Knitted fabrics potential energy of deformation during one load / unload cycle

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The aim of this paper is to analyze the force/elongation diagram of a knitted fabrics loaded in the row's direction, and then in the walle direction, and to define a common characteristic point at a certain elongation until the knitted fabric sample breaks. Then carry out a test with one load/unload cycle and determine the potential energy of the knitted fabric for different yarn count. Smooth tubular knitted fabrics for fine women's socks made of polyamide microfilament yarns with a nominal yarn count of 20, 33, 40 and 60 tex were used for the test. Knitted fabric samples are cut in the row direction and in the walle direction. Tests were performed on fabric samples that were fixed in two parallel clamps that were placed in a tensile tester. The knitted fabric samples are first exposed to an axial force acting in the row direction and in the walle direction until they break, and then the knitted fabric samples are exposed to one loading/unloading cycle until the relative elongation ε=200% in the row direction and ε=200% in the walle direction. The obtained results were used to calculate the potential energy and how the nominal yarn count affects the potential energy values for different directions of force action.

Keywords: *axial load; potential energy of deformations; knitted fabric; yarn count*

Izvorni znanstveni rad**

Potencijalna energija deformacije pletiva pri jednom ciklusu opterećenje / rasterećenje

Cilj ovog rada je analizirati dijagram sila/istezanje pletiva opterećenog u smjeru redova, a zatim u smjeru nizova očica i definirati zajedničku karakterističnu točku pri određenom istezanju do prekida uzorka pletiva. Zatim provesti ispitivanje s jednim ciklusom opterećenje/rasterećenje, te odrediti potencijalnu energiju pletiva za različite finoće pređe. Za provođenje ispitivanja korištena su glatka cjevasta pletiva za fine ženske čarape izrađena poliamidne mikrofilamentne pređe nazivne finoće 20, 33, 40 i 60 tex. Uzorci pletiva izrezani su u smjeru nizova i u smjeru redova. Ispitivanja su provedena na uzorcima pletiva koji su učvršćeni u dvije paralelne stezaljke koje su postavljene u dinamometar. Uzorci pletiva su najprije izloženi aksijalnoj sili koja djeluje u smjeru nizova i u smjeru redova očica do njihovog prekida, a zatim su uzorci pletiva izloženi jednom ciklusu opterećenje/rasterećenje do relativnog istezanja ε=200% u smjeru redova i ε=200% u smjeru nizova. Dobiveni rezultati korišteni su za računanje potencijalne energije i kako nazivna finoća pređe utječe na vrijednosti potencijalne energije za različite smjerove djelovanja sile.

Ključne riječi: *aksijalno opterećenje; potencijalna energija deformacija; pletivo; finoća pređe*

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1. Introduction

Knitted fabrics are flat textile products made up of loop courses and loop wales. The loop is the basic unit of knitted fabric. The yarns are interlooped into a wavy shape and create loops and then interlaced with another yarn, whereby half loops are formed first, and then loops are formed by interlooping the following yarns. One of the most significant properties of knitted fabrics for clothing is its elasticity, both in the direction of courses and wales. Elastic knitted fabrics find numerous applications in the industry of compression socks, sports and recreational clothing, swimwear, ballet clothing, etc. The physical and mechanical properties of knitted fabrics determine the extent of their final use in different needs. Therefore, it is essential to have a better understanding of the parameters that influence the behavior of these materials [1-3]. Knitted fabrics are elastic orthotropic materials which, in terms of structural characteristics, are defined as orthotropic plates with two mutually perpendicular planes of elastic symmetry. Their cross-sections are the main axes. The x-axis is in the direction of the course, and the y-axis is in the direction of the wale [4,5]. Measuring the elongation of knitted fabrics under the action of a tensile force in the direction of wales and courses is the most wide-spread procedure for testing and analyzing the physical and mechanical properties of knitted fabrics [6-8]. Consecutive loading-unloading of knitted fabrics, i.e. the cyclic loading of the knitted fabric affects the size of the elastic area in which the permanent deformation completely disappears. Cyclic measurements are used to analyze the behavior of knitted fabrics in use. If the knitted fabric is successively loaded and unloaded, the force-elongation diagram will have the shape of a loop [9,10]. This phenomenon of lagging deformations according to stress is called elastic hysteresis. The area of the hysteresis loop represents the energy spent on permanent deformations during one load cycle. When repeating the cycle, the area of the loop slowly increases until a break occurs.

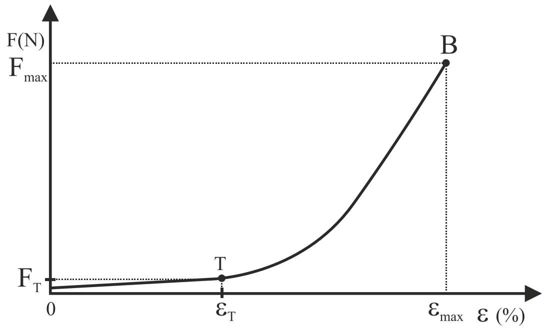
The aim of this paper is to determine the potential energy of knitted fabric for different yarn count during one loading/unloading cycle. For this purpose, tests were carried out on knitted fabric samples of different yarn count loaded in the direction of the courses, and then in the direction of the wales of loops for elongation. The force/elongation diagram of the knitted fabrics was analyzed, and a common characteristic point was defined at a certain elongation until the breaking of the knitted fabric sample.

2. Knitted fabrics potential energy of deformations

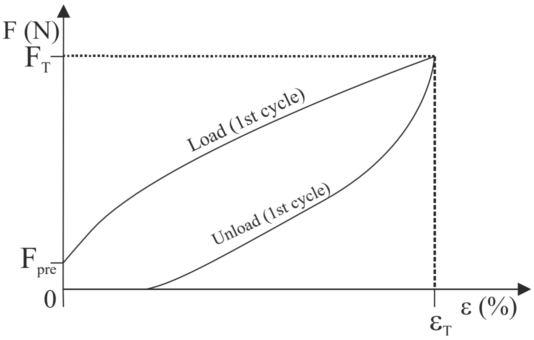
When tensile force F is applied, normal stress and its elongation occur in the knitted fabric. In Fig.1a the curve of the relationship between the tensile force and the relative elongation of the knitted fabric is presented [11,12]. Point T represents an arbitrarily chosen common characteristic point at a certain elongation of the knitted fabric. In order to observe the behavior of the knitted fabric in use and to analyze the phenomenon of hysteresis and the energy consumed by the knitted fabric, it is necessary to cyclically load the knitted fabric [13].

The knitted fabric sample is fixed in a tensile tester consisting of two clamps. The upper clamp is fixed, i.e. there is a force measuring probe on it. The bottom clamp is automatically moved down and up by a motor. In this way, motion is realized for a certain number of cycles, causing stresses in the knitted fabric. First, during the dynamic test, the lower clamp of the tensile tester is moved until it reaches elongation at a predetermined preload [14]. Then the sample is loaded-unloaded once between two defined elongation points (0-εT), Fig.1b.

With this deformation of the knitted fabric sample, changes in temperature and kinetic energy of the knitted fabric sample are insignificant, so they can be ignored, so that the total work W is completely



a.



b.

Fig.1 a) dependence diagram between the force *F* and the relative elongation of the knitted fabric ε, b) load-unload curve for cyclic load transformed into potential deformation energy U (the ability to produce mechanical work). Thus, potential deformation energy accumulates in the knitted fabric sample.

3. Experimental part

The experiments included the elongation to break of smooth tubular knitted fabric samples under static load. During this test, the values of the tensile forces and the corresponding elongations until break were determined. For this purpose, classical methods and instruments for testing the tensile properties of knitted fabrics were applied [15-17]. Dynamic tests of knitted fabric samples, cyclic loading and unloading of knitted fabrics were also carried out. The load-elongation diagrams for the cyclic testing of knitted fabrics were obtained.

The experiment was carried out by measuring the elongation of the knitted fabric samples under static and dynamic loading in the course and the wale direction of the knitted fabrics. The purpose of the conducted experiment is to determine the influence of nominal yarn count on potential energy values for different directions of force action during one cycle of dynamic load action. Polyamide microfilament yarns of yarn count 20, 33, 40 and 60 tex were used to make smooth tubular knitted fabrics. The properties of the mentioned knitted are shown in Tab.1.

The measuring method and procedure used to test the thickness of the knitted fabrics is defined by the ISO 5084:1996 *Textiles — Determination of thickness of textiles and textile products*. DIN EN 14971:2006 *Textiles - Knitted fabrics - Determination of number of stitches per unit length and unit area* was used to determine the number of courses and wales of loops per unit length. Standards that were also used to determine knitted fabrics parameters: ASTM D8007-15(2019) *Standard Test Method for Wale and Course Count of Weft Knitted Fabrics* was used to determine the wale and course counts of weft knitted fabrics per unit of length and ISO 3801:1977 *Textiles — Woven fabrics — Determination of mass per unit length and mass per unit area* for determination of mass per unit area. Before testing all samples were conditioned to standard atmosphere (relative air humidity 65 ± 2%, at a temperature of 20 ± 2°C). Samples of dimension 200 x 50 mm were cut, clamped in the clamps of the device at a distance of 100 mm. Five measurements were carried out for each knitted fabric sample. The tensile properties of all knitted fabric samples were tested according to ISO 13934-1:2013 *Textiles — Tensile properties of fabrics, Part 1: Determination of maximum force and elongation at maximum force using the strip method* using the Statimat M tensile tester (Textechno). After the selected point T (ε_T=200%) was determined for all the knitted fabric samples, the cyclic loading of the knitted fabric samples for elongation up to the predetermined point T was started. The dynamic tests of the knitted fabric samples were carried out according to the DIN 53835-2:2024-05 *Testing of textiles - Testing of the tenso-elastic behaviour - Part 2: Single and plied elastomeric yarns, repeated application of tensile load between constant extension limits* for determination of the elastic behavior of single and plied elastomeric yarns by repeated application of tensile load between constant extension limits.

4. Results and discussion

Diagrams (F-ε) of mean values of the test results of tensile force F and corresponding elongation ε on knitted fabric samples when the force acts in the course direction and in the wale, direction are shown in Fig.2 and Fig.3. The related mean values of breaking force, elongation at break and potential energy at break during static testing are given in Tab.2. As the yarn count increases, the knitted fabric sample becomes coarser, and a higher value of tensile force is required under static load to break the sample in both the course direction and the wale direction.

Tab.1 Structural properties of knitted fabrics

Label	Raw material composition	D_h (number of loops in course (cm^{-1}))	D_v (number of loops in wale (cm^{-1}))	Yarn count (tex)	Weight (g/m^2)	Thickness (mm)
P20	Polyamide	17.0	37.6	20	37	0.31
P33	Polyamide	18.0	32.0	33	51	0.34
P40	Polyamide	16.7	31.2	40	54	0.35
P60	Polyamide	17.2	34.2	60	92	0.43

Tab.2 Mean values of breaking force, breaking elongation and potential energy at break under static load

	Wale				Course			
	P20	P33	P40	P60	P20	P33	P40	P60
Elongation (%)	330.2	270.4	240.8	275.1	310.6	291.2	251.4	265.1
Breaking force (N)	41.5	96.9	87.1	154.7	81.4	69.2	83.3	172.2
Work to break (N·cm)	97.6	272.2	156.2	646.9	319.2	314.7	328.4	867.9

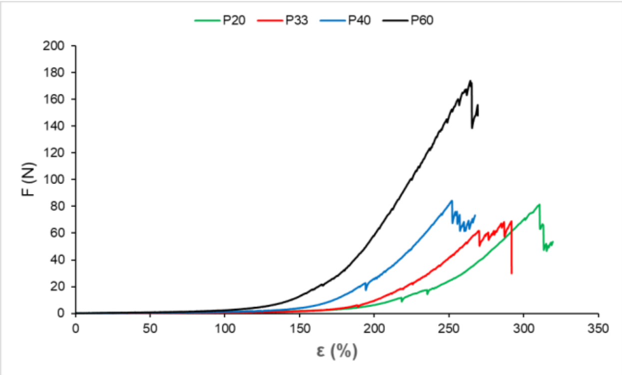


Fig.2 Diagram force – elongation (F-ε) in course direction

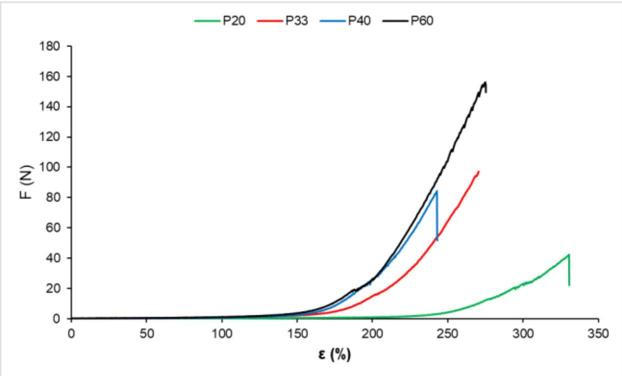


Fig.3 Diagram force – elongation (F-ε) in wale direction

The highest value of breaking force, breaking elongation and potential energy at break has the knitted fabric in the wale direction and in the course direction with the highest yarn count. All samples were loaded with tensile force up to the selected value of relative elongation ε_T=200% (point T). After loading to the selected elongation, the samples were unloaded. Diagrams of the results of cyclic loading and unloading of knitted fabric up to point T are shown in Fig.4 and Fig.5.

The potential energy U_1 is equal to the work W_1 that needs to be spent to elongate the fabric for a certain elongation ε, the potential energy U_2 is equal to the work W_2 that was spent to relieve the fabric sample, ΔU=ΔW is the energy spent on permanent deformations during one load cycle and relief of knitted fabric sample. The values are shown in Tab.3. For knitted fabric samples with a higher number of yarn count (both for the course direction and for wale direction of loops), it is necessary to spend more energy during one dynamic loading/unloading cycle

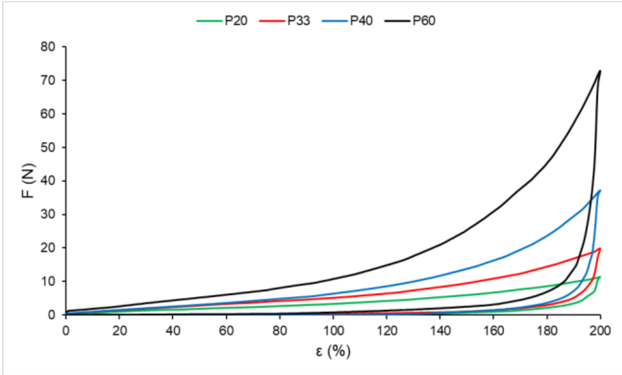


Fig.4 Diagrams of the results of cyclic loading and unloading of knitted fabrics samples up to point T in the course direction

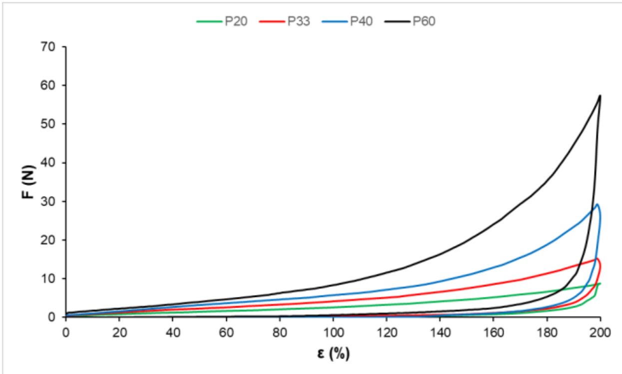


Fig.5 Diagrams of the results of cyclic loading and unloading of knitted fabrics samples up to point T in the wale direction

up to the predetermined elongation value. The potential energy values in the wale direction in relation to the yarn count of the knitted fabric is shown in Fig.6, and in the wale direction in Fig.7. This relationship is linear both in the course direction and in the wale direction.

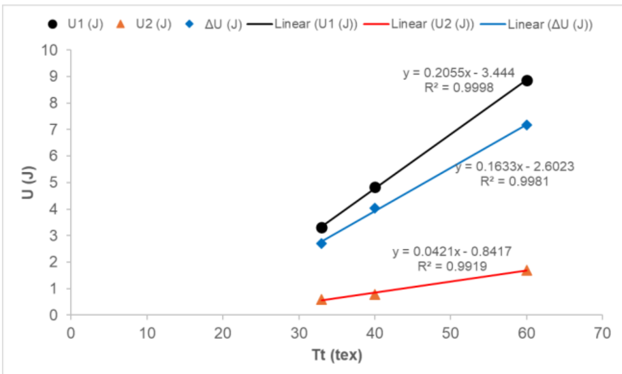


Fig.6 Potential energy values in the course direction in relation to the yarn count of the knitted fabric

Tab.3 Values at Ɛ = 200%: Tt, U_1, U_2, ΔU

	Wale			Course		
Tt (tex)	U_1 (J)	U_2 (J)	ΔU (J)	U_1 (J)	U_2 (J)	ΔU (J)
20	2.064	0.388	1.676	1.613	0.305	1.308
33	3.299	0.592	2.707	2.618	0.430	2.188
40	4.825	0.784	4.041	4.004	0.523	3.481
60	8.871	1.701	7.170	6.921	1.277	5.644

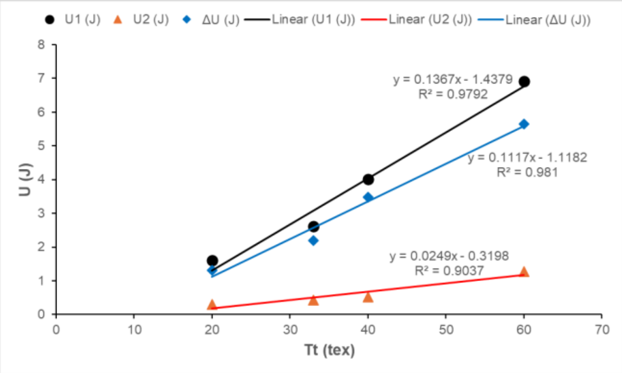


Fig.7 Potential energy values in the wale direction in relation to the yarn count of the knitted fabric

With an increase in the yarn count of the knitted fabric, the value of the consumed potential energy increases linearly when the sample is loaded and when the sample is unloaded. Also, with the increase in the yarn count of the knitted fabric, the area of the hysteresis loop (ΔU) which represents the residual energy in one cycle of cyclic loading-unloading of the sample increases linearly. For the course direction, the correlation coefficient for ΔU is R^2=0.9981, and for the wale direction R^2=0.981, which shows a very high correlation between the yarn count and the spent potential energy.

5. Conclusion

In the static testing of knitted fabrics, an increase in the yarn count causes an increase in the value of the breaking force of the sample when the tensile force acts in the course direction and in the wale direction. When unloading a pre-loaded tensile knitted fabric sample, the part of the diagram corresponding to the unloading does not have to be a straight line, and neither does the part of the diagram corresponding to the reloading.

When stretching the knitted fabric sample, when the force acts in the wale direction and in the course direction, the work, that is, the potential energy that needs to be spent on elongation the sample is the smallest for the samples with the smallest number of yarn count, and the highest for the knitted fabric samples with the highest number of yarn count. The potential energy expended in unloading the knitted fabric samples is also the lowest for the samples with the lowest yarn count.

With an increase in the force acting on the sample, more work must be spent to elongate the sample and to relieve it. The loading and unloading curves are further apart, i.e. the energy spent ΔU on permanent deformations during one cycle increases. ΔU is greater when the force acts in the course direction, than in the wale direction. When the force acts in the course direction and in the wale direction, the highest ΔU has a knitted fabric sample with the highest yarn count. The results of the cyclic tests showed that the yarn count of the knitted fabric samples significantly affects the value of the consumed potential energy and the hysteresis area.

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