Original Scientific Paper
UDK 687.254.8 : 677.074.16 : 677.1/.5
DOI: 10.46793/NovelTDS16.153T

COMPRESSIBLE PROPERTIES OF MEN'S SOCKS MADE FROM DIFFERENT FIBERS IN PLAIN JERSEY

Predrag Tasić[1,*] ID, Dušan Trajković[2] ID, Nenad Ćirković[2] ID, Jelka Geršak[3] ID
[1]V.I."Vunil", d.o.o., Leskovac, Serbia
[2]University of Nis, Faculty of Technology in Leskovac, Serbia
[3]University of Maribor, Faculty of Mechanical Engineering, Slovenia

This paper examines the most important compressible properties of socks made from different fibers in a plain jersey. These properties indirectly affect the parameters of thermo-physiological comfort of socks during wear. Three yarns were used in the sock composition; the first, a dominant yarn made from six different fibers, makes up 77%. The other two yarns are made from nylon and wrapped elastic threads, accounting for 23%. The most compressible sock is made from cotton yarn, with the modal yarn sock model being very close in performance. The highest linearity of compression, compression energy, and compression resistance are found in socks made from bamboo and modal yarns, with viscose yarn socks not falling far behind. Bamboo yarn socks exhibit weaker elastic recovery compared to socks made from cotton-compact yarn, which have better elastic characteristics. Out of the six combinations of raw material compositions for socks and the examination of several compression properties, sock models in plain jersey can be selected for specific purposes, such as medical, home, or outdoor use.

Keywords: men's socks, plain jersey, fibers, compressibility.

INTRODUCTION

Compressibility is a property of a material that describes its ability to change volume under the influence of pressure. In physics and engineering, compressibility is quantitatively expressed as the relative change in the material's volume per unit change in pressure [1].
Understanding the compressibility of materials is crucial for accurately modeling and predicting their behavior under different pressure conditions, which is essential in the design and analysis of engineering systems [2].

* Author address: Predrag Tasić, V.I."Vunil", d.o.o., Viljema Pušmana 19, 16000, Leskovac, Serbia
e-mail address: tasic.predrag1970@gmail.com

The compressibility of textiles refers to the ability of textile materials to reduce their volume under the influence of external pressure and return to their original state once the pressure is removed. Compressibility depends on several factors that determine how the textile will behave under pressure: the type of fibers, the weave or knit structure, material density, thickness, treatments and finishes, elasticity, and others [3, 4].

The compressibility of socks refers to the ability of the material from which the socks are made to compress or adjust under pressure. This property is crucial for the functionality of certain types of socks, particularly compression socks, which play a medical and preventive role [5].

Socks made from elastic fibers, such as spandex, elastane, and nylon, have a greater compression capability. The combination of these materials allows for even expansion and return to their original shape, which is crucial for the proper application of pressure. Thinner socks generally have lower compressibility and provide lighter pressure. Thicker materials offer stronger compression but may be less comfortable to wear over longer periods [6].

Quality socks have high resistance to permanent deformation, meaning they return to their original shape and retain their properties over time. Medical socks have high compressibility and precisely defined pressure levels to provide a therapeutic effect. Sports socks focus on muscle support and reducing fatigue, with slightly lower compressibility. Fashion socks usually have a lower degree of compressibility as they are primarily aesthetic [7].

This paper explores the most important compressible properties of men’s socks in plain jersey made from different yarns to determine which raw material composition of socks is best suited to providing adequate comfort during wear.

MATERIALS AND METHODS

For the research and production of men's short socks, yarns made from fibers such as bamboo, modal, viscose, cotton, cotton-compact, and a cotton/PES blend, 60/40%, (77% dominant yarn) from the company Bimtex (Serbia), polyamide yarn (22% participation), and rubber thread (1% participation) from the company Dunav Grocka (Serbia) were used. Based on the given knitting parameters, all socks were knitted at the local company Nikoplet in Leskovac. The socks were made in plain jersey in size 11 (42-43).

The examination of sock characteristics was conducted according to the relevant standards and methods:

- Thickness, according to the EN ISO 5084 standard.
- Surface mass, according to the EN 12127 standard.
- Volumetric mass was calculated based on the research paper [8].
- Porosity was calculated based on the research paper [9].
- The compressibility properties of knitted fabrics under low loads were tested on the KES-FB system (Kato Technical Co. Ltd., Japan). The testing conditions for the compressive characteristics of the knitted fabrics involved lateral compression of a 2 cm^2 surface tube at a speed of 50 $s \cdot mm^{-1}$ within a compression range of 0.5 $cN \cdot cm^{-2}$ to 50 $cN \cdot cm^{-2}$ [12, 13].

Table 1 presents the results of the structural parameters of size 11 socks in plain jersey. The thickness of the socks depends on the type of dominant yarn used. Since the socks are made from yarns with similar properties, significant differences in knitting thickness arise due to differences in the raw material composition. For socks in plain jersey, cotton and modal socks, as the dominant yarn, have the greatest thickness.
The surface mass of the socks varies depending on the type of dominant yarn in the structure. Socks knitted from bamboo-dominant yarn have the highest numerical value for surface mass. This parameter combines essential structural parameters and is an important economic factor [10].
The volumetric mass of the sock best reflects and defines the structural parameters of the sock, as it represents the mass of the knit of a certain volume, which is directly related to the thickness, type of knit, and surface mass of the knitted fabric. Volumetric mass generally follows the surface mass and is the highest in cases where the surface mass is also the highest [10].
Compactness - porosity of the knitted fabric represents the fill of the empty space between the loops or the empty space within the loop itself. Good porosity is a result of the structure of knitted products, as the yarn in the loops is arranged in a way that allows a large amount of air to be present between the loops [11]. Generally, socks made from cotton-dominant yarn have the highest percentage of porosity. Porosity depends on thickness, with thinner socks usually having lower porosity and vice versa.

Table 1. Key parameters of men's socks with different raw material compositions in plain jersey

Raw Material Composition of Socks	Thickness (mm)	Surface Mass ($g \cdot m^{-2}$)	Volumetric Mass ($g \cdot cm^{-3}$)	Porosity (%)
Bamboo (BB), 30 tex PA 6.6, 4.4/13×2 tex Wrapped Rubber Yarn, 100 tex	0.918	282.9	0.3082	79.7
Modal (MD), 30 tex PA 6.6, 4.4/13×2 tex Wrapped Rubber Yarn, 100 tex	0.928	279.1	0.3007	80.2
Viscose (CV), 30 tex PA 6.6, 4.4/13×2 tex Wrapped Rubber Yarn, 100 tex	0.911	281.4	0.3089	79.7
Cotton (CO), 30 tex PA 6.6, 4.4/13×2 tex Wrapped Rubber Yarn, 100 tex	0.949	274.9	0.3003	80.6
Cotton-compact (COc), 30 tex PA 6.6, 4.4/13×2 tex Wrapped Rubber Yarn, 100 tex	0.892	275.6	0.3202	79.3
Cotton/Polyester (CO/PES), 30 tex PA 6.6, 4.4/13×2 tex Wrapped Rubber Yarn, 100 tex	0.893	267.4	0.2995	79.8

The relationship between thickness and compressive load is expressed by the following equation [14]:

$$h = \frac{k}{\sqrt[3]{F_k}} \qquad (1)$$

where:
h – thickness of the knitted fabric (mm), k – proportionality constant,
F_k – compressive or surface force per unit area (cN).

The compressibility of knitted fabrics is calculated using the formula [14]:

$$C = \frac{h_o - h_m}{h_o} \cdot 100 \quad (2)$$

where:
h_o – knitted fabric thickness under compressive load of 0.49 cN·cm^{-2} (mm),
h_m – knitted fabric thickness under compressive load of 49.035 cN·cm^{-2} (mm).

The deformation work, Wc, represents the energy required for the compressive deformation of the knitted structure and is calculated using the formula [11]:

$$c = \int_{h_m}^{h_o} F_k \Delta h \quad (3)$$

where:
Wc – deformation or compressive work per unit area of 1 cm² of the sample (cN·cm),
F_k – compressive force per unit area (cN),
Δh – change in the thickness of the knitted structure (mm),
h_0 – thickness under compressive load of 0.49 cN·cm^{-2} (mm),
h_m – thickness under compressive load of 49.035 cN·cm^{-2} (mm).
3The linearity of the curve, LC, of compressive load and deformation F_k is calculated using the formula [15,16]:

$$LC = \frac{WC}{WOC} \quad (4)$$

where:
WOC – deformation work in the case of linear deformation (cN·cm),
WC (J·m^{-2}) - compression energy.

The relaxation ability, RC, expresses the ratio between reversible and deformation energy under compressive load, and is calculated using the formula [15,16]:

$$RC = \frac{WC'}{WC} 100 \quad (5)$$

where:
RC – relaxation ability (%),
WC′ – recoverable or reversible energy per unit area (cN·cm).

RESULTS AND DISCUSSION

The results presented in Table 2 provide various values of important compressibility parameters for socks made from different fiber compositions in plain jersey. The softest (most compressible) sock is made from cotton-dominant yarn, very close to the model of socks made from modal-dominant yarn (according to the results for parameter C). The parameter C (%), on the other hand, represents the percentage comparison of the initial thickness measurement with the measurement at maximum applied force; a higher value indicates greater compressibility (softness).
The socks made from bamboo and modal-dominant yarn exhibit the highest linearity of compression, compression energy, and resistance to compression. For the LC parameter, values closer to one indicate firmer (stiffer) compressibility, while lower values provide higher stretchability in the initial stage of stress, which enhances comfort

during wear. A higher value of the WC parameter corresponds to greater compressibility, meaning the textile product becomes softer and more comfortable. It should be noted that the resistance to compression, RC, represents the percentage of recovery or return to the original thickness once the compressive force is removed; a higher value indicates greater recovery from compression, or in other words, assesses the sponge-like behavior of the knit. The greater the stretchability of the knit, the better the quality in terms of the tactile feel of the knit, meaning a higher RC value results in greater comfort during wear, as well as a fuller and smoother sensation of the textile product.
Greater work or compression energy means a lower ability for elastic recovery of the socks. The highest work or compression energy of the „softest" cotton knit (C=41.78%) indicates that it exhibited the least ability for elastic recovery (RC=42.62%). In contrast, ithe lowest compressibility was observed in socks made from cotton-compact dominant yarn (C=35.16%), which is partly compensated by the highest elastic recovery (RC=47.36%).
When examining the sock models made from cotton and cotton-compact, it is noticeable that due to the lower fuzziness of the yarn in the cotton-compact sock model, the outer layers of the knit are poorer in fibers, which contributed to its lower compressibility. Specifically, compared to traditional cotton spinning, the production of cotton-compact yarn involves an additional phase in which protruding fibers are drawn into the yarn body with the help of air, resulting in a more compact structure of the cotton yarn, which is less fuzzy compared to the yarn produced through traditional spinning.
Plain jersey, regardless of the type of fibers in the dominant yarn, has a low LC value (Table 2), indicating a less linear compression characteristic of these socks. This implies that, due to the appropriate construction of the knit and the absence of surface fibers, the fibers in the inner layer of the knit tend to slide under the influence of compressive forces, which contributes to a reduction in the relative compressibility of the knit.
The elasticity of the fibers did not significantly affect the compression capability of the socks. Specifically, the less elastic fibers of the cotton-dominant yarn generally exhibit the highest compressibility in socks. The thickness of the socks under different pressures varies according to the raw material composition of the dominant yarn. The greatest thickness is found in socks made from cotton-dominant yarn at both pressure levels.

Table 2. Compression properties results of men's socks in plain jersey

Dominant yarn	C (%)	LC	WC ($J \cdot m^{-2}$)	RC (%)	Knitted fabric thickness ($\times 10^{-3}$ m)	Knitted fabric thickness ($\times 10^{-3}$ m)
BB	36.15	0.52	0.59	47.77	1.30	0.83
MD	40.29	0.46	0.61	40.81	1.39	0.83
CV	36.72	0.40	0.46	45.00	1.28	0.81
CO	41.78	0.39	0.56	42.62	1.46	0.85
COc	35.16	0.36	0.39	47.36	1.28	0.83
CO/PES	38.17	0.35	0.43	42.85	1.31	0.81

The surface properties of the yarn could also be involved or have an impact as a potential factor in the compression of the knitted fabric, although there is no absolute certainty.

Fibers protruding from the surface of the socks, along with a larger amount of air, form practically two outer layers that are quite susceptible to compression. In other words, it can be expected that the knitted fabric with more pronounced fuzziness on the surface will be softer, i.e., it will exhibit greater compressibility, which is confirmed in the case of the cotton-dominant yarn sock model. This establishes a direct link between the fuzziness of the yarn and the softness (compressibility) of the socks used in the models.
The compression curves, derived from recorded changes in the thickness of the knitted fabrics during loading and unloading, shown in Figures 1–3, provide a more detailed insight into the phenomenon of lateral compression. These curves show a nonlinear relationship between the change in knitted fabric thickness and the increase in compressive load, except in the initial phase of the compression cycle. In this part, at lower load values, the thickness of the knitted fabric changes linearly with the load, corresponding to elastic deformation. With further increase in compressive load, the compressibility of the socks decreases, which can be explained by their structure. The third phase of compression, in which there is minimal change in knitted fabric thickness with an increase in compressive load, involves the lateral compression of the fibers themselves. It has been determined that the parts of each region, as well as the slopes of the linear regions, vary depending on the knitted construction and the yarn structure of the socks.

Although the facilitated sliding and shifting of fibers during compression contribute to the compressibility of the material, which is important for the feeling of softness and comfort, it should be noted that these processes are partially irreversible. The hysteresis that occurs in knitted fabrics indicates the presence of permanent deformation during the compression of socks (Figures 1–3). Since the ability of the material to elastically recover is inversely proportional to the area of the hysteresis loop, a smaller hysteresis area indicates better elastic recovery of the socks.

The differences in the slope of the compression curves of the tested sock models confirm the assumptions about the impact of surface geometry and the fiber composition of the knitted fabrics. Although the results of compression tests at low loads indicated differences in the behavior of socks made from different dominant yarns, it was found that the surface properties of different yarns significantly affect the compression properties of socks, including both their compression capability and the material's elastic recovery ability.

In comparison of sock models in plain jersey with different fiber compositions (Figures 1–3), a similarity in the appearance of the compression and decompression curves can be observed. For example, in socks made from BB yarn as the dominant material, the thickness during compression varies from 1.4 mm, while during decompression, it decreases to 1.1 mm. In contrast, socks made from COc yarn have a thickness range from 1.25 mm to 1.05 mm. A greater difference between the starting and final points of the hysteresis loop results in a larger loop area. Since the elastic recovery ability of the knitted fabric is inversely proportional to the area of the hysteresis loop, socks made from BB yarn exhibit weaker elastic recovery compared to socks made from COc yarn, which show better elastic characteristics.

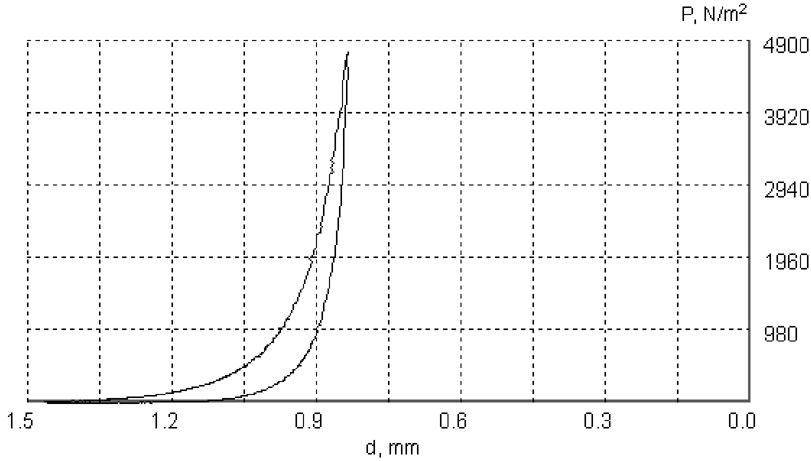

Figure 1. Pressure/Thickness diagram for bamboo men’s socks

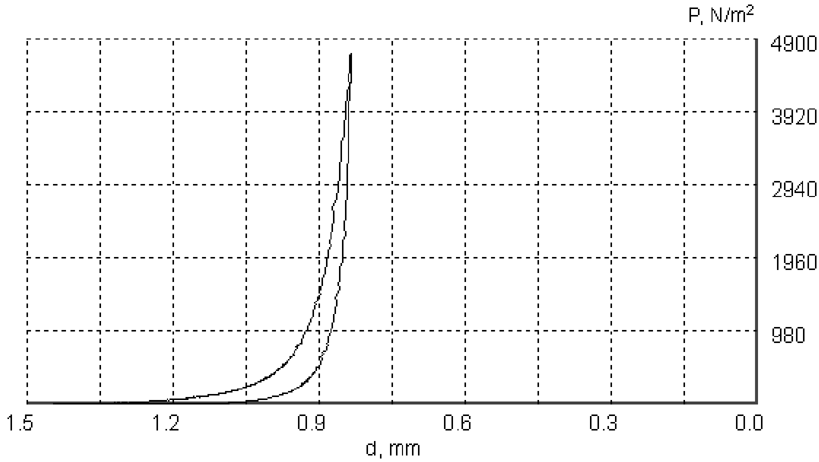

Figure 2. Pressure/Thickness diagram for cotton-compact men’s socks

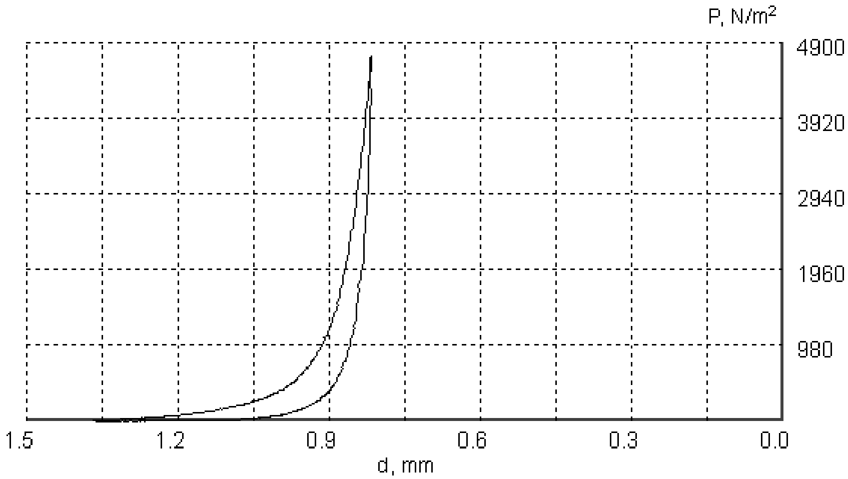

Figure 3. Pressure/Thickness diagram for CO/PES men's socks

CONCLUSION

This paper discusses the most important compressible properties of men's socks knitted in plain jersey, made from six different fibers in three yarns used .
The sensation a textile material leaves in contact with the skin can vary depending on various parameters, such as the physiological state of the body, climatic conditions, moisture content in the material, the surface area, or the intensity of the contact between the material and the skin. Testing the compressive behavior of the material under low loads provides an opportunity to assess functionality, feel, etc., in relation to comfort.
The most compressible sock is made from yarn with a cotton dominance, while the sock made from modal-dominant yarn is very similar in this property. Socks made from bamboo and modal-dominant yarns exhibit the greatest linearity of compression, as well as the highest energy and resistance to compression. Greater compression energy indicates a reduced ability for elastic recovery of the socks. The "softest" cotton socks have the weakest ability to return to their original shape. In contrast, socks made from cotton-compact dominant yarn, although the least compressible, compensate for this with the highest elastic recovery ability.
Based on six different combinations of fiber compositions and the analysis of several compressive properties, the most suitable material combination for plain-jersey socks was chosen, in accordance with their specific purpose: for recreation, medical needs, home use, or for outdoor wear.

Acknowledgement:

Project BG16RFPR002-1.014-0005-Competence Centre „Smart Mechatronic, Eco and Energy-Saving Systems and Technologies", Technical University-Gabrovo, Bulgaria.

The project was financed by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (ev.No. 451-03-137/2025-03/ 200133)

References

[1] Çengel YA, Boles MA, Kanoglu M. *Thermodynamics, An Engineering Approach*. McGraw-Hill, United Kindom, 2023.

[2] White F. *Fluid Mechanics*. McGraw Hill, United Kindom, 2015.

[3] Nawab Y. *Textile Engineering: An Introduction.* De Gruyter Textbook, Germany, 2016. https://doi.org/10.1515/9783110413267

[4] Muthu SS. *Textiles and Clothing Sustainability*. Springer Singapore, 2017. https://doi.org/10.1007/978-981-10-2131-2,

[5] Roshan S. *Textiles for Sportswear*. Woodhead Publishing, United Kingdom, 2015. https://doi.org/10.1016/C2013-0-16491-4

[6] Pan N, Sun G. *Functional Textiles for Improved Performance, Protection and Health.* Woodhead Publishing Series in Textiles, United Kingdom, 2011.

[7] Vink P. *Comfort and Design, Principles and Good Practice,* CRC Press, Boca Raton, 2004. https://doi.org/10.1201/9781420038132

[8] Elmogahzy Y. *Engineering Textiles: Integrating the Design and Manufacture of Textile Products.* Woodhead Publishing, United Kingdom, 2019.

[9] Khalila A, Eldeeb M, Těšinova P, Fouda A. *Theoretical Porosity of Elastic Single Jersey Knitted Fabric Based on 3D Geometrical Model of Stitch Overlapping,* Journal of Natural Fibers. 2023, 20, 1, 2181274. https://doi.org/10.1080/15440478.2023.2181274.

[10] Trajković DS, Tasić PS, Stepanović JM, Šarac TI, Radmanovac NM. *Physiological Characteristics of the Socks Made from Bamboo and Conventional Fibers*. Advanced technologies. 2014, 3(1) 59-65. https://doi.org/10.5937/savteh1401059T

[11] Asanovic KA, Kostic MM, Mihailovic TV, Cerovic DD. *Compression and strength behaviour of viscose/polypropylene nonwoven fabrics*. Indian Journal of Fibre & Textile Research. 2019, 44, 329-337.

[12] Stankovic SB, Bizjak M. *Effect of Yarn Folding on Comfort Properties of Hemp Knitted Fabrics*. Clothing and Textiles Research Journal. 2014, 32(3) 202-214. https://doi.org/10.1177/0887302X14537114

[13] Geršak J. *Objektivno vrednovanje plošnih tekstilija i odjeće*. Sveučilište u Zagrebu, Tekstilno-tehnološki fakultet, Zagreb, 2014.

[14] Stojanović S, Geršak J, Trajković D. *Compression properties of knitted fabrics printed by sublimation transfer printing technique*. Advanced technologies. 2021, 10(1) 46-53. https://doi.org/10.5937/savteh2101046S

[15] Murthyguru, *Novel Approach To Study Compression Properties In Textiles*. Autex Research Journal. 2005, 5(4) 176-193. https://doi.org/10.1515/aut-2005-050401

[16] Gurumurthy B.R. *Prediction of Fabric Compressive Properties Using Artificial Neural Networks.* Autex Research Journal. 2007, 7, 1, 19-31. https://doi.org/10.1515/aut-2007-070103

Izvod

KOMPRESIBILNA SVOJSTVA MUŠKIH ČARAPA OD RAZLIČITIH VLAKANA U GLAT PREPLETAJU

Predrag Tasić[1] ID, Dušan Trajković[2] ID, Nenad Ćirković[2] ID, Jelka Geršak[3] ID
[1] V.I.“Vunil“, d.o.o., Leskovac, Srbija
[2] Univerzitet u Nišu, Tehnološki fakultet, Leskovac, Srbija
[3] Univerzitet u Mariboru, Mašinski fakultet, Slovenija

U ovom radu razmatraju se najvažnija kompresibilna svojstva čarapa od različitih vlakana u glat prepletaju. Ova svojstva, posredno utiču na parametre termo-fiziološke udobnosti čarapa tokom nošenja. Korišćene su tri pređe u sastavu čarapa, prva, dominantna pređa izrađena od šest različitih vlakana čini 77%. Ostale dve pređe su od poliamida i obmotane gumene niti sa učešćem od 23%. Najkompresibilnija čarapa je izrađena od pamučne pređe, vrlo blizu je i model čarapa od modalne pređe. Najveću linearnost kompresije, energiju kompresije i otpornost na kompresiju imaju modeli čarapa od bambus i modalne pređe, ne zaostaje puno ni viskozna pređa. Čarape od bambus pređe pokazuju slabiji elastični oporavak u poređenju sa čarapama od pamuk-kompakt pređe, koje imaju bolje elastične karakteristike. Od šest kombinacija sirovinskog sastava za čarape i provere više kompresijskih svojstava, mogu se odabrati modeli čarapa u glat prepletaju za odgovarajuću namenu, na primer za medicinsku, kućnu ili izvan kućnu namenu.

Ključne reči: čarapa, glat prepletaj, vlakna, kompresibilnost.