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Parametri zbitega levo-desnega pletiva (1. del): moduli zanke in Mundenove konstante – stanje raziskav

Pregledni znanstveni članek

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Parameters of Compact Single Weft Knitted Structure (Part 1): Loop Modules and Munden Constants – State of research

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Izvleček

Različni avtorji so eksperimentalno preverjali veljavnost geometrijskih modelov zanke ter analizirali strukturne parametre pletiva in module zanke. Nekateri avtorji so, podobno kot avtorji geometrijskih modelov zanke, opisno in/ali matematično ločili ohlapno, normalno (idealno) in zbito strukturo pletiva. Preskušali so pletivo iz konvencionalnih prej brez elastanskega jedra. Podan je pregled parametrov pletiva ter analizirano stanje raziskav na področju zbitosti/poroznosti levo-desne pletene strukture.

Ključne besede: pletenje, pletena struktura, moduli zanke, Mundenove konstante, faktor kritja

Abstract

Various authors have experimentally examined the validity of geometrical loop models and analysed the structural parameters of the knitted structure and loop modules. Similar to the authors of geometrical loop models, some researchers have described and/or mathematically defined the open, normal (ideal) and compact knitted structure. They mainly examined knitted fabrics made from conventional yarns without the elastane core. The review of the knitted structure parameters is given and the state of research of the single structure porosity/compactness is analysed.

Keywords: knitting, knitted structure, loop modules, Munden constants, cover factor

1 Uvod

Različni avtorji [1–22] so eksperimentalno preverjali veljavnost geometrijskih modelov zanke ter analizirali strukturne parametre pletiva in module zanke. Preskušanje pletiv iz prej različne surovinske sestave, pletenih pod različnimi procesnimi pogoji in relaksiranih na različne načine, se je izrazilo v širokih mejah eksperimentalnih vrednosti posameznih strukturnih parametrov pletiva in modulov zanke. Nekateri avtorji so, podobno kot avtorji geometrijskih modelov zanke, opisno in/ali matematično ločili ohlapno, normalno (idealno) in zbito strukturo pletiva. Večinoma so preskušali pletivo iz konvencionalnih prej brez elastanskega jedra.

1 Introduction

Various authors [1–22] have experimentally examined the validity of geometrical loop models and analysed the structural parameters of the knitted structure and loop modules. The examination of knitted fabrics made from yarns of different material composition knitted under different process conditions and re-

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laxed with different methods resulted in a wide range of values of individual structural parameters and loop modules. Similar to the authors of geometrical loop models, some researchers have described and/or mathematically defined an open, normal (ideal) and compact knitted structure. They mainly examined knitted fabrics made from conventional yarns without the elastane core.

2 Knitted fabric parameters

Knitted fabric parameters describe the knitted structure on the basis of geometrical loop models. A comparison of the calculated values of investigated fabric parameters and theoretical values of ideal knitted fabrics enables the compactness/porosity evaluation of the knitted structure. The calculated values of parameters also enable the evaluation of anticipated performance properties of knitted fabrics.

The density coefficient is defined by the ratio of the horizontal and the vertical density of the knitted fabric [23]. We have (Equation 1), where are: C – density coefficient of knitted fabric, D_h *– horizontal density of knitted fabric (cm*$^{-1}$*),* D_v *– vertical density of knitted fabric (cm*$^{-1}$*), A – loop width (mm), B – loop height (mm).*

Munden [5] defined the loop shape factor $K_4 = D_v / D_h$*.* K_4 *is inversely proportional to the density coefficient C defined by Dalidovič [23], therefore* $K_4 = 1 / C$*.*

The density coefficient, paradoxically, does not directly describe the porosity/compactness of the knitted structure. It only defines the ratio between the loop width and loop height, or the ratio between the horizontal and vertical density of the knitted structure. A lower density coefficient along with the equal horizontal density indicates a more compact knitted structure in the vertical direction. With the increased couliering depth and the unchanged loop width, the loop length increases while simultaneously, the vertical density of the knitted structure decreases. The loop shape and the ratio between the loop width and the loop height (the density coefficient) change.

The density coefficient of basic single knitted fabrics is usually C = 0.7–0.9, depending on the fabric structure. According to Dalidovič, the

2 Parametri pletiva

Parametri pletiva na osnovi geometrijskih modelov zanke opisujejo strukturo pletiva. Primerjava izračunanih vrednosti parametrov preiskovanih pletiv s teoretičnimi vrednostmi parametrov idealnih pletiv omogoča ocenjevanje zbitosti/poroznosti pletene strukture. Izračunane vrednosti parametrov pletiv tudi omogočajo ocenjevanje pričakovanih uporabnih lastnosti pletiv.

Koeficient gostote pletiva je razmerje med horizontalno in vertikalno gostoto pletiva [23]. Velja:

$$C = \frac{D_h}{D_v} = \frac{B}{A} \quad (1),$$

kjer je: C – koeficient gostote pletiva, D_h – horizontalna gostota pletiva (cm^{-1}), D_v – vertikalna gostota pletiva (cm^{-1}), A – širina zanke (mm), B – višina zanke (mm).

Munden [5] je definiral faktor oblike zanke $K_4 = D_v / D_h$. K_4 je obratno sorazmeren koeficientu gostote C, ki ga je definiral Dalidovič [23], torej je $K_4 = 1 / C$.

Koeficient gostote, paradoksalno, ne opisuje neposredno poroznosti/zbitosti pletiva, temveč le razmerje med širino in višino zanke oz. med horizontalno in vertikalno gostoto pletiva. Manjši koeficient gostote pri enaki horizontalni gostoti pomeni večjo zbitost pletiva v vertikalni smeri. Pri povečani globini kuliranja in nespremenjeni širini zanke se poveča dolžina zanke, hkrati pa se zmanjša vertikalna gostota pletiva. Spremeni se oblika zanke ter razmerje med širino in višino zanke, tj. koeficient gostote pletiva.

Koeficient gostote za enostavno levo-desno pletivo je običajno, glede na strukturo, C = 0,7 – 0,9. Teoretični koeficient gostote za idealno enostavno levo-desno pletivo normalne strukture je po Dalidoviču C = 0,865 [23].

Faktor kritja je za votkovna levo-desna pletiva kot funkcijo dolžine zanke in metrske številke preje definiral Munden [24]. Z uzakonjeno uporabo merskih enot tex je faktor kritja pletiva funkcija dolžinske mase preje in dolžine zanke. Velja:

$$K = \frac{\sqrt{T_t}}{\ell} \quad (2),$$

kjer je: K – faktor kritja pletiva (tex$^{1/2}$mm^{-1}), T_t – dolžinska masa preje (tex), ℓ – dolžina zanke (mm).

Priporočljiv faktor kritja enostavnega levo-desnega pletiva je K = 1,4 ± 10 % (tex$^{1/2}$mm^{-1}) [18]. Večji faktor kritja opisuje bolj zbito strukturo pletiva.

Širinski faktor vpletanja niti opisuje razmerje med dolžino zapletene niti v eni zančni vrsti ter dolžino zančne vrste oz. razmerje med dolžino in širino zanke [25, 26, 27, 17]. Velja:

$$V_s = \frac{L}{n \cdot A} = \frac{n \cdot \ell}{n \cdot A} = \frac{\ell}{A} \quad (3),$$

kjer je: v_s – širinski faktor vpletanja niti, L – dolžina niti v zančni *theoretical density coefficient of the ideal basic single knitted structure is C = 0.865 [23].*

The cover factor of the weft single knitted structure was defined by Munden [24] as a function of the loop length and yarn count. As the use of tex units was enacted, the cover factor has been the function of the yarn linear density and loop length. It holds (Equation 2), where are: K – knitted fabric cover factor ($tex^{1/2}mm^{-1}$), T_t – yarn linear density (tex), ℓ – loop length (mm).

The recommended cover factor of the basic single knitted fabrics is K = 1.4 ±10% ($tex^{1/2}mm^{-1}$) [18]. A higher cover factor describes a more compact knitted structure.

The width interlacing factor describes the ratio between the length of the interlaced yarn within the course and course length, or the ratio between the loop length and loop width [25, 26, 27, 17]. It holds (Equation 3), where are: v_s – width interlacing factor, L – length of the interlaced yarn within a course (mm), n – number of the wales (loops) within a course, ℓ – loop length (mm), A – loop width (mm).

The length interlacing factor describes the ratio between the loop length and the loop height [27]. It holds (Equation 4), where are: v_d – length interlacing factor, ℓ – loop length (mm), B – loop height (mm).

The width loop module is the ratio between the loop width and yarn thickness. It shows to which extent the loop is filled with yarn in the width direction, i.e. the widthwise compactness of the loop [25]. The width loop module is an inverse value of the width α_K, defined by Korlinski [27].

We have (Equation 5), where are: α – width loop module, A – loop width (mm), d_{pr} – yarn thickness (mm).

The height loop module is the ratio between the loop height and yarn thickness. It shows to which extent the loop is filled with yarn in the height direction, i.e. the lengthwise compactness of the loop [25]. It holds (Equation 6), where are: β – height loop module, B – loop height (mm), d_{pr} – yarn thickness (mm).

The linear loop module is the ratio between the loop length and yarn thickness [23, 28]. We have (Equation 7), where are: δ – linear loop module, ℓ – loop length (mm), d_{pr} – yarn thickness (mm).

vrsti (mm), *n* – število zančnih stolpcev (zank) v zančni vrsti, ℓ – dolžina zanke (mm), *A* – širina zanke (mm).

Dolžinski faktor vpletanja niti opisuje razmerje med dolžino in višino zanke [27]. Velja:

$$V_d = \frac{\ell}{B} \qquad (4),$$

kjer je: v_d – dolžinski faktor vpletanja niti, ℓ – dolžina zanke (mm), *B* – višina zanke (mm).

Širinski modul zanke je razmerje med širino zanke in debelino preje in kaže, kako je zanka po širini izpolnjena s prejo, tj. prečno zbitost zanke [25]. Širinski modul zanke je nasprotna vrednost širinskega koeficienta zanke α_K, ki ga je definiral Korlinski (27). Velja:

$$\alpha = \frac{A}{d_{pr}} \qquad (5),$$

kjer je: *α* – širinski modul zanke, *A* – širina zanke (mm), d_{pr} – debelina preje (mm).

Višinski modul zanke je razmerje med višino zanke in debelino preje in kaže, kako je zanka po višini izpolnjena s prejo, tj. vzdolžno zbitost zanke [25]. Velja:

$$\beta = \frac{B}{d_{pr}} \qquad (6),$$

kjer je: *β* – višinski modul zanke, *A* – širina zanke (mm), d_{pr} – debelina preje (mm).

Dolžinski modul zanke je razmerje med dolžino zanke in debelino preje [23, 28]. Velja:

$$\delta = \frac{\ell}{d_{pr}} \qquad (7),$$

kjer je: *δ* – dolžinski modul zanke, ℓ – dolžina zanke (mm), d_{pr} – debelina preje (mm).

Večji dolžinski modul pomeni ohlapnejšo, manjši pa bolj zbito strukturo. Za pletiva za različne namene se dolžinski moduli zanke razlikujejo in znašajo *δ* = 18–50 [25, 17]. Razmerje med dolžino zanke in premerom preje ℓ / d_{pr}, tj. dolžinski modul zanke, so nekateri avtorji [8, 29–33] imenovali faktor kritja pletiva, preden in po tem, ko je pojem faktorja kritja $K = T_t^{1/2} / \ell$ definiral Munden [24]. Grosberg [34] je zbitost strukture opisal s parametrom d_{pr} / ℓ, tj. z nasprotno vrednostjo dolžinskega modula zanke *δ*; parameter d_{pr} / ℓ je imenoval nominalni faktor kritja pletiva. Oba parametra, dolžinski modul zanke *δ* in pravi faktor kritja pletiva *K*, opisujeta polnost/poroznost pletiva; faktor kritja pletiva *K* pri tem upošteva tudi surovinsko sestavo preje, dolžinski modul zanke *δ* pa ne.

Ploščinski modul zanke je razmerje med površino zanke in površino niti, ki oblikuje zanko [23]. Opisuje zapolnjenost površine zan-

A higher value of the linear loop module describes a more open structure, while a lower value describes a more compact structure. The loop modules of knitted structures designed for different end-uses differ and their values are δ = 18–50 [25, 17].

Before and after the cover factor $K = T_t^{1/2} / \ell$ was defined by Munden [24], the ratio between the loop length and yarn thickness, i.e. the linear loop module, was called cover factor by some authors [8, 29–33]. Grosberg [34] described the compactness of the knitted structure with the parameter d_{pr} / ℓ, i.e. with the inverse value of the linear loop module δ. The parameter d_{pr} / ℓ was denoted the nominal cover factor. Both parameters, the linear loop module δ and the genuine cover factor K, describe the compactness/openness of the knitted structure. The genuine cover factor K also takes into consideration the material composition of the yarn, while the linear loop module δ does not.

The area loop module is defined by the ratio between the loop area and the area of yarn forming the loop [23]. It describes the filling of the loop area with yarn. A higher value of the area loop module describes a more open structure. It holds (Equation 8), where are: δ_p – area loop module, A – loop width (mm), B – loop height (mm), ℓ – loop length (mm), d_{pr} – yarn thickness (mm).

The volume loop module is the ratio between the loop volume and the volume of yarn forming the knitted loop within the fabric [23]. It describes the voluminosity of the knitted structure. A higher value of the volume loop module indicates a more open knitted structure. We have (Equation 9), where are: δ_v – volume loop module, A – loop width (mm), B – loop height (mm), d_{pl} – knitted fabric thickness (mm), ℓ – loop length (mm), d_{pr} – yarn thickness (mm).

The Munden constants [5] define the interdependence of individual basic knitted fabric parameters and knitted loop parameters. They describe the ratio between the knitted structure density (uniaxial, area) and the loop length. The Munden constants are defined as (Equations 10–14), where are: D – knitted fabric area density, D_v – knitted fabric vertical density, D_h – knitted fabric horizontal density, ℓ – loop length, and K_1, K_2, K_3, K_4 – Munden constants.

ke s prejo. Večji ploščinski modul zanke opisuje ohlapnejšo strukturo. Velja:

$$\delta_v = \frac{A \cdot B}{d_{pr} \cdot \ell} \quad (8),$$

kjer je: δ_p – ploščinski modul zanke, A – širina zanke (mm), B – višina zanke (mm), ℓ – dolžina zanke (mm), d_{pr} – debelina preje (mm).

Prostorninski modul zanke je razmerje med prostornino zanke in prostornino niti, ki oblikuje zanko v pletivu [23]. Opisuje voluminoznost pletiva. Večji prostorninski modul zanke opisuje ohlapnejšo strukturo. Velja:

$$\delta_v = \frac{4 \cdot A \cdot B \cdot d_{pl}}{\pi \cdot d_{pr}^2 \cdot \ell} \quad (9),$$

kjer je: δ_v – prostorninski modul zanke, A – širina zanke (mm), B – višina zanke (mm),
d_{pl} – debelina pletiva (mm), ℓ – dolžina zanke (mm), d_{pr} – debelina preje (mm).

Mundenove konstante [5] definirajo odvisnost posameznih temeljnih parametrov pletiva in zanke. Opisujejo razmerje med gostoto pletiva (enosmerno, ploskovno) in dolžino zanke. Mundenove konstante so definirane:

$$D = \frac{K_1}{\ell^2} \quad (10),$$

$$D_v = \frac{K_2}{\ell} \quad (11),$$

$$D_h = \frac{K_3}{\ell} \quad (12),$$

$$K_1 = K_2 \cdot K_2 \quad (13),$$

$$\frac{D_v}{D_h} = \frac{K_2}{K_3} = K_4 \quad (14),$$

kjer so: D – ploskovna gostota pletiva, D_v – vertikalna gostota pletiva, D_h – horizontalna gostota pletiva, ℓ – dolžina zanke in K_1, K_2, K_3, K_4 – Mundenove konstante.

3 Raziskave

Tompkins [1] je med prvimi matematično zapisal medsebojno odvisnost parametrov pletiva in zanke. Tompkinsov zakon definira, da je produkt vertikalne in horizontalne gostote pletiva pri dani dolžini zanke konstanta, torej če je ℓ = konst., je $D = D_v \cdot D_h = konst.$ Debelina enostavnega levo-desnega pletiva je enaka dvakratni debelini preje, torej $d_{pl} = 2d_{pr}$.

3 State of research

Tompkins [1] was one of the first researchers who mathematically defined the interdependence of the knitted fabric parameters and loop parameters. The Tompkins's law defines that with the noted loop length, the product of the vertical and horizontal density of the knitted fabric is a constant, therefore if ℓ = const., $D = D_v \cdot D_h$ = const. The thickness of the basic single weft knitted fabric equals the double yarn thickness, i.e. $d_{pl} = 2d_{pr}$.

Doyle [2] defined the open and the compact knitted structure descriptively and graphically, yet not mathematically. On the basis of extensive experimental work, he established that the area density of the dry relaxed knitted fabric is exclusively a function of the loop length, and that it depends neither on the yarn type and yarn structure nor on the knitting process. It holds: $D = 19.3 / \ell^2$.

That means that even before Munden [5], Doyle defined the value of the constant $K_1 = 19.3$ valid for the real knitted fabrics, which are mainly of normal or approximately normal structure.

On the basis of the loop geometrical proportions derived from Tompkins's law [1] and Peirce's loop model [4], Shinn [3] defined the linear loop module equal to Peirce's: $\delta = 16.66$. The ratio between the vertical and horizontal density of the knitted fabric which was later defined as the loop shape factor by Munden [5] was found $K_4 = 1.15$. With his experimental work, Shinn established a good correlation between the practically measured and theoretically defined loop shape factor K_4. Shinn's research was based on Peirce's planar loop model [4]; the lengthwise and widthwise joints of the needle and sinker arcs indicated that only the normal knitted structure was anticipated. Simultaneously, the value of the constant $K_4 = 1.15$ signifies the value of the density coefficient $C = 0.87$ ($K_4 = 1 / C$), which corresponds to the value of C, defined for the normal knitted structure by Dalidovič [6].

Nutting [7] determined the structural parameters of knitted fabrics in the process of relaxation based on Doyle's [2] and Munden's [5] conclusions. He analysed woollen single weft structures with different knitted fabric densities,

Doyle [2] je ohlapno in zbito strukturo opredelil opisno in slikovno, ne pa tudi matematično. Na podlagi obširnega eksperimentalnega dela je ugotovil, da je ploskovna gostota suho relaksiranega pletiva izključno funkcija dolžine zanke in ni odvisna od vrste in strukture preje, niti od postopka pletenja. Velja: $D = 19,3 / \ell^2$.

To pomeni, da je Doyle že pred Mundenom [5] določil vrednost konstante $K_1 = 19,3$, ki velja za realno pletivo, večinoma normalne oz. približno normalne strukture.

Shinn [3] je na podlagi geometrijskih razmerij zanke, izpeljanih iz Tompkinsovega zakona [1] in Peirceovega modela zanke [4], določil, da je dolžinski modul zanke enak Peirceovemu: $\delta = 16,66$. Razmerje med vertikalno in horizontalno gostoto, ki ga je pozneje Munden [5] definiral kot faktor oblike zanke, je $K_4 = 1,15$. Z eksperimentalnim delom je ugotovil dobro korelacijo med praktično izmerjenimi in teoretično določenim faktorjem oblike zanke K_4. Shinnove raziskave so se opirale na ploskovni Pierceov model zanke [4]; vzdolžno in prečno stikanje igelnih in platinskih lokov je pomenilo predvidevanje izključno normalne strukture pletiva. Hkrati vrednost $K_4 = 1,15$ pomeni vrednost koeficienta gostote $C = 0,87$ *($K_4 = 1 / C$)*, ta pa ustreza vrednosti *C*, ki jo je za pletivo normalne strukture podal Dalidovič [6].

Nutting [7] je na podlagi sklepov Doyla [2] in Mundena [5] ugotavljal strukturne parametre pletiv v procesu relaksacije. Analiziral je volnena votkovna levo-desna pletiva različnih gostot, tj. napletena iz prej različne dolžinske mase. Preiskovana pletiva so bila različno suho in mokro relaksirana. Ugotovil je, da se Mundenova konstanta K_1 za preskušana mokro relaksirana pletiva zbite do ohlapne strukture odlično ujema z vrednostjo, ki jo je za mokro relaksirano volneno pletivo eksperimentalno določil Munden [5], $K_1 = 21,6$. K_1 za pletiva, ki so bila poleg mokre relaksacije tudi toplotno obdelana v vodi oz. pari, je za vse strukture, od zbite do ohlapne, $K_1 = 22,5–24,4$.

Fletcher in Roberts [8] sta po petih ciklih pranja merila strukturne parametre neobdelanih in pozneje obdelanih volnenih pletiv, pletenih iz prej različne dolžinske mase in z različno dolžino zanke. Dolžinski modul zanke $\delta = \ell / d_{pr}$ za preiskovana pletiva (preračunan iz podanih rezultatov d_{pr} / ℓ) se je v odvisnosti od uporabljene dolžinske mase preje in napletene dolžine zanke gibal v mejah $\delta = 9,64–22,32$. Faktor kritja $K = T_t^{1/2} / \ell$, preračunan iz podanih rezultatov $K = 1 / \ell N^{1/2}$, se je gibal v mejah $K = 1,01–2,19$ $tex^{1/2} \cdot mm^{-1}$. Fletcher in Roberts sta torej preiskovala pletiva zbite do ohlapne strukture. Iz rezultatov njunih preiskav je videti, da se pletivo z večjim dolžinskim modulom zanke, tj. ohlapnejše pletivo, pri relaksaciji po petih pranjih bolj krči. Skupno ploščinsko krčenje narašča z zmanjšanjem razmerja vertikalne in horizontalne gostote K_4.

Hurley [9] se je ukvarjal z dimenzijsko stabilnostjo votkovnega levo-desnega pletiva iz predivnih prej, spredenih iz različnih vrst poliakrilonitrilnih vlaken. Preskušana pletiva so bila napletena z dvema globinama kuliranja; bila so surova in naknadno obdelana ter suho in mokro relaksirana po različnih postopkih. V svojem eks-

i.e. fabrics made from various yarns with different linear densities. The investigated knitted fabrics were dry and wet relaxed with various processes. He established that the Munden constant K_1 for the investigated wet relaxed knitted fabrics with a compact to open structure corresponds perfectly to the value, defined for the wet relaxed woollen knitted structure by Munden [5], K_1 = 21.6. K_1 for the knitted fabrics which were wet relaxed and additionally heat-treated in water or steam was K_1 = 22.5–24.4 for all structures, from compact to open.

Fletcher and Roberts [8] measured after five cycles of laundering the structural parameters of greige and after-treated woollen knitted fabrics made from yarns of different linear density and different loop length. For the investigated knitted fabrics, the linear loop module $\delta = \ell / d_{pr}$ (calculated from the given results of d_{pr} / ℓ) was found in the range δ = 9.64–22.32, depending on the yarn linear density and loop length. The cover factor $K = T_t^{1/2} / \ell$ calculated from the given results by $K = 1 / \ell N^{1/2}$ was in the range K = 1.01–2.19 $tex^{1/2}mm^{-1}$. Thus, Fletcher and Roberts investigated knitted fabrics from a compact to open structure. From their results, it is evident that the knitted fabric with a higher value of the linear loop module, i.e. more open structure, exhibits higher relaxation shrinkage after five laundering cycles. The total surface shrinkage increases with the decrease in the ratio between the vertical and horizontal density, i.e. constant K_4.

Hurley [9] studied the dimensional stability of single weft knitted fabrics made from yarns spun from different types of polyacrylonitrile fibres. The investigated fabrics were knitted with two couliering depths. They were greige or after-treated, and dry or wet relaxed in various processes, respectively. In his experimental work, Hurley analysed the knitted structure by measuring the horizontal and vertical density, and calculating the loop shape factor, i.e. Munden constant K_4 [9]. From the research results, it can be seen that in most cases, K_4 for the dry and wet relaxed polyacrylonitrile single weft knitted fabric differs significantly from the theoretical value K_4 = 1.3 [5]. The most evident deviation of the measured values from the theoretical values of K_4 can be seen with the after-treated wet

perimentalnem delu je analiziral strukturo pletiva z merjenjem horizontalne in vertikalne gostote ter izračunavanjem faktorja oblike zanke oz. Mundenove konstante K_4 [5]. Iz rezultatov njegovih preiskav je videti, da K_4 za suho in mokro relaksirano poliakrilonitrilno votkovno levo-desno pletivo v večini primerov pomembno odstopa od teoretične vrednosti K_4 = 1,3 [5]. Največje odstopanje izmerjenih vrednosti K_4 od teoretičnih je pri naknadno obdelanih mokro in suho relaksiranih pletivih, kjer je v vseh primerih, razen enega, K_4 < 1,0. S toplotnim utrjevanjem dimenzij pletiva se odstopanje K_4 po suhi in mokri relaksaciji zmanjša. Ravnotežna oblika zanke je funkcija toplotne zgodovine poliakrilonitrilnega pletiva.

Hurley in Duby [10] sta v nadaljnjih raziskavah dimenzijske stabilnosti poliakrilonitrilnega pletiva iz voluminozne preje ugotovila, da je ravnotežna vrednost faktorja oblike zanke K_4 = 1,3 [5] dosežena le pri pletivu, pletenem z najmanjšo globino kuliranja, tj. vertikalno najbolj zbitem pletivu.

Knapton et al. [11] je preiskoval volnena votkovna levo-desna pletiva iz prej različnih dolžinskih mas, pletenih z različno dolžino zanke, tj. pletiv z različnim faktorjem kritja. Ugotovil je, da za pletiva v popolnoma relaksiranem stanju velja Mundenova konstanta K_1 = 23,1 ± 1,0. Faktor oblike zanke je neodvisen od faktorja kritja in je v popolnoma relaksiranem stanju konstanta: K_4 = 1,30 ± 0,05. Z naraščanjem dolžine zanke se zmanjša debelina suho in mokro relaksiranega pletiva. Debelina popolnoma relaksiranega pletiva je odvisna od debeline preje in neodvisna od dolžine zanke. Definirati je mogoče konstanto K_5 – Knaptonovo konstanto, ki določa debelino pletiva d_{pl} v odvisnosti od debeline preje d_{pr}. Velja $d_{pl} = d_{pr} \cdot K_5$, pri čemer je K_5 v mejah K_5 = 4,8–6,8.

Hepworth in Leaf [12, 13] sta v svojem mehanskem modelu zanke, ki predvideva, da je preja nestisljiva in da v zanki ni trenja, definirala, da je struktura pletiva vzdolžno zbita, če je dolžinski modul zanke δ < 32.

Shanahan in Postle [14] sta teoretično analizirala nastanek zbite strukture pletiva. V ohlapni strukturi pletiva se preje dotikajo le v točkah prepleta, v zbitih strukturah pa se stikajo tudi na drugih mestih. Pletivo je zbito, kadar je minimalna razdalja med osema prepletajočih se prej manjša od premera (debeline preje), kar pomeni, da je preja stisnjena. Shanahan in Postle [14] sta v svoji analizi ločila prečno in vzdolžno zbito strukturo pletiva. Prečna zbitost pletiva nastopi, ko se stikajo platinski oz. igelni loki dveh sosednjih zank ene zančne vrste. Vzdolžna zbitost pletiva nastopi, ko se stikajo igelni loki ene zančne vrste in platinski loki naslednje zančne vrste. Shanahan in Postle [14] sta s teoretično analizo ugotovila, da ima pletivo prečno normalno ali ohlapno strukturo, če je dolžinski modul zanke 17 < δ < 21. Prečno zbita struktura nastopi pri vrednosti δ < 16. Mejni dolžinski modul zanke, pri katerem nastopi vzdolžna zbitost strukture, je odvisen od kota prepleta ε, definiranega v mehanskem modelu zanke [15]. Vzdolžna zbitost pletiva nastane pri dolžinskem modulu zanke δ < 16,4, če je $sin\varepsilon$ = 0,055, in pri dolžinskem modulu zanke δ < 18,4, če je $sin\varepsilon$ = 0,050.

and dry relaxed knitted fabrics where the loop shape factor was $K_4 < 1.0$ in all cases but one. With heat-setting of knitted fabric dimensions, the deviation of the K_4 values after the dry and wet relaxation decreases. The equilibrium loop shape is the function of thermal history of the polyacrylonitrile knitted fabric.

In their further investigations of dimensional stability of polyacrylonitrile fabrics made from voluminous yarns, Hurley and Duby [10] established that the equilibrium value of the loop shape factor $K_4 = 1.3$ [5] can only be attained in the case of the structure knitted with the smallest couliering depth, i.e. in the case of the most vertically compact structure.

Knapton et al [11] investigated woollen single weft knitted fabrics made from yarns of various linear densities and knitted with various loop lengths, i.e. knitted fabrics with various cover factors. They found out that for the knitted fabrics in a fully relaxed state, the Munden constant is $K_1 = 23.1 \pm 1.0$. The loop shape factor is independent of the cover factor. In a fully relaxed state, it is a constant: $K_4 = 1.30 \pm 0.05$. With the loop length increase, the thickness of the dry and wet relaxed knitted fabric decreases. The thickness of the fully relaxed knitted fabric depends on yarn thickness and is independent of the loop length. The constant K_5 can be defined as that it indicates the fabric thickness d_{pl} dependence on the yarn thickness d_{pr}. It holds that $d_{pl} = d_{pr} \cdot K_5$, where K_5 values are in the range of $K_5 = 4.8–6.8$.

In their mechanical loop model, which presumes that yarn is incompressible and that there is no friction within the loop, Hepworth and Leaf [12, 13] defined that the knitted structure is lengthwise compact if the length loop module is $\delta < 32$.

Shanahan and Postle [14] theoretically analysed the origin of the compact knitted structure. In an open structure, the yarns join only at interlacing points, while in compact structures, they also join at other points. The knitted fabric is compact when the minimum distance between the axes of the interlacing yarns is smaller than the yarn diameter (yarn thickness), which means that the yarn is compressed. In their analysis, Shanahan and Postle [14] distinguished between a width- and

Lasić, Vrljičak in Srdjak [16] so raziskovali vpliv strukture preje in procesnih parametrov pletenja na stukturne parametre pletiva. Preskušali so bombažno in poliakrilonitrilno pletivo iz prej različne dolžinske mase, pleteno z enako globino kuliranja. Rezultati raziskave so pokazali, da je bil koeficient gostote za preskušana pletiva $C = 0{,}677–1{,}07$. Dolžinski modul zanke za preskušana pletiva je bil $\delta = 14{,}9–30{,}8$, površinski $\delta_p = 0{,}79–1{,}58$, prostorninski pa $\delta_v = 3{,}43–5{,}11$. Širinski faktor vpletanja niti je bil $v_s = 3{,}67–4{,}55$, razmerje med debelino pletiva in debelino preje pa $d_{pl} / d_{pr} = K_5 = 2{,}33–3{,}78$. Vzorci s površinskim modulom zanke $\delta_p < 1$ so imeli zelo zbito strukturo.

Srdjak in Čuk [17] sta ohlapnost oz. zbitost pletene strukture definirala s poroznostjo pletiva. Njuna definicija je dvoplastna: poleg poroznosti strukture pletiva upošteva tudi poroznost preje in vlaken. Primarna poroznost pletiva je določena z velikostjo medprostorov v množici med seboj povezanih zank, nastalih s prepletanjem. Sekundarna poroznost pletiva je določena s poroznostjo surovine, iz katere je izdelana pletena struktura; nanjo vplivata struktura in gladkost površine preje. Velikost medprostorov v preji je odvisna od dolžinske mase, debeline in vitja preje.

Srdjak in Čuk sta v svojem eksperimentalnem delu [17] ugotovila, da je poroznost pletiva bistveno odvisna od horizontalne in vertikalne gostote pletiva. Povečana globina kuliranja povečuje poroznost. Različne debeline preje pri enaki globini kuliranja pomembno vplivajo na poroznost. Z relaksacijo se pri vseh preiskovanih vzorcih povečujeta horizontalna in vertikalna gostota, kar vodi k zmanjševanju poroznosti pletiva.

Bešker, Srdjak in Vrljičak [18] so ugotavljali odvisnost strukturnih parametrov levo-desnega pletiva od dolžine zanke ter njihov vpliv na uporabne lastnosti pletiva. V svojem delu so primerjali teoretično izračunane in ekperimentalno dobljene parametre zanke in pletiva ter ugotovili, da je izdelava pletiva željene strukture in lastnosti na vsakem stroju zahteven proces. Rezultati njihovega eksperimentalnega dela kažejo, da globina kuliranja ne vpliva bistveno na horizontalno gostoto pletiva. Z zmanjšanjem globine kuliranja se zmanjša dolžina zanke, poveča se vertikalna gostota pletiva, zmanjša se koeficient gostote ter poveča ploščinska masa.

Lasić [19] je raziskoval medsebojno odvisnost strukturnih parametrov desno-desnega pletiva: debeline pletiva, horizontalne in vertikalne gostote pletiva, koeficienta gostote pletiva, ploščinske mase ter dolžinskega, ploščinskega in prostorninskega modula zanke od faktorja kritja pletiva. Ugotovil je, da so strukturni parametri pletiva in moduli zanke pomembno odvisni od faktorja kritja pletiva.

Quayanor, Takahashi in Nakajima [20] so raziskovali strukturne parametre, površinsko trenje in hrapavost svilenega, bombažnega in poliestrskega votkovnega levo-desnega pletiva, pletenega z dvema različnima gostotama. Faktor kritja preiskovanih vzorcev pletiv je bil $K = 0{,}996–1{,}606$ tex$^{1/2}$mm^{-1}, koeficient gostote pletiva pa, glede na podatke o horizontalni in vertikalni gostoti pletiva, $C =$

lengthwise compact knitted structure. The widthwise compactness occurs when the sinker or the needle arcs of the two adjacent loops of the same knitting course are in contact. The lengthwise compactness occurs when the needle arc of one knitting course and the sinker arcs of the next knitting course are in contact. By theoretical analysis, Shanahan and Postle [14] established that the knitted structure is widthwise normal or open if the linear loop module is 17 < δ < 21. The widthwise compact structure occurs at the value δ < 16. The limit value of the linear loop module by which the lengthwise compactness of the structure occurs depends on the interlacing angle ε defined by the mechanical loop model [15]. The lengthwise compactness occurs with the value of the linear loop module δ < 16.4 if sinε = 0.055, and with the value of the linear loop module δ < 18.4 if sinε = 0.050.

Lasić and Vrljičak and Srdjak [16] investigated the impact of the yarn structure and the knitting process parameters on the structural parameters of knitted fabrics. They examined cotton and polyacrylonitrile knitted fabrics made from yarns of various linear densities and knitted with the same couliering depth. The results of the research indicated that the density coefficient of the examined knitted fabrics was C = 0.677–1.07. The linear loop module for the examined knitted fabrics was δ = 14.9–30.8 while the area loop module was δ_p *= 0.79–1.58 and the volume loop module was* δ_v *= 3.43–5.11. The width interlacing factor was* v_s *= 3.67–4.55 and the ratio between the knitted fabric thickness and yarn thickness was* $d_{pl} / d_{pr} = K_5$ *= 2.33–3.78. The structure of the samples exhibiting the area loop module* δ_p *< 1 was very compact.*

Srdjak and Čuk [17] defined the openness and compactness of the knitted structure by its porosity. Their definition is two-step: apart from the knitted structure porosity it also considers the porosity of the yarn and fibres. The primary porosity of the knitted structure is defined by the size of the interspace in the set of loops connected by interlacing. The secondary porosity of the knitted structure is defined by the porosity of the raw material from which the knitted structure is made. It is influenced by the struc-

0,47–0,67. Rezultati raziskav kažejo, da se je po desetih pranjih vzdolžno najbolj krčilo svileno pletivo, ki je imelo najmanjši faktor kritja. Poliestrsko pletivo je kazalo negativno krčenje.

4 Sklepi

Različni avtorji so na podlagi študija teoretičnih geometrijskih modelov zanke in eksperimentalnih raziskav dejanskih pletiv definirali podobne vrednosti parametrov pletiva, ki opisujejo zbitost/poroznost pletene strukture.

Preiskovano je bilo večinoma volneno, poliakrilonitrilno ter bombažno, pa tudi svileno, viskozno in poliestrsko pletivo. V zadnjih desetletjih se je obširneje preiskovalo raztezno pletivo z vpletenimi (platiranimi) elastanskimi nitmi.

Zbitost/poroznost strukture je bila najpogosteje ocenjevana na podlagi vrednosti dolžinskega modula zanke, Mundenovih konstant, faktorja oblike zanke oz. koeficienta gostote pletiva ter faktorja kritja pletiva. Redkeje je bila ocenjevana na podlagi izračunanih vrednosti ploščinskega in prostorninskega modula zanke. Ocenjevanja horizontalne in vertikalne zbitosti realnega pletiva na podlagi širinskega in višinskega modula zanke ter širinskega in višinskega faktorja vpletanja niti v znanstveni literaturi ni zaslediti.

5 Viri

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ture and smoothness of the yarn surface. The size of interspaces within the yarn depends on the yarn linear density, yarn thickness and yarn twist.

In their experimental work, Srdjak and Čuk [17] established that the porosity of the knitted structure is significantly dependent on the horizontal and vertical density of the knitted structure. The increased couliering depth increases the structure porosity. With the same couliering depth, various yarn thicknesses significantly influence the structure porosity. The horizontal and vertical density of the knitted structure increase with relaxation, which leads to a decrease in the structure porosity.

Bešker and Srdjak and Vrljičak [18] studied the dependence of structural parameters of the single weft knitted structure on the loop length and their influence on performance properties of knitted fabrics. In their research, they compared the theoretically calculated and experimentally measured values of the loop and knitted structural parameters. They established that the production of the knitted fabric with the desired structure and properties on any knitting machine is a very complex process. The results of their experimental work show that the couliering depth does not significantly influence the horizontal density of the structure. With the couliering depth decrease, the loop length decreases, the vertical density of the structure increases, the density coefficient decreases and the knitted fabric mass per unit area increases.

Lasić [19] investigated the interdependence of the structural parameters of double weft knitted fabrics, i.e. fabric thickness, horizontal and vertical density, density coefficient, mass per unit area, linear loop module, area lop module, volume loop module and cover factor. He established that the structural parameters of knitted fabrics and loop modules depend on the cover factor.

Quayanor and Takahashi and Nakajima [20] studied structural parameters, surface friction and the roughness of the silk, cotton and polyester single weft knitted structure, knitted in two different densities. The cover factor of the investigated samples was $K = 0.996–1.606$ $tex^{1/2}mm^{-1}$*, and according to the horizontal and vertical density, the density coefficient of the in-*

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vestigated structure was C = 0.47–0.67. The results of the investigation showed that after ten cycles of laundering, the silk knitted fabric with the smallest cover factor exhibited the biggest lengthwise shrinkage. The polyester knitted fabric exhibited a negative shrinkage.

4 Conclusions

On the basis of the studies of theoretical geometrical loop models and the experimental research of real knitted fabrics, various authors have defined similar values of knitted structure parameters describing compactness/porosity of the knitted structure.

Mainly the woollen, acrylic and cotton, as well as silk, viscose and polyester knitted fabrics have been investigated. During the last decades, elasticised knitted structures with interlaced (plated) elastane threads have been investigated extensively.

The compactness/porosity of the knitted structure was most frequently evaluated on the basis of the length module, Munden constants, loop shape factor or density coefficient respectively, and cover factor value. Rarely, it was evaluated on the basis of the surface and volume loop module values. There is no trace in the scientific literature of the horizontal and the vertical compactness of the real fabric evaluation on the basis of the width and height loop module, and the width and length interlacing factor.

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