the beginning of the process of course wise stretching of a rib knitted structure, it does exist, such an interval, where an increase of the knit's linear size along the courses occurs without a significant shrinkage in the wale wise direction. It is suggested to name the upper limit of this interval as "unidimensional extension limit" and define it as an extension of a standard (100×50mm) specimen, at which its width decreases by 10%. It was found as well that the value of this index significantly depends on the ribbing variation and much less on the type of raw materials.*

Keywords: *knitting, rib knits, stretching, courswise extension, crosswise shrinking.*

1 INTRODUCTION

Knitted fabrics are widely used for production of underwear, sports apparel, other kinds of clothes, which conform closely to the body shape due to their elasticity. The fit and elasticity belong to the characteristics most influencing the feeling of wearing comfort. Knitted products are subjected to different kinds of deformation during operation. Tight-fitting knitted clothes have a smaller circumference than the corresponding body part's girth. Sometimes an extra extension is also required to provide comfortable taking on and off for such knitted products as socks, sweaters, gloves, balaclavas, mittens, and others. In addition, it is necessary to take into account possible changes in the dimensions in the process of different body movements, as dimensions of some body parts increase during movements. Many researchers emphasize the importance of considering the elasticity in the knitted garment design. Clothes are in contact with the skin in the process of the using. Therefore, the feeling of comfort and discomfort directly depends on the mechanical influence of clothes on the skin [1]. The present study aims to analyze the tensile process of rib knits and to determine the limit of course wise elongation from which the wale wise shrinkage should be taken into consideration for patterning and knitting programming.

In scientific publications the issue of stretchy knitted products made of different types of yarn is being discussed quite widely. Vasconcelos et al. assume the importance of determining the optimal parameters of elasticity for sport clothes produced with a content of elastomeric yarns [2]. The pressure of clothes on the body is one of the important criteria of personal comfort. Spahiu et al. [3] investigate the implementation of new computer design technologies, which provide a parametric regeneration of a virtual mannequin for the assessment of the fitting quality of apparel, which provides an opportunity to assess the comfort of clothing for a given consumer. Guo & Kuzmichev [4] developed a method of assessing the pressure of a women's dress on the body in the important anthropometric points of the female torso that allows to estimate the wearing comfort of the product in the mode of virtual try-on systems. Many scientific papers are aiming to study the elasticity of knitted fabrics and garments, manufactured with the use of elastomeric yarns [5-7], for sports and medical textile garment manufacture. Changing structure parameters of the knit in a deformed state causes a change in its properties. Gupta et al. [8] studied the influence of the deformation state of the pressure garments on the indices of hygienic comfort such as thermal comfort, air, and water vapor permeability. The effect of the tension level on the thermal properties of compression socks is analyzed by Siddique et al. [9]. The change of air permeability in the stretched textiles is investigated in articles [10, 11]. The knit stitch type significantly affects the ability of a knitted product to extend and return to the original size. Manufacturing of complete garments opens wide possibilities for product customization [12]. However, to expand the range and improve the design quality of seamless products, it is necessary to take into consideration the knitwear elasticity.

The fundamentals of the theory of knitted structure's stretching has been laid out in works [13, 14]. Different aspects of knitted textiles' deformation are being discussed in recent research works. Tensile properties of basic weft knitted stitches, such as plain and rib 1×1 stitch, made of cotton yarn and blended cotton yarn with the content of Lycra, are analyzed in paper [15]. Pavlović & Vrljičak [16] considered the mechanical properties of Tensel and modal knitted fabrics. Mechanical properties of knitted fabrics for technical application are studied by Araújo et al. in the works [17, 18]. The means of three-dimensional modeling of knitted structures open new possibilities in analyzing deformation characteristics [19, 20, 21, 22]. At the same time, means of automation are using theoretical calculation methods as mathematical software, which are often based on the empirical data.

Methods of calculation of knitwear structure parameters that consider operational deformations account reduction of the course spacing at the increase of the wale spacing and vice versa [23]. It is known that the yarn in the knitted structure is being redistributed under tensile load [14]. However, at the beginning of tensile process rib knits have a certain interval, where the increase of the specimen's linear size along courses occurs without changing the course spacing value [24]. In rib knitted structures the process of course wise elongation includes such sub processes as reducing the curvature of plain stitch areas, reducing the amount of mutual shifting of adjacent wales belonging to different layers of the fabric, pulling yarn from loops' legs into the head and feet segments, extension the yarn itself [25]. The first two of the above mentioned sub processes take place without yarn redistribution, i.e. without reduction of the loop height as it is shown schematically in Figure. 1.

The value of course wise elongation, at which the process of the yarn redistribution starts, depends on both the number of knit and purl stitches in the repeated unit of the ribbing variation and the yarn's raw material. At present, there is no information about publishing results of research of the rib knits stretching intervals along the course lines, occurring without reduction of linear dimensions in the crosswise direction.

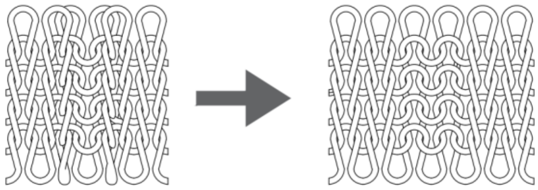


Figure 1 Unfolding process of rib 2x2 under coursewise tensile forces action

At present, there is no information about publishing results of research of the rib knits stretching intervals along the course lines, occurring without reduction of linear dimensions in the crosswise direction. In order to establish the limit value of stretching along one axis without significant shrinkage along the other, a study of geometric characteristics of rib knitted fabrics in the process of course wise stretching was carried out.

2 MATERIALS AND METHODS

Stretchability and elasticity of knitted structures belong to the number of indicators most influencing wearing comfort. Their significance is determined by the purpose and functionality of the knitwear product. The most common method of the study of textile fabrics load/extension properties is so called "strip method". This method is based on stretching a ribbon of textile cloth of a rectangular shape, fixed between two clamps of tensile testing machine.

In this study, a concept of deformation of a section of knit has been used. Under a deformation state we understand a state of a specimen of certain dimensions and the structure's parameters gets under the application of a given load, characterized by both magnitude and direction. The unidimensional extension limit is a deformation condition characterized by such a relative elongation value, until which a specimen of a knitted fabric of standardized size (50×100mm) can be stretched before the crosswise shrinking begins.

2.1 Preparing samples

The most widely used types of yarn, such as cotton, bamboo, polyacrylonitrile (PAN), wool/acrylic (blended) and wool yarn with equal value of operational diameter have been chosen for the experimental study. Theoretical calculation, performed according to [14], gives such a set of yarn types: cotton yarn with linear density of 42 tex, bamboo yarn – 31×2 tex, wool yarn 31 tex ×2, wool/acrylic blend yarn 31×2 tex and polyacrylonitrile 31×2 tex. The test samples of rib 1×1, 2×2, 3×3, 4×4 and 5×5 structures have been produced on a V-bed flat knitting machine PVRK, 10 gauge. After knitting, the samples were kept 24 hours under normal atmospheric conditions (temperature 22±3°C and relative air humidity 62±5 %) to get a dry relaxed state. During relaxation process configuration of the thread and stitches changes, but after 24 hours a knitted fabric laying of on a plane surface doesn't change its size without an external load application. Rectangular specimens with linear dimensions 200±1mm × 50±1mm were cut out for uniaxial stretching in the course wise direction. The characteristics of the samples are given in Table 1.

To know the value of operational deformations relative to the initial circumference of a knitted tubular part, which is measured in a free, undeformed state is also important for the improvement of technological development of complete garment knitwear; as well as for the assessment of wearing comfort. Therefore, the test length for determining deformation characteristics was set at 100 mm, measured in the free state without a prior loading.

2.2 Setting the experiment

To study the deformation properties of knitwear, a tensile testing machine WDW-05M (Fig. 2(a)) has been used. This machine is equipped with one fixed clamp and one clamp, that can move with a constant velocity. A strip-test with automatic recording of load-extension diagrams (Fig. 2(b)) has been carried out. The research was realized in an accredited testing laboratory of analytical research TLAR "Textile-test".

During the tensile testing, a wide-angle camera was set with a tripod in front of the specimen. Each test simultaneously started together with the video recording. To ensure a possibility of the correct scaling, a calibration ruler was placed next to the sample as shown in Fig. 2(a). The use of this equipment allowed to study the nature of crosswise narrowing dynamics.

For accurate calculation the required number of knitting needles and rows of knitting in a certain garment part, it is important to understand how much the product can be stretched in the process of operation without significant crosswise shrinking. In other words, what reduction in the height of the loops will occur under a certain width extension. Wearing comfort relates to the pressure of a textile shell to the body part. In turn, it depends on the difference between the body girth and the knitted shell's circumference in a free state, as well as on the tensile strength of the fabric. Preliminary experiment with chosen structures has shown that in the first stage of coursewise stretching (up to 50%) the elongation occures with little or no loading. The stretching interval has been established for the reason of detectable loading difference (more than 0.05 N). For example, the load-extension diagram represented in Figure 2(b) shows a slow increment of the load value up to the extension of approximately 240%. In the course of the study it has been proposed to assess the values of the width of the specimen in five states of stretching, which will be designated as states T1-T6, corresponding to the relative elongation of the sample on 50, 100, 150, 200, 250 and 300mm respectively.

3 RESULTS AND DISCUSSIONS

In order to determine the crosswise shrinking of the knitted samples during stretching, video recording of each test was processed with the VSDC Free Video Editor. Raster images corresponding to the chosen stretching states were stored. Since the movement of the upper clamping of the tensile tester machine is moving at a constant speed equal to 100 mm/min, evidently, 50, 100, 150, 200, 250 and 300mm elongation of all samples corresponds to 30th, 60th, 90th, 120th, 150th and 180th second of video recording respectively. The received raster images have been imported in the Autodesk AutoCAD environment, scaled and processed to measure the width of the specimens in their narrowest parts.

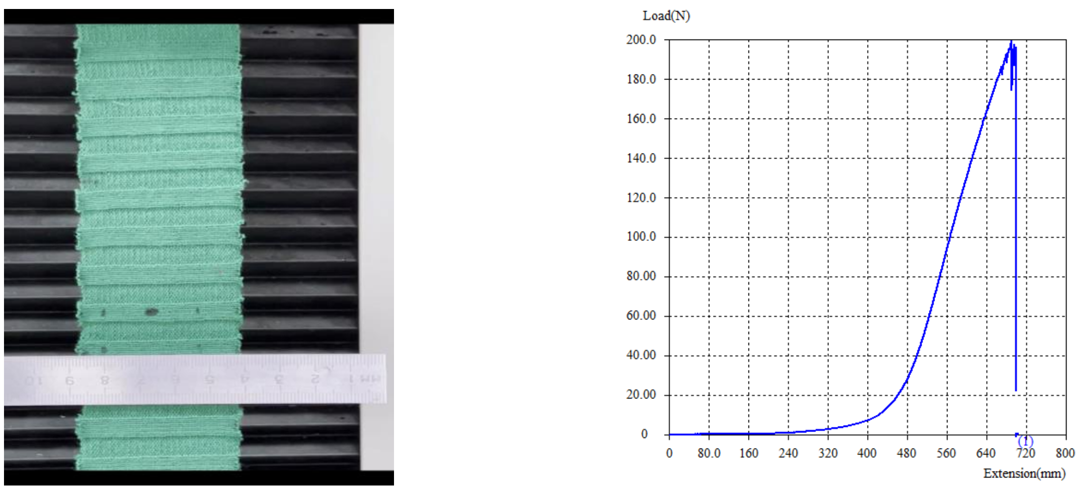
In Fig. 3 raster images of different ribbing variation from the polyacrylonitrile yarn in the stretching states T1-T6 are shown.

As it can be seen in the photograph, the specimen of 1×1rib knit begins to narrow yet after the extension by 50%, the narrowing of the specimen of 3×3 rib knit occurs at a later stage of tension, between 150 and 200%. The 4×4 rib knit keeps its initial width value by approximately 200% of longwise extension. And the beginning of the width reduction of the specimen of 5×5 rib knit is being observed when the relative elongation value reaches 250%.

Due to the peculiarities of the structure of rib knits, in the beginning of the stretching process, a so-called unfolding is going on. Under the action of tensile force in the structure of rib knits the shifting of purl stitches behind the knit stitches reduces. Therefore, at the initial stage of stretching in the range from 0 to 50% narrowing in the transverse direction is observed only in the structure of rib 1x1 and 2x2 knits. As can be seen from Fig.3, the larger is ribbing pattern, the smaller shrinkage of the test specimen in the transverse direction (along the line of the loop column) occurs in a given deformation state.

Table 1 Characteristics of the experimental samples of knitted fabrics

Ribbing structure type	Code of the sample	Raw material, Linear density	Number of courses in the specimen	Number of wales in the gauge length
Rib 1x1	1.1	Cotton, 42 tex	39±1	100±2
	1.2	Bamboo, 31×2 tex	42±1	110±2
	1.3	Polyacrylonitrile (PAN), 31×2 tex	41±1	102±2
	1.4	Wool/acrylic blend, 31×2 tex	39±1	104±2
	1.5	Wool, 31 tex ×2	38±1	110±2
Rib 2x2	2.1	Cotton, 42 tex	44±1	124±2
	2.2	Bamboo, 31×2 tex	50±1	126±2
	2.3	Polyacrylonitrile (PAN), 31×2 tex	45±1	130±2
	2.4	Wool/acrylic blend, 31×2 tex	46±1	124±2
	2.5	Wool, 31 tex ×2	50±1	133±2
Rib 3x3	3.1	Cotton, 42 tex	54±1	180±2
	3.2	Bamboo, 31×2 tex	59±1	180±2
	3.3	Polyacrylonitrile (PAN), 31×2 tex	50±1	168±2
	3.4	Wool/acrylic blend, 31×2 tex	49±1	168±2
	3.5	Wool, 31 tex ×2	50±1	201±2
Rib 4x4	4.1	Cotton, 42 tex	56±1	192±3
	4.2	Bamboo, 31×2 tex	57±1	192±3
	4.3	Polyacrylonitrile (PAN), 31×2 tex	52±1	180±3
	4.4	Wool/acrylic blend, 31×2 tex	50±1	200±3
	4.5	Wool, 31 tex ×2	50±1	212±3
Rib 5x5	5.1	Cotton, 42 tex	55±1	195±3
	5.2	Bamboo, 31×2 tex	59±1	195±3
	5.3	Polyacrylonitrile (PAN), 31×2 tex	49±1	200±3
	5.4	Wool/acrylic blend, 31×2 tex	48±1	210±3
	5.5	Wool, 31 tex ×2	51±1	210±3



(a) (b)

Figure 2 Tensile testing of the specimen of rib 5×5 knit from polyacrylonitrile yarn (a) and load – extension diagram, automatically generated during the test (b)

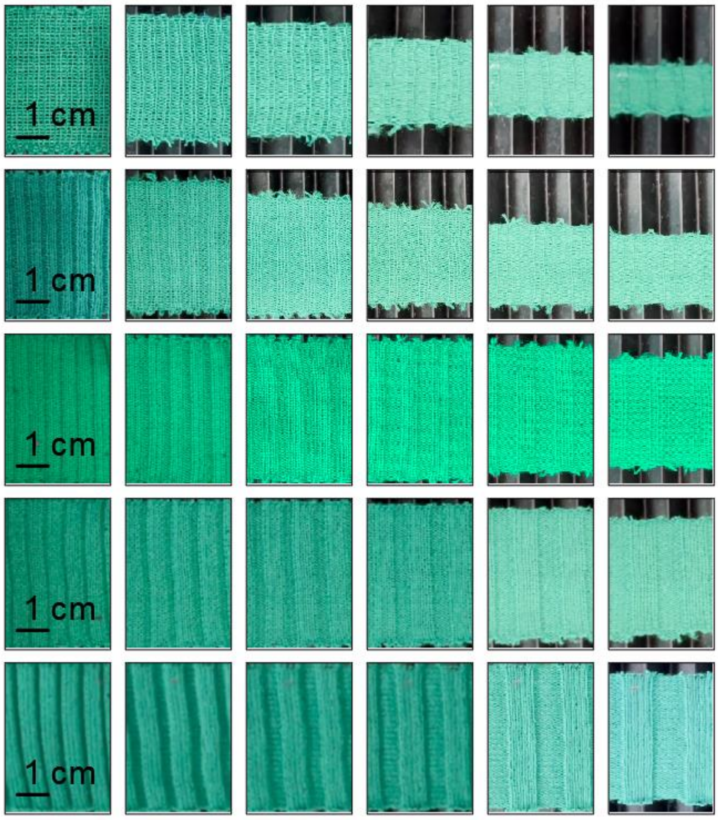


Figure 3 The transformation of surface geometry 1×1, 2×2, 3×3, 4×4, 5×5 rib knits (top-down) from polyacrylonitrile yarn at the relative elongation of 50, 100, 150, 200, 250, and 300% (left-right)

3.1 Unidimensional extension limit

During the study, the character of the size changing has been analyzed. Five specimens of each sample were taken for checking the dispersion homogeneity during the preliminary experiment. In cases of inhomogeneous dispersion, the number of specimens increased. According to the obtained average data for each sample of knitwear, the diagrams of dependence of the absolute specimen width on its relative elongation and the linear approximation graphs are built as shown in Fig. 4. Linear equations for all samples are shown in Table 2. In all samples, regardless the ribbing variation and the raw material composition, the linear nature of the influence of tension along the courses on its narrowing in the transverse direction in the range of 0 ÷ 200% is observed. For rib knits of bamboo and wool yarn after stretching by 200% the dependence becomes polynomial. But because during the wearing use of knitwear products tensile deformation does not reach more than 200%, we admit linear dependence for practical use. Table 2 shows the information about the probability of approximation of the obtained curvilinear dependences.

As it is known, during the knitting process the width of a segment containing a certain number of wales depends on the number of knitting needles in action and out of action, and on the distance between needles. The width of the sample that it had during the knitting process; mm is also shown in Table 2. Based on the results obtained, it is assumed that the rib knit crosswise shrinking over 10%, should be considered during the calculation of the number of rows for manufacturing knitted garment details. The unidimensional extension limit value has been determined for each sample, using the approximation equation having the y value (wale wise size) constant - 10 % of the original length, as shown in Table 2. The value of the unidimensional extension limit as well as the load, necessary to attain this elongation, depends most of all on the ribbing variation. At the same time, samples with the same indicators of unidimensional extension limit, like samples 3.3 and 3.4 are characterized by different tensile forces. It shows that such properties as bending rigidity, roughness, yarn stretchability also influence the stretching process.

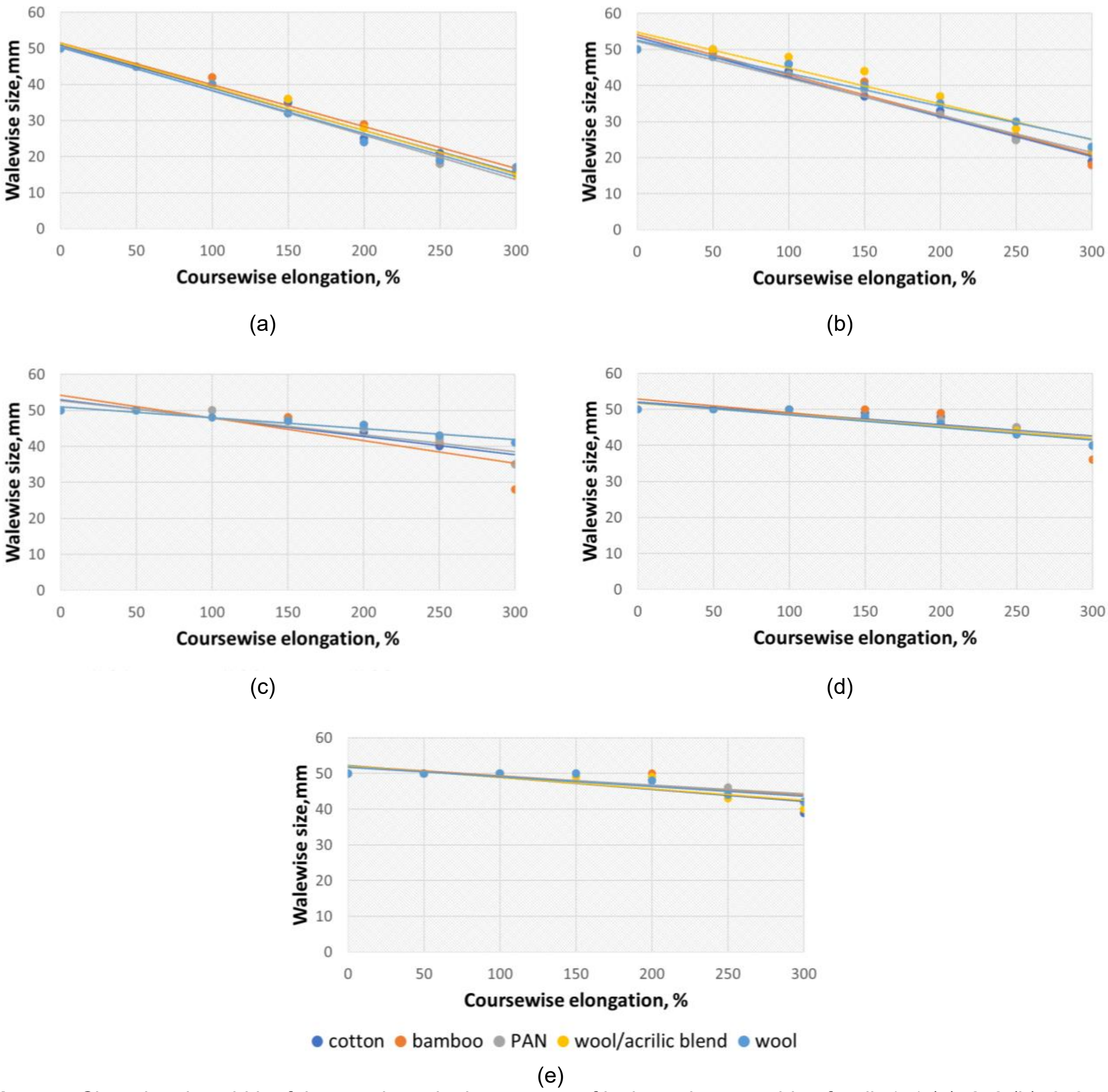


Figure 4 Changing the width of the specimen in the process of its longwise stretching for rib 1x1 (a); 2x2 (b); 3x3 (c); 4x4 (d); 5x5 (e) knitted samples

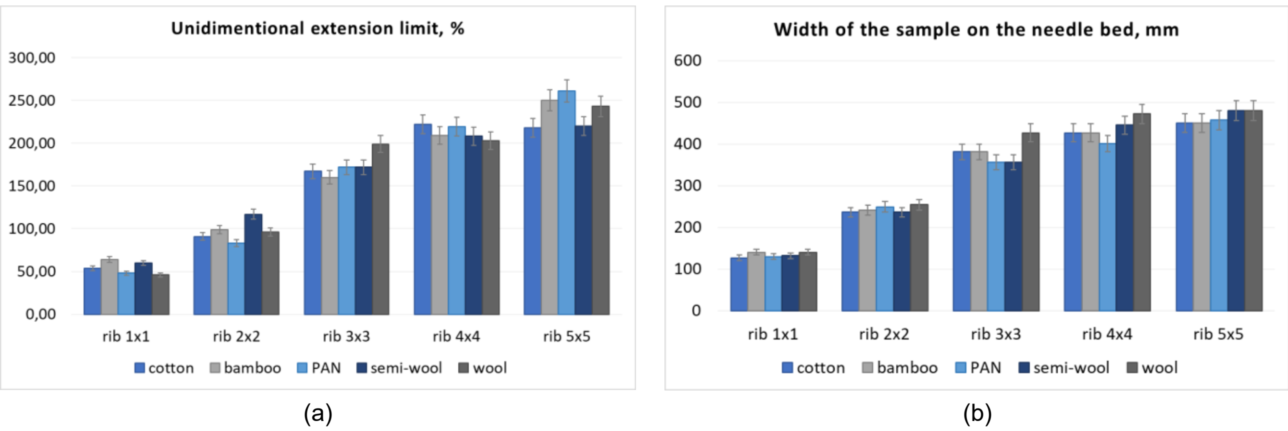


Figure 5 Geometric characteristics of the samples: the value of the unidimensional extension limit (a) and the width of the sample (gauge) in the knitting process (b)

Table 2 Characteristics of the stretching process

Code of the sample	Approximation equation (y- specimen width; x- specimen elongation), probability	Width of the sample on the needle bed, mm	Unidimensional extension limit, %	Load of unidimensional extension limit, N
1.1	$y = -0.1211x + 51.533$, $R^2=0.9858$	127±1	54	0.3
1.2	$y = -0.1217x + 52.8$, $R^2=0.9798$	140±1	64	0.45
1.3	$y = -0.1251x + 51.067$, $R^2=0.9776$	130±1	48	0.55
1.4	$y = -0.1263x + 52.6$, $R^2=0.9834$	132±1	60	0.7
1.5	$y = -0.1206x + 50.6$, $R^2=0.9732$	140±1	46	0.5
2.1	$y = -0.1234x + 56.267$, $R^2=0.9958$	236±1	91	0.5
2.2	$y = -0.128x + 57.733$, $R^2=0.9801$	241±1	99	0.4
2.3	$y = -0.112x + 54.267$, $R^2=0.9918$	249±1	83	0.6
2.4	$y = -0.1183x + 58.867$, $R^2=0.9612$	236±1	117	1.15
2.5	$y = -0.1017x + 54.8$, $R^2=0.984$	254±1	96	0.65
3.1	$y = -0.0623x + 55.4$, $R^2=0.925$	381±1	167	0.25
3.2	$y = -0.0794x + 57.733$, $R^2=0.7735$	381±1	160	0.3
3.3	$y = -0.0577x + 54.933$, $R^2=0.895$	356±1	172	0.8
3.4	$y = -0.0554x + 54.533$, $R^2=0.9411$	356±1	172	1.15
3.5	$y = -0.0349x + 51.933$, $R^2=0.9694$	427±1	199	0.75
4.1	$y = -0.0394x + 53.733$, $R^2=0.8414$	427±1	222	0.5
4.2	$y = -0.0491x + 55.267$, $R^2=0.6802$	427±1	209	0.5
4.3	$y = -0.0377x + 53.267$, $R^2=0.8724$	401±1	219	0.85
4.4	$y = -0.04x + 53.333$, $R^2=0.9292$	445±1	208	0.6
4.5	$y = -0.0417x + 53.467$, $R^2=0.9418$	472±1	203	0.55
5.1	$y = -0.0429x + 54.333$, $R^2=0.7969$	450±1	218	0.35
5.2	$y = -0.0354x + 53.867$, $R^2=0.659$	450±1	250	0.7
5.3	$y = -0.0309x + 53.067$, $R^2=0.8115$	457±1	261	1.2
5.4	$y = -0.0406x + 53.933$, $R^2=0.7928$	480±1	220	0.9
5.5	$y = -0.0343x + 53.333$, $R^2=0.8385$	480±1	243	0.83

In Fig. 5 a bar chart of the value of the unidimensional extension limit for the rib knitted samples is shown. The diagram shows that the type of raw material influences the value of the indicator much less than the ribbing variation. The use of the obtained unidimensional extension limit values in technological calculations contributes to the improvement of the design quality.

4 CONCLUSIONS

Stretchability and elasticity of knitted materials belongs to the number of indicators, most influencing wearing comfort. The structure of the rib knit stitch affects the ability of the knitwear to increase in size and return to the original dimensions. Methods of calculation of knitwear structure parameters taking into account operational deformations, predict reduction of course spacing at increase of wale spacing and vice versa. The value of the extension where the process of the yarn redistribution inside the loop starts, depends on the ribbing variation and the type of raw material. Rib stitches have a certain stretching interval when the course wise elongation occurs without wale wise shrinking. During of the study, it was found that the unidimensional extension limit value much more depends on the ribbing variation than on the type of raw materials. Empirical data and interpolation equations are gathered for use in algorithmic software of computer aided design systems for knitted garments development.

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5 REFERENCES

1. Das A., Alagirusamy R.: 9 – Improving tactile comfort in fabrics and clothing, Editor(s): Guowen Song, In Woodhead Publishing Series in Textiles, Improving Comfort in Clothing, Woodhead Publishing, 2011, pp. 216-244, ISBN 9781845695392. https://doi.org/10.1533/9780857090645.2.216
2. Vasconcelos F., Casaca F., Vasconcelos F., Marcicano J., Sanches R.: Design of Elastic Garments for Sports in Circular Knitting, International Journal of textile and Fashion Technology, 3(1), 2013, pp. 39-48.
3. Spahiu T., Shehi E., Piperi E.: Personalized Avatars for Virtual Garment Design and Simulation, UNIVERSI - International Journal of Education, Science, Technology, Innovation, Health and Environment, 1(3), 2015, pp. 56-63.
4. Guo M., Kuzmichev V.: Pressure and comfort perception in the system “female body–dress”, AUTEX Research Journal, 13(3), 2013, pp. 71 – 78. https://doi.org/10.2478/v10304-012-0032-6
5. Kyzymchuk O, Melnyk L.: Stretch properties of elastic knitted fabric with pillar stitch, Journal of Engineered Fibers and Fabrics, 13(4), 2018. https://doi.org/10.1177/1558925018820722

6. Gorjanc D., Pracek S.: The prediction of elastic behavior of fabric from stretch yarn, Ind Textila, 67(3), 2016, pp. 157–163.
7. Senthilkumar M, Anbumani N., Hayavadana J.: Elastane fabrics—a tool for stretch applications in sports, Indian J Fibre Text, 36(3), 2011, pp. 300–307
8. Gupta D., Chattopadhyay R., Bera M., Kumar M.: Comfort properties of pressure garments in extended state, Indian Journal of Fibre & Textile Research, 36(4), 2011, pp. 415-421.
9. Siddique H., Mazari A., Havelka A., Laurinová R.: Analysis of Thermal Properties Affected by Different Extension Levels of Compression Socks, Vlakna a Textil, 26(2), 2019, pp. 64-69.
10. Kumar V., Sampath V., Prakash C.: Investigation of stretch on air permeability of knitted fabrics part II: effect of fabric structure, The Journal of the Textile Institute, 107(10), 2015, pp. 1213-1222. https://doi.org/10.1080/00405000.2015.1099949
11. Muraliene L., Mikucioniene D.: Influence of structure and stretch on air permeability of compression knits, International Journal of Clothing Science and Technology, 32(6), 2020, pp. 825-835. https://doi.org/10.1108/IJCST-11-2019-0175
12. Peterson J., Larsson J., Mujanovic M., Mattila H.: Mass customisation of flat knitted fashion products: simulation of the co-design process, Autex Research Journal, 11(1), 2011, pp. 6-13.
13. Kobliakov A.: Structure and mechanical properties of knit. Moscow: Legkaya Industria, 1973, 240 p. (in Russian).
14. Dalidovich A.: Knitting Theory Basics. M.: Legkaya industriya., 1970, 432 p. (in Russian).
15. Sitotaw D., Adamu B.: Tensile Properties of Single Jersey and 1×1 Rib Knitted Fabrics Made from 100% Cotton and Cotton/Lycra Yarns, Hindawi Journal of Engineering, 2017, 4310782. https://doi.org/10.1155/2017/4310782
16. Pavlović Ž, Vrljičak Z.: Comparing double jersey knitted fabrics made of Tencel and modal yarns, spun by different spinning methods, Journal of Engineered Fibers and Fabrics, 15, 2020. https://doi.org/10.1177/1558925020919854
17. Araújo M., Fangueiro R., Hong H.: Modelling and simulation of the mechanical behaviour of weft-knitted fabrics for technical applications. Part II: 3D model based on the elastica theory, AUTEX Research Journal, 3(4), 2003, pp. 166-172.
18. Araújo M., Fangueiro R., Hong H.: Modelling and simulation of the mechanical behaviour of weft-knitted fabrics for technical applications. Part III: 2D hexagonal fea model with non-linear truss elements, AUTEX Research Journal, 4(1), 2004, pp. 25–32.
19. Cirio G., Lopez-Moreno J., Otaduy M.: Efficient simulation of knitted cloth using persistent contacts. In: Proceedings of the 14th ACM SIGGRAPH/Eurographics Symposium on Computer Animation, 2015, pp. 55–61.
20. Galavska L., Yelina T.: Using of computer 3D geometic models of the knitted structures knitwear for virtual simulations, Visnyk KNYTD, 2(84), 2015, pp. 94-103.
21. Abghary M., Hasani, H., Nedoushan, R.: Numerical simulating the tensile behavior of 1×1 rib knitted fabrics using a novel geometrical model, Fibers Polym 17, 2016, pp. 795–800. https://doi.org/10.1007/s12221-016-5791-6
22. Yelina T., Halavska L., Manoilenko O.: Development of a parametric surface model of rib 2x2 knits, Visnyk KNYTD, 2(132), 2019, pp. 80-89 (in Ukrainian).
23. Kudryavin L., Shalov I.: Basics of designing knitwear production with CAD elements - M.: Legprombytizdat, 1989.- 288 p.
24. Yelina T., Halavska L.: Design of Tubular Shape Products Taking into Account the Deformation Properties of Knitwear, Bulletin of KhNU: Technical Sciences, 6(291), 2020, pp. 168-174.
25. Yelina T., Pukhova A., Romaniuk V., Halavska L.: Study of the Process of Streching in the Coursewise Direction of Different Knitting Rib Structure, Visnyk KNUTD, 4, 2020, pp. 98-106.