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THERMOPHYSIOLOGICAL PROPERTIES OF KNITTED FABRICS FOR SPORTS UNDERWEAR

TERMOFIZIOLOŠKE KARAKTERISTIKE PLETENINA ZA IZRADU SPORTSKOG VEŠA

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- sports underwear
- activewear
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- heat and moisture management

Ključne reči
- pletenine
- sportski veš
- aktivni veš
- termofiziološka udobnost
- upravljanje toplotom i vlagom

Abstract

In this paper are examined and compared properties of four knitted fabrics for making sports underwear: knitwear of 100% polyester and mixture of polyester/cotton and cotton/elastane. The aim is choosing appropriate knitwear for making sports underwear, considering various climate conditions and consumer activity. The results show that the thermal-, water vapour- and air permeability properties, that affect the comfort of garment, depend on the type fiber used and structural parameters of knitwear. Knitwear in interlock pique interlacement of polyester and cotton mixture has properties suitable for warmer climates and moderate activities, whereas the knitwear of polyester in jacquard interlacement with the trap on each loop is suitable for intense activities in a warm climate, but for materials which are not in contact with the skin. Knitted polyester in jacquard interlacement with the trap on the second loop, according to its properties, is suitable for application in cold conditions, whereas the interlock knitwear raising on one side of mixture of cotton and elastane is not recommended for production of sports underwear. The results are important for the selection of appropriate knitted fabrics or their combinations in sports underwear manufacture to satisfy certain requirements of thermophysiological comfort.

Izvod

U radu su ispitivana i poređena svojstva četiri pletenine za izradu sportskog veša: pletenine od 100% poliestra i mešavine poliestar/pamuk i pamuk/elastan. Cilj rada bio je da se za izradu sportskog veša odabere adekvatna pletenina, imajući u vidu različite klimatske uslove i nivoe aktivnosti nosilaca. Rezultati su pokazali da termalna i svojstva propustljivosti vodene pare i vazduha, koja utiču na udobnost odevnog predmeta, zavise od tipa upotrebljenih vlakana i strukturnih parametara pletenine. Pletenina u interlok pike prepletaju od mešavine poliestra i pamuka poseduje svojstva koja su pogodna za izradu sportskog veša za toplije klimatske uslove i srednje aktivnosti, dok je pletenina od poliestra u žakard prepletaju sa zamkom na svakoj petlji pogodna za intenzivne aktivnosti u toploj klimi, ali za materijale koji nisu u kontaktu sa kožom. Pletenina od poliestra u žakard prepletaju sa zamkom na drugoj petlji, prema svojstvima koja poseduje, pogodna je za primene u hladnim uslovima, dok se interlok pletenina čupavljena sa jedne strane od mešavine pamuka i elastana ne preporučuje za izradu sportskog veša. Rezultati ovih istraživanja su od značaja za izbor adekvatnih pletenina ili njihovih kombinacija u izradi sportskog veša koji će zadovoljiti određene zahteve u pogledu termofiziološke udobnosti.

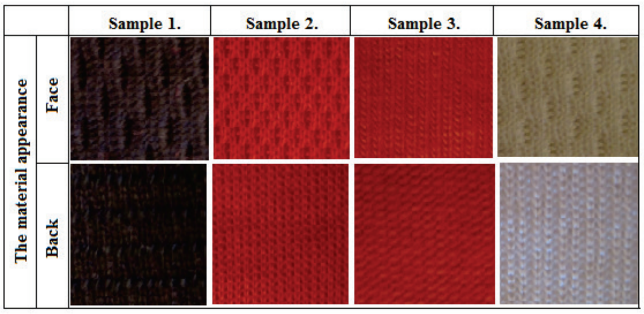
INTRODUCTION

Sports underwear should meet the needs of modern athletes. It should provide maximum comfort to the wearer during certain activities, so the choice of materials for its production is of special importance. For this purpose the latest achievements are used in the field of fibers performance, textile surfaces and manufacturing technology, /1-6/. The main advantage of sportswear made of textile materials of special properties is the simultaneous controlling of heat and humidity and breathability (ventilation). Humidity control involves regulating body temperature and preventing increase garment weight from sweating, /7/. In the sports underwear production there are also used combinations of materials with different properties in order to apply the right material for each zone of the human body. The used materials allow the heating and cooling of different body parts at different rates, which ensures optimal body climate. This paper examines the properties of four knitwear made of different materials and different interlacement, which are use for making sports underwear. They proposed their application for certain climatic conditions and levels of activity. In this paper the level 1 system is applied for the analysis of physiological properties of textiles and garments for comparing different characteristics of textile materials used in the manufacture of sports clothing, /8/.

EXPERIMENTAL PART

The experimental part is conducted at the CIS Institute (Belgrade, Serbia). Properties of four knitted fabrics (marked as samples 1-4) are examined and compared with different compositions and types of interlacement for sports underwear production, which are shown in Table 1.

Table 1. Examined textile materials (magnification 4×).



The tests includes the determination of:
- the composition of 4 knitted fabrics and linear density of the yarn from which they are made of,
- types of interlacement, thickness and mass per unit area of knitted fabrics,
- thermophysiological properties of knitted fabrics: air permeability, water vapour transmission, water repellency, waterproof-hydrostatic pressure test, resistance to water vapour (R_{et}) and thermal resistance (R_{ct}),
- dimensional change after washing at 40° C (shrinkage).

Applied methods for determinating physical and thermal properties of the tested materials are listed in Table 2 with the corresponding test property. For determining specific thermal properties of clothing there are tests in which the heated flat plates are used, /9/. At that, the quantity of water vapour absorbed by the sample of the material during one hour exposure on the skin model (standard wet flat plate) /8, 10, 11/ represents a measure of moisture transfer and is denoted by F_i (%), and it depends on material thickness.

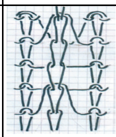
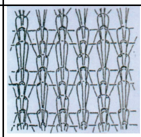
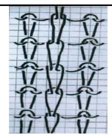
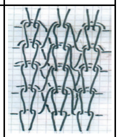
In order to allow comparison between textile materials, a water vapour permeability index, i_{mt}, is used which compares the thermal resistance ratio (R_{ct}) with resistance to water vapour (R_{et}) of the textile material, whose values range between 0 (impermeable material) and 1. F_i and i_{mt} are used to assess the physiological quality of textile material (high i_{mt} and F_i values are desirable), /8, 12/.

RESULTS AND DISCUSSION

Results of testing certain properties of four knitted fabrics are shown in Table 2. Sample 1 represents a 100% PES jacquard knitted fabric with a trap on another loop; sample 2 is a knitted fabric made of 92% PES and 8% cotton mixture in interlock pique interlacement; sample 3 is a interlock knitted fabric raising on one side, made of 91.5% cotton and 8.5% elastane mixture; and sample 4 is a 100% PES jacquard knitted fabric with a trap on each loop.

In order to be able to select appropriate materials for making sportswear for certain climatic conditions and levels of activity, their properties are compared. The thickness of the knitted fabric and mass per unit area depend on

Table 2. Test results.

Properties	Samples			
	1	2	3	4
Composition ISO 1833-1 /13/	100% PES	92% PES 8% Co	91.5% Co 8.5% El	100% PES
Linear density [tex] SRPS ISO 7211-5 /14/ SRPS F.S2.511 /15/	5.3×2	10×1	16.8×1	5×2
Interlacement SRPS F. C0.012 /16/	 Jacquard (trap on 2nd loop)	 Interlock pique	 Interlock twitched on one side	 Jacquard (trap on each loop)
Knitwear thickness [mm] ISO 5084 /17/	0.7	0.44	0.81	0.54
Mass per unit area [g/m^2] ISO 3801 /18/	134.4	135. 6	193.1	123.8
Puncture force [N] SRPS F.S2.022 /19/	444.7	626	435.2	329.5
Peeling resistance [grade], SRPS EN ISO 12945 -1 /20/	4	4-5	2	4
Air permeability [mm/s] ISO 9237/21/	1063.9	1.099.4	152.8	862.83
Water vapour transmission [g/m^2/24h] ASTM E-96 M /22/	4907.1	4088.5	3979.98	4432.3
Water repellency [grade] ISO 4920 (method C) /23/	0	0	0	0
Waterproof-hydrostatic pressure test (pressure gradient 60 cm H_2O/min.) [cm H_2O], ISO 811 /24/	0	0	25	0
Thermal resistance, R_{ct} [m^{2}K/W] ISO11092 /9/	0.3	0.007	0.04	0.003
Water vapour transmission, R_{et} [m^{2}Pa/W] ISO 11092 Amd:2012 /9/	1.17	0.1	1.78	0.1
Dimen. change after washing at 40 °C, [%] - per length - per width ISO 5077 /25/ SRPS EN ISO 3759 /26/	0 0	-0.8 -0.4	-4.2 -0.8	0 0
F_i [%] CEN/TR 16422 /12/	1.27	2.88	3.68	0
i_{mt}, ISO 11092 /9/	0.379	0.159	0.028	0.055

from steach density, so as is expected, sample 3 has the highest thickness and mass per unit area, considering the the type of interlacement and linear density of the yarn, i.e. linear density of the yarn, interlacement, and that it was raising on one side. According to the thickness, follow samples 1 and 4, and the smallest thickness has sample 2. The mass per unit area of these samples does not follow the thickness of the knitted fabric due to different voluminous, i.e. stitch densities, which is a result of various interlacement, so that samples 1 and 2 have approximately the same mass per unit area, from which the mass per unit area of the sample 4 slightly deviates (Fig. 1).

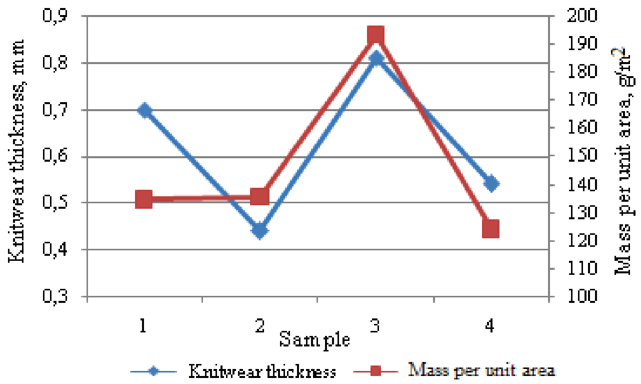


Figure 1. Knitted fabric thickness (mm) and mass per unit area (g/m^2).

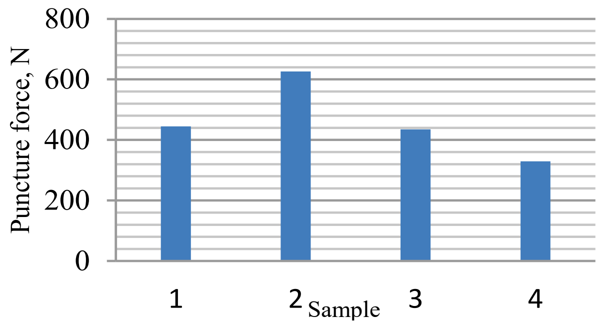


Figure 2. Puncture force [N] vs. interlacement type.

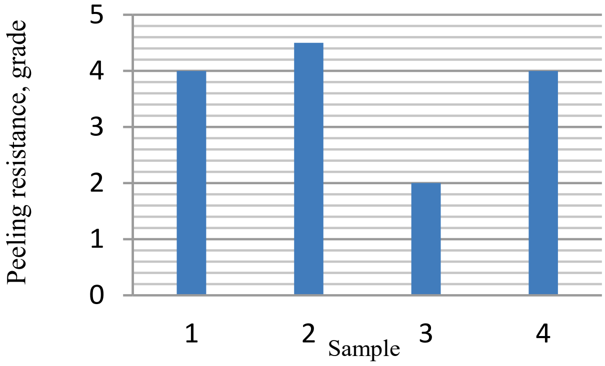


Figure 3. Peeling resistance [grade] vs. interlacement type.

The largest puncture force has knitted fabric (sample 2) with interlacement interlock pique (Fig. 2). The weakest puncture forces are obtained on sample 4, where the interlacement is jacquard (trap on every loop). Interlacement interlock-pique has the largest number of stitches per unit area which affects the high results of puncturing forces. Based on Fig. 3, it is concluded that during the procedure peeling process the largest changes occur on sample 3. The visual effect of the knitted fabrics after the peeling process on the sample 3 is rated by grade 2, which is very bad. The riping process has contributed in breaking the twisted fibers in the yarn, and afterwards the short fibers have propensity surface fuzzing on the knitted fabric. These fibers in the process of peeling have formed into pills. Samples 1 and 4 have a jacquard interlacement, and on the peeling process is a grading of 4. The best grade is on sample 2 which was produced in the interlock-pique interlacement.

The highest air permeability (Fig. 4) show samples 2 and 1, and the smallest on sample 3, which indicates a significant impact on the structure, thickness and number of stitch density, the air permeability, as well as fiber geometry. The lowest air permeability shows the thickest knitwear with the highest mass per unit area and the highest stitch density (interlock raising on one side).

A larger surface of the fibers and thicker knitwear of sample 1 cause lower air permeability than in the sample 2, whereas the stitch density and structure of sample 4 probably cause less air permeability compared to samples 1 and 2.

Sample 1 shows the highest water vapour transmission, Fig. 4, which is correlated with the fiber morphology and hydrophobicity of PES fibers. Slightly lower water vapour transmission of sample 4 is a consequence of knitwear characteristics: structure, thickness, and number of stitches. Sample 3 shows the lowest water vapour transmission which is in accordance with its thickness, mass per unit area and interlacing, as well as material composition - a high percentage of cotton, which swells due to the moisture absorption.

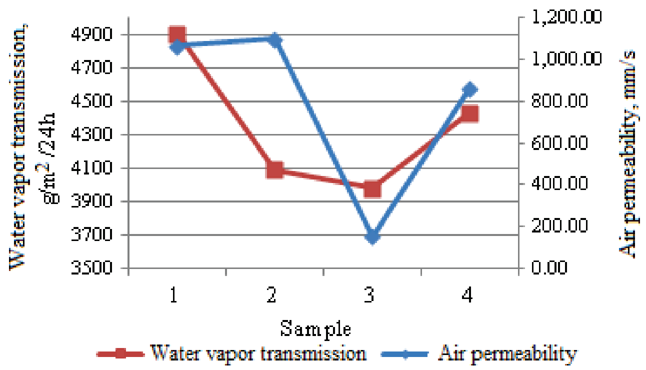


Figure 4. Air permeability and water vapour transmission.

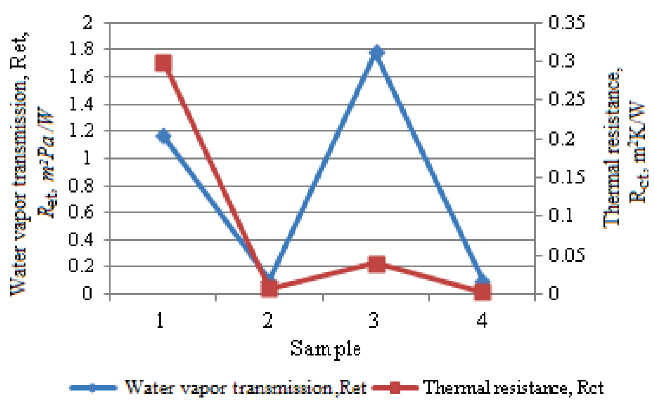


Figure 5. Resistance to water vapour and thermal resistance.

None of these materials has the property of water repellency (Table 2) (no water repellency finishing), and only sample 3 has a little waterproof property, probably due to the characteristics of knitwear and can be ignored. All samples compared by water vapour resistance (R_{et}) are located in the area of 'very good or extreme comfort at higher activity rate' (R_{et} 0-6). At the same time, samples 2 and 4 show the lowest water vapour resistance, and sample 3 the highest. Sample 1 has the highest thermal resistance, Fig. 5.

On the basis of the obtained results, according to the standard CEN/TR 16422: 2012 /12/, the classification of the tested knitted fabrics (samples 1-4) can be performed (class A-very good, class B-good, class C-acceptable), the following can is concluded:
- knitted fabric 1 is suitable for cold weather applications, as a material for all layers, especially as a layer in contact with the skin, but also as an outer layer in a multilayer material for a very cold climate;
- knitted fabric 2 is characterized as acceptable for a warm climate in all layers, especially for medium activity;
- knitted fabric 3 is not recommended for use in sportswear;
- knitted fabric 4 can be applied in a warm climate as an intermediate or outer layer for intense activities.

Further implications are that knited fabric 1 is acceptable for making sportswear for cold weather applications, and knitted fabric 2 for use in a warm climate, while knitted fabrics 3 and 4 are not recommended for making sportswear. Samples 1 and 4 (100% PES) show no change in dimensions when washing, while the sample with the highest content of cotton shows the greatest changes in dimensions, both in width and length (Fig. 6), which is in accordance with the nature of the raw materials that they are made of. Considering the fact that we are discussing knitted fabrics, where allowed shrinkage is up to 5%, all of the knitted fabrics are within the tolerance boundaries.

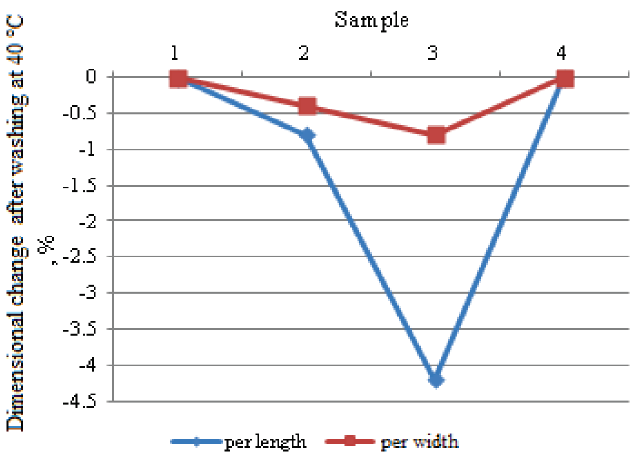


Figure 6. Dimensional change after washing at 40°C-shrinkage (%).

Moisture transfer properties (amount of water vapour absorbed by a sample of material during one-hour exposure on the skin model) of samples examined could not be compared due to different thicknesses of samples, so the index i_{mt} is applied for comparing the physiological quality. Sample 1 shows the best physiological quality (Fig. 7), as a consequence of fiber morphology, and sample 3 shows the weakest physiological quality, as a consequence of knitwear characteristics.

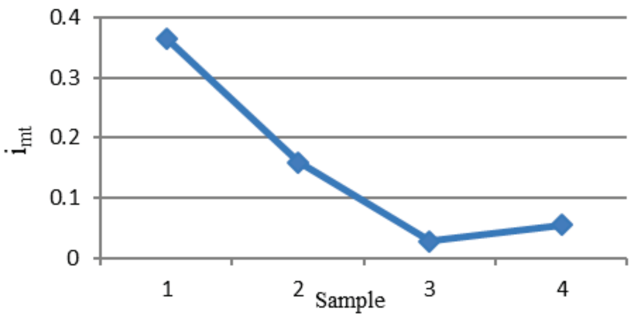


Figure 7. Values of water vapour transmission index i_{mt}.

CONCLUSIONS

The results show that thermal and moisture management performances of examined knitwear largely depend on the properties of raw materials they are made of, the characteristics of knitwear and structures, especially the thermal properties and the air and water vapour transmission.

It can be concluded that samples 2 and 4 are suitable for warmer climates, because they show lower thermal resistance (higher thermal conductivity) and higher water vapour permeability, while sample 2 shows higher absorptivity too, given the nature of the components it is made of. At the same time, sample 2 is more suitable for medium-activities, and sample 4 for intensive activities, since they exhibit a high air permeability and low heat resistance, and sample 4 is of high water vapour permeability too (high water vapour transfer). Sample 1 is suitable for colder conditions, since it shows high heat resistance and good moisture management. The material sample 3 is made of is not recommended for sports underwear production.

Sample 2 that has an interlock pique interlace and a good peeling grade is recommended for producing sportswear, and sample 3 is not recommended since it would be quickly pilling during use and maintenance.

Based on these results, a selection of materials for sportswear can be made for certain climatic conditions and a certain degree of wearer activity.

REFERENCES

1. Onofrei, E., Rocha, A.M., Catarino, A. (2011), *The influence of knitted fabrics' structure on the thermal and moisture management properties*, J Eng. Fibers & Fabrics, 6(4): 10-22.
2. Su, C.-I., Fang, J.-X., Chen, X.-H. (2007), *Moisture absorption and release of profiled polyester and cotton composite knitted fabrics*, Textile Res. J, 77(10): 764-769.
3. Voyce, J., Dafniotis, P., Towlson, S., Textiles in Sports – Chapter 10: Elastic Textiles, R. Shishoo (Ed.), Woodhead Publications in Textiles, 2005, pp.204-230.
4. Das, B., Das, A., Kothari, V.K., Fanguiero, R., Araujo, M. de (2008), *Effect of fibre diameter and cross-sectional shape on moisture transmission through fabrics*, Fibers & Polymers, 9(2): 225-231.
5. Prahsarn, C., Barker, R.L., Gupta, B.S. (2005), *Moisture vapor transport behavior of polyester knit fabrics*, Textile Res. J, 75(4): 346-351.

6. Cil, M.G., Nergis, U.B., Candan, C. (2009), *An experimental study of some comfort-related properties of cotton-acrylic knitted fabrics*, *Textile Res. J*, 79(10):917-923.
7. Onofrei, E., Rocha, A.M., Catarino, A. (2011), *Thermal comfort properties of knitted fabriucs made od elastane and bioactive yarns*, J Mat. Sci. & Engng., 1(3A): 428-435.
8. Parsons, K.C., Human Thermal Environments: The Effects of Hot, Modrate and Cold Environments on Human Health, Comfort and Performance, 2nd Ed., CRC Press, Taylor & Francis Group, New York, USA, 2003.
9. ISO 11092: 1993 Amd 1:2012 – Textiles – Physiological effects – Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test).
10. Scott, R.A. (Ed.), Textiles for Protection, The Textile Institute, Woodhead Publ. Ltd., Cambridge, England, 2005.
11. Bartels, V.T., Textiles in Sports – Chapter 9: Physiological Comfort of Sportswear, R. Shishoo (Ed.), Woodhead Publ. in Textiles, 2005, pp.177-203.
12. CEN/TR16422:2012 - Classification of thermoregulatory properties.
13. ISO 1833-1:2006 - Textiles- Quantitative chemical analysis - Part 1: General principles of testing.
14. SRPS ISO 7211-5:2005 - Tekstil - Tkanine - Konstrukcija - Metode analiza - Deo 5: Određivanje linearne gustine pređe iz tkanine
15. SRPS F.S2.511:1977 - Tekstil - Proveravanje kvaliteta sečenih hemijskih vlakana (prediva)
16. SRPS F.C0.012:1986 - Tekstil - Metražna roba - tkanine - Izbor osnovnih karakteristika
17. ISO 5084:1996 - Textiles – Determination of thickness of textiles and textile products
18. ISO 3801:1977 - Textiles - Woven fabrics - Determination of mass per unit length and mass per unit area
19. SRPS F.S2.022:2017 - Tekstil - Određivanje otpornosti tekstilnih površina prema pucanju
20. SRPS EN ISO 12945-1:2017 - Tekstil - Određivanje maljavosti i pilinga na tekstilnim površinama - Deo 1: Metoda u kojoj se koristi kutija za piling
21. ISO 9237:1995 - Textiles - Determination of the permeability of fabrics to air
22. ASTM E-96 M:2010 - Standard Test Methods for Water Vapor Transmission of Materials
23. ISO 4920:2012 - Textile fabrics - Determination of resistance to surface wetting (spray test)
24. ISO 811:1981 - Textile fabrics - Determination of resistance to water penetration - Hydrostatic pressure test
25. ISO 5077:2007 - Textiles - Determination of dimensional change in washing and drying
26. SRPS EN ISO 3759:2012 - Tekstil - Priprema, označavanje i merenje epruvete tekstilne površine i odevnih predmeta za ispitivanje određivanja promene mera