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Transfer and Friction Characteristics of Sports Socks Fabrics Made of Synthetic Fibres in Different Structures
Prenos tekočin in torne lastnosti sintetičnih pletiv za športne nogavice v različnih vezavah

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Abstract
Sports socks fabrics produced from polyester, polypropylene, their modified forms Thermocool®, Polycolon®, in three different structures (single jersey, piquet, terry) were investigated for their skin-fabric friction, permeability (air and water vapour), liquid absorption and transfer (absorbency, immersion, absorption capacity, wetback and drying) properties. According to the results, the effect of structure is dominant for frictional characteristics but focusing on the material, polypropylene created a bulkier and lighter structure with lower friction coefficients, an advantage for sports socks. The effect of structure is greater than the material also for some thermal comfort parameters, e.g. air permeability and absorbency. Focusing on materials, besides their better liquid transfer characteristics, modified forms of both fibres had worse performances for air permeability and absorbency compared to their standard forms. Absorption capacity, wetback and drying performances were related to fabric density besides the polyester's higher regain capacity. While Polycolon® had superiority for wetback performance against standard polypropylene, this was not the case for Thermocool®; however, both modified materials showed apparent superiority for drying periods. Piquet structures were advantageous for absorption capacity and wetback performances for polypropylene. For sports socks parts, specific needs can be met by changing the fabric structure. Considering the materials, polypropylene and Polycolon® can be recommended for both thermal and tactile aspects.
Keywords: sports socks, Thermocool®, Polycolon®, friction, liquid transfer

Izvleček
Na levo-desnih pletivih za športne nogavice, izdelanih iz poliestra, polipropilena in njunih modificiranih oblik Thermocool® in Polycolon® v treh vezavah, tj. enostavni levo-desni, pike in frotir, so bili preizkušani trenje pletiva ob kožo, prepustnostne lastnosti (zračna prepustnost, prepustnost vodne pare), absorpcija in prenos tekočine (vpojnost, omočljivost pri potapljanju, zmogljivost vpojnosti, povratno vlaženje in sušenje). Glede na rezultate ima vezava prevladujoč vpliv na torne lastnosti, pri osredotočenju na material pa je pletivo iz polipropilena lažje in bolj voluminozno ter ima nižji koeficient trenja, kar je za športne nogavice prednost. Vpliv vezave je večji od vpliva materiala tudi za nekatere dejavnike toplotnega udobja, kot sta zračna prepustnost in vpojnost. Če se osredinimo na materiale, modificirani tipi vlaken Thermocool® in Polycolon® bolje prenašajo tekočine ter imajo slabšo zračno prepustnost in vpojnost kot standardni tipi vlaken. Vpojnost, povratno vlaženje in sušenje so bili povezani z višjo reprizo poliestra in gostoto pleti-

va. Medtem ko je bil za Polycolon® prenos vlage na hrbtno stran večji kot pri standardnem polipropilenu, to ne velja za Thermocool®; oba modificirana materiala sta občutno boljša glede časa sušenja. Vezava piké ugodno vpliva na zmogljivost vpojnosti in povratno vlaženje pletiva iz polipropilena. Za sestavne dele športnih nogavic je zadovoljevanje specifičnih potreb mogoče doseči s spremembo vezave pletiva, glede izbire materiala pa sta z vidika toplotnih in taktilnih lastnosti priporočljiva polipropilen in Polycolon®.
Ključne besede: toplotna udobnost, tipna udobnost, prenos mase

1 Introduction

Consumers require multifunctional apparel products with superior comfort performance and sports socks is one of the clothing groups for which both thermal, pressure and tactile comfort performances are crucial. Socks comfort has a big influence on the performance of sports people and it is difficult to enable dryness, necessary insulation and mechanical comfort for different kinds of sports shoes as it is a closed system. Compression support, minimisation of foot blisters as a result of cyclic friction under high temperature and relative humidity within the shoes [1], moisture management properties, anatomically placed cushioning and shock absorbing properties [2] can be listed as characteristics of optimal sports socks. Sweating, which may reach up to 0.5 litres per foot during a sports activity within shoes not allowing adequate liquid, and water vapour transfer is the main reason for dampness sensation, decreased insulation, foot injuries occurring as a result of softer skin or wet fabric having a higher friction coefficient, some health problems sourcing from microorganisms and increased fatigue feeling [3–10]. Therefore, besides liquid absorption period and capacity, good athletic socks fabric must also transport sweat away from the foot surface not to create the above mentioned problems. Mechanical interactions between the skin and fabric are the sources of skin irritations for some specific garments such as socks and fitted sports clothing, e.g. swimwear, leggings etc. [11]. The mentioned friction characteristics of fabrics produced from different materials and fabric structures are generally evaluated by subjective tests [12–14] and fabric surface analyses with a reciprocating linear tribometer [15–17], horizontal platform method [18] and 3D biomechanical models with computational simulations [19].

The material and fabric structure of sports socks are the determinant factors of comfort and deformation related problems. Ideally, under pressure, an athlete should wear hydrophobic socks in regions prone to blister formation and shoes with a hydrophilic inner liner [20]. Sports socks are usually produced from standard or modified synthetic fibres and their blends for insulating and moisture wicking abilities without absorption and lighter weight upon sweating, enabling less energy expenditure [21–24]. Polyester, polyamide, polypropylene, acrylic (generally as pile structure) and elastane are the most common fibres used in sports and active wear [22, 24]. Polypropylene and its modified forms are increasingly being used in the sportswear market for generally inner layers [21] with their very low moisture absorbency, insulation retaining performance, excellent moisture vapour permeability and transplanar/in plane wicking capabilities [11]. A worsted spun yarn, Polycolon®, was suggested for cold weather protective gloves [25] and for shoe insoles with its good capillary wicking abilities [26]. Bioceramics (1%) were also used for socks and managed moisture on foot better than cotton/polyester [27]. Generally single jersey, false rib, terry and piquet structures are used on different parts of sports socks for thermal comfort enhancements, to decrease friction and pressure on specific parts [2].

In this study, permeability, liquid absorption/transfer and skin-fabric friction characteristics of sports socks fabrics produced from polyester, its modified form Thermocool®, polypropylene and its modified form Polycolon® were investigated. Single jersey (without elastane), piquet and terry fabrics were knitted to simulate structures on different parts of functional sports socks.

2 Materials and methods

2.1 Materials

Socks fabrics were knitted from Ne 26 standard polyester, its modified form Thermocool®, Ne 34 standard polypropylene and its modified form Polycolon® staple yarns, the characteristics of which are summarised in Table 1. Thermocool® is a unique blend of fibres with a hollow core that enables light weight,

Table 1: Characteristics of yarns used for socks fabrics

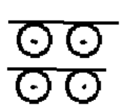
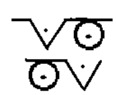
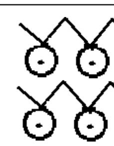
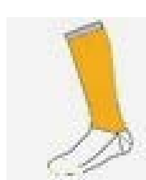
Fabric code	Knit type	Material	Yarn count	Twist coefficient (αe) [S.D.] [a)]
PESA	Single jersey	100% polyester	227 dtex	4.34 [0.12]
PESB	Piquet	78% polyester/15% polyamide/7% elastane	227 dtex PES + 20/40dtex /13f PA gimped	–
PESC	Terry			
MPESA	Single jersey	100% Thermocool®	227 dtex	5.34 [0.02]
MPESB	Piquet	78% Thermocool®/15% polyamide/7% elastane	227 dtex PES + 20/40 dtex /13f PA gimped	–
MPESC	Terry			
PPA	Single Jersey	100% polypropylene	174 dtex	3.43 [0.10]
PPB	Piquet	74% polypropylene/17% polyamide/9% elastane	174 dtex PP + 20/40 dtex/13f PA gimped	–
PPC	Terry			
MPPA	Single Jersey	100% Polycolon®	174 dtex	3.29 [0.09]
MPPB	Piquet	74% Polycolon®/17% polyamide/9% elastane	174 dtex PP + 20/40dtex/13f PA gimped	–
MPPC	Terry			

[a)] standard deviation

higher insulation and a channelled cross section for better wicking and drying abilities [28]. Polycolon® is a modified, polypropylene-based, worsted-spun long-staple yarn produced by Scholler. It has the lowest surface tension of all synthetic functional fibres and does not absorb moisture. With its good liquid transfer properties, it decreases the risk of blisters when used for socks. It is the lightest functional fibre in the world; around 40% lighter than cotton and 35% lighter than polyester [29].

Fabrics having single jersey, piquet and terry structures were knitted on a Lonati 400 socks knitting machine with 3 3/4 inch diameter, 200 needles and E value of 18. Single jersey fabrics were knitted without any other component to see the material effects clearly, while the piquet and terry structures were knitted with 20/40 dtex/13 f (spandex/polyamide) elastomeric inlay yarn (full plating). The socks parts where investigated knit types are used can be seen in Table 2.

Table 2: Knitting structures used on different parts of sports socks

Knit code	A	B	C
Knit type	Single Jersey	Piquet	Terry
Needle diagram			
Regions of knit types on socks			

2.2 Methods

2.2.1 Physical and frictional characteristics

Weight and thickness were tested according to TS 251 and ASTM D 1777 with 5 g/cm^2 pressure with a James Heal R&B Cloth Thickness Tester (James Heal Corp., UK) in turn. Physical porosity characteristics were calculated according to Equation 1 [22].

$$P = \left(1 - \frac{m}{\rho}\right) x\, 100 \qquad (1)$$

where P is porosity (%), m is fabric density (g/cm^3) and ρ is fibre density (g/cm^3).

Friction coefficients of socks fabrics were calculated with friction force measurements conducted according to ASTM D 1894-14 with a Lloyd LR5K Plus (Lloyd Instruments, Inc., USA) tensile strength tester. Static and kinetic friction coefficients were calculated (cf. Equation 2) from force results obtained for wale direction as a result of movement of a sled (3.9 cm × 4 cm) covered with lambskin with a speed of 25 mm/min and normal force of 2.50 g/cm^2 on a platform covered with the socks fabric (inner side up).

$$\mu = F/N \qquad (2)$$

where N is normal force (N) and F is static/kinetic frictional force.

2.2.2 Permeability and liquid absorption/transfer characteristics

The air and water vapour permeability values were tested according to TS 391 EN ISO 9237 by FX Textest 3300 (James Heal Corp., UK) and ASTM E96-16 Cup Method in turn. The absorbency and liquid transfer characteristics of samples were tested with drop test according to AATCC 79:2018 and with sinking time (immersion) test according to AATCC 79-Method B. Absorption capacities were calculated according to the modified version of ISO 20158:2018 and drying periods were determined according to a preceding study [30] until the fabrics come to their conditioned weight. From drying graphics, slopes of the weight loss lines (amount of evaporated liquid/evaporation period) that give idea about the drying rates were calculated to have an exact comparison. Transverse wicking (wetback) rates were determined according to a preceding study [31] from the liquid amounts transferred from the wet sample (including liquid equal to their absorption capacities) to the dry samples 74.5 mm in diameter under the pressure of 15.6 kg/m^2 after the periods of 5 min, 10 min, 15 min, 20 min, 25 min and 30 min.

All fabrics were washed according to TS EN ISO 6330:2012 in a Wascator FOM71 CLS washing machine (James Heal and Co. Ltd., Halifax, UK) and conditioned under standard atmospheric conditions (20 ± 2 °C, 65 ± 2% RH) according to ASTM D1776-08e1 (2009) before the tests.

2.2.3 Statistical analyses

IBM SPSS 21.0 Statistics Software (SPSS Inc. USA) was used for the Multivariate Analysis of Variance (MANOVA) test to investigate the effects of material and structure on the investigated parameters. MANOVA is used when more than one factor affecting the dependent variable, including all their combinations at different levels, are studied and tested. Duncan and Student Newman Keuls (SNK) tests were used to examine significant differences. Statistical significances were investigated with p values ($p < 0.05$ meaning significant difference). A correlation analysis was conducted to determine the relationships among physical and mechanical parameters.

3 Results and discussion

Material (polyester, polypropylene, Thermocool®, Polycolon®), structure/knit type (single jersey, piquet and terry) of the fabrics and their interactions obtained from MANOVA had significant effects on all physical, surface, permeability and liquid transfer characteristics, as it can be seen in Table 3 ($p < 0.05$).

Table 4 shows material effects of socks fabrics grouped according to three different knit types.

3.1 Physical and surface properties

Physical properties of socks fabrics produced from different synthetic yarns in different knit types are compiled in Table 5.

As it can be seen in Table 4, for single jersey fabrics, the lowest weight belonged to polypropylene (PP) followed by Polycolon® (MPP) related to their fibre densities, while the polyester (PES) fabric had significantly the maximum weight. The trend is valid for other structures except for the higher value of MPP for the piquet fabric. Thickness values

Table 3: MANOVA results of main factor-parameter interactions

Dependent variable	Significance values of main factors (p)		
	Material	Structure	Material × structure
Weight	0.00	0.00	0.00
Thickness	0.00	0.00	0.00
Static friction coefficient	0.00	0.00	0.00
Kinetic friction coefficient	0.000	0.001	0.000
Air permeability	0.00	0.00	0.00
Absorption period (drop) test	0.00	0.00	0.00
Immersion period	0.00	0.00	0.00
Absorption capacity	0.00	0.00	0.00

Table 4: Post-hoc test results of fabric properties

Property	Single jersey	Piquet	Terry
Weight	PP < MPP < MPES < PES	PES < PP < MPES = MPP	PP = MPP < PES = MPES
Thickness	PES = MPES < PP = MPP	MPES = PP < PES < MPP	PES < MPES = MPP < PP
Static fric. coeff.	MPP = PP = PES < MPES	PP = MPES = MPP < PES	PP = MPP < MPES = PES
Kinetic fric. coeff.	PP = MPP = PES < MPES	PP = MPES = MPP < PES	PP = MPP < MPES < PES
Air permeability	MPES < PES < MPP < PP	MPP < PP < MPES < PES	MPP < PP < MPES < PES
Absorption period (drop) test	PES < PP < MPES < MPP	PP did not absorb MPP did not absorb PES=MPES	PP did not absorb MPP did not absorb PES < MPES
Immersion period	PP did not sink MPP did not sink PES < MPES	PP did not sink MPP did not sink MPES < PES	PP did not sink MPP did not sink MPES < PES
Absorption capacity	PP = MPP < MPES < PES	Statistically identical	PP < MPP < PES < MPES

(cf. Figure 1) are generally higher for PP and MPP, enabling bulkier structures. However, there are some exceptions that PES had higher thickness than PP for the piquet fabric, and the modified forms of both (MPES and MPP) had identical thickness values for the terry fabric. According to the porosity values compiled in Table 5, higher values belonged to the piquet and single jersey structures for polyester and polypropylene fabrics in turn. The piquet and terry structures generally had identical porosity values due to the tuck and pile loops within the fabric structures in turn. The differences among polyester and polypropylene fabrics were not clear as the porosity equation includes a ratio of fibre and fabric densities, despite the lower fabric (as a result of lower yarn linear density) and fibre densities of polypropylene.

According to friction coefficient results, the minimum and identical static and kinetic friction

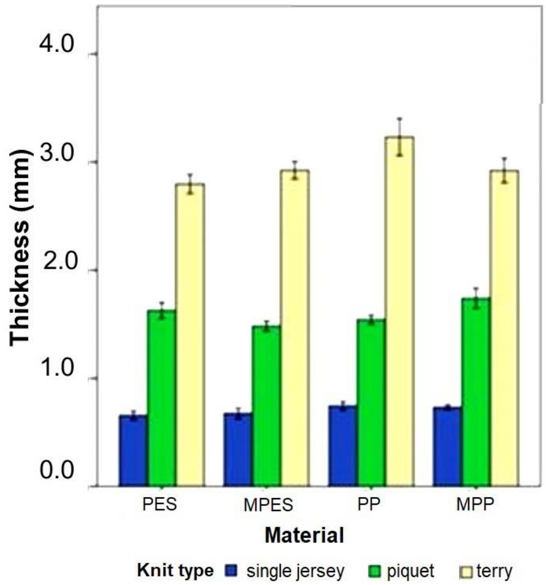


Figure 1: Fabric thickness values

Table 5: Physical properties of fabrics

Fabric code	Courses-wales (1/cm)	Weight (g/m^2) [S.D.]	Density (g/cm^3) [S.D.]	Porosity (%) [S.D.]
PESA	70-42	255.20 [2.34]	0.39 [0.013]	71.85 [0.92]
PESB	84-50	266.4 [5.48]	0.16 [0.005]	94.81 [0.36]
PESC	80-56	544.62 [26.80]	0.19 [0.013]	85.88 [0.95]
MPESA	70-42	149.60 [9.22]	0.22 [0.013]	83.93 [0.93]
MPESB	88-75	264.87 [3.00]	0.18 [0.003]	87.05 [0.25]
MPESC	92-57	553.35 [25.52]	0.19 [0.007]	86.29 [0.56]
PPA	84-51	93.70 [1.92]	0.13 [0.005]	86.01 [0.55]
PPB	86-38	254.98 [5.01]	0.17 [0.005]	81.63 [0.61]
PPC	84-40	520.98 [4.46]	0.16 [0.006]	82.08 [0.71]
MPPA	72-54	94.98 [1.38]	0.13 [0.001]	85.59 [0.12]
MPPB	80-54	263.40 [3.21]	0.15 [0.004]	83.17 [0.43]
MPPC	74-55	475.33 [12.04]	0.16 [0.007]	81.91 [0.83]

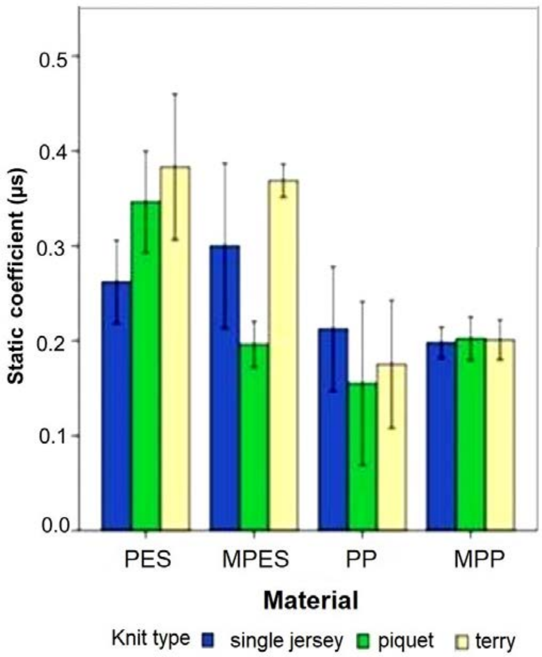
Legend: PES: polyester, MPES: Thermocool®, PP: polypropylene, MPP: Polycolon®
A: Single Jersey, B: Tucked, C: Terry

coefficients were obtained for PP, MPP (confirming Dyck's study in 1993), maximum values belonged to MPES for single jersey, and PES for the piquet and terry fabrics (cf. Figure 2). For the knit types, while terry fabrics created rougher surfaces for polyester fabrics, single jersey fabrics were rougher for polypropylene according to both static and kinetic friction coefficients. Both material and fabric structure were affective [18]; however, the effect of the fabric structure seems greater on friction coefficients confirming the results by Richie [32].

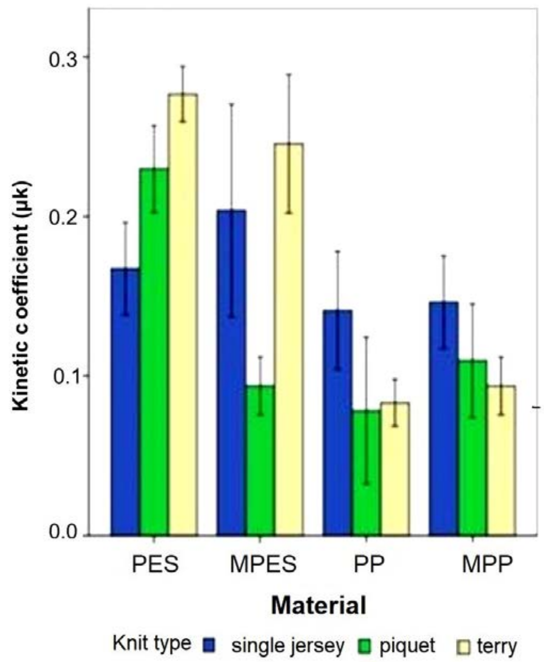
3.2 Permeability and liquid absorption/ transfer properties

The permeability and absorbency/transfer characteristics of the socks fabrics can be seen in Table 6.

Air permeability results (cf. Figure 3), giving idea about the porous structure of the fabric, show the ranking of PP, MPP, PES and MPES from the maximum values for single jersey fabrics, a result proportional to fabric density and porosity values (cf. Table 4). Worse performances of MPES and MPP, when compared to their standard forms, can be attributed to the rougher surfaces of modified fibres within staple yarn having higher frictional area with air. While terry fabrics had significantly lower air permeability values than piquet fabrics (cf. Figure 3), material trends are the same for both structures. Both standard and modified PES fabrics had higher values than PP and modified PP for piquet and terry fabrics as a result of their higher porosity, confirming a preceding study [33]. As a general look, effects of fabric structure seem greater than material on air permeability, confirming a preceding study [11]. The effect of linear density was not observed for piquet and terry structures including elastomeric inlay yarn.



a)



b)

Figure 2: Static (a) and kinetic (b) friction coefficients

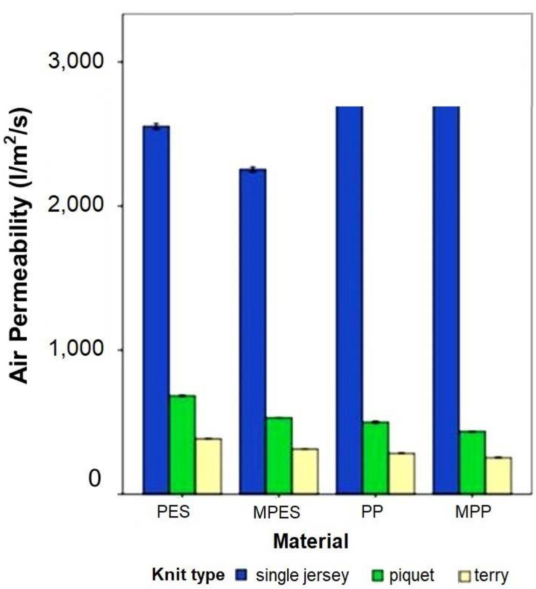


Figure 3: Air permeability values

Water vapour permeability results could not discriminate the fabrics ($p > 0.05$), probably due to the insufficient precision of the cup method and environmental condition variations (cf. Table 6), despite the test conducted under standard atmospheric conditions.

To move in a fibrous medium, a liquid must wet the fibre surface before being transported through inter-fibre pores by means of capillary action. The fibre-liquid surface attraction force causes wetting action and is determined by fibre and fabric surface characteristics, pore distribution and liquid properties [34–35]. The PP and MPP fabrics did not absorb water within acceptable periods (around 5 seconds), except for the PP single jersey fabric (6.63 s), due to their lowest surface tensions (cf. Table 6). Only single jersey fabrics absorbed liquid within acceptable limits (2.24–8.08) as a result of their open pore structures where liquid can be bound better. MPES and MPP yarn fabrics (mainly designed for better liquid transfer and insulation) absorbed moisture within significantly longer periods than PES and PP as a result of irregular cross sections of these fibres that might decrease contact surface area with water, hence surface energy. Rougher surfaces of piquet and terry fabrics also decreased their surface energy that they absorbed water within 16.45–26.17 seconds contrary to the preceding statement about better wettability of rougher surfaces by well wetting fluids [35]. The procedure and real life simulation ability of the test method should also be considered, namely, sports socks are normally used within shoes under pressure and the surface energy surely differs under these conditions.

Table 6: Permeability and liquid absorption/transfer characteristics

Fabric code	Water vapour permeability ($g/m^2/24$ h) [S.D.]	Absorption period (drop) test (s) [S.D.]	Sinking period (s) [S.D.]	Drying rate/speed (g/h)
PESA	659.57 [191.46]	2.24 [0.20]	102.01 [21.54]	0.477
PESB	561.91 [129.64]	20.14 [6.54]	427.39 [22.92]	0.762
PESC	489.04 [49.33]	16.45 [6.18]	207.71 [19.45]	0.786
MPESA	604.21 [62.04]	8.08 [0.04]	–	0.435
MPESB	566.37 [40.90]	21.51 [0.13]	271.08 [90.14]	0.692
MPESC	616.85 [75.98]	26.17 [0.09]	173.78 [63.69]	0.866
PPA	493.80 [106.63]	6.62 [0.17]	–	0.344
PPB	580.36 [148.15]	–	–	0.779
PPC	569.70 [100.13]	–	–	0.651
MPPA	534.02 [94.58]	11.44 [0.15]	–	0.253
MPPB	609.98 [178.56]	–	–	0.764
MPPC	462.58 [42.32]	–	–	0.807

Legend: PES: Polyester, MPES: Thermocool®, PP: Polypropylene, MPP: Polycolon®
A: Single Jersey, B: Tucked, C: Terry
–: did not absorb water or did not sink

The immersion or sinking period results (cf. Table 6) giving idea about both absorption and transfer of liquid within a fabric were also in harmony with the absorption period results that the PP and MPP fabrics did not sink as they did not absorb liquid. Although designed for better transfer capability, the MPES fabric did not have superior performance than standard PES for single jersey fabric showing solely the material effect. MPES Thermocool® had lower sinking periods for both piquet and terry fabrics showing the effects of fibre cross sections and the porous structure of fabrics. The sinking time of about 5 seconds is generally considered satisfactory for well-prepared cellulosic materials [36] and none of the fabrics had a closer performance due to their hydrophobic natures. The absorption capacity values, which affect the dampness sensation, hence comfort, were discriminated more for terry fabrics. For the terry fabrics, MPES had better performances than PES, followed by MPP and PP (cf. Figure 4). Single jersey fabric results showing solely the material effect were the highest for PES; modified forms of both PET and PP could not show superior performances as the absorption capacity is related to the macromolecular structure of the fibre, not its cross section. Better performances of PES against PP can be attributed to their higher moisture regain values (0.4% when compared to 0% of polypropylene) [37]. When the fabric structure is considered, piquet structures had significantly better performances when compared to terry fabrics. Summing up, apart from the fibre macromolecular structure, the fabric structure is also effective on the absorption capacity confirming a preceding study [33].

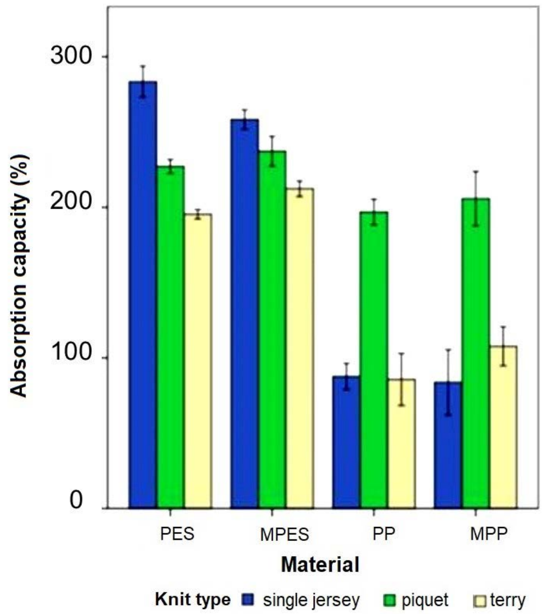


Figure 4: Absorption capacity values

Besides moisture absorption capacity of the socks fabric, its liquid transfer to another clothing layer (wetback) under pressure is important as well. The geometric configuration of pore structures (inter and intrayarn capillaries) and mechanical stress on a fabric play roles on water transport [11]. According to the transplanar wicking under pressure (wetback) test results (cf. Figure 5), standard polyester (PES) transferred the maximum amount of liquid to the outer dry layer for all structures, hence a drier feeling, having the rating of single jersey (A), piquet (B) and terry (C) fabrics starting from the maximum. MPES fabrics come after PES fabrics for the determined period of 30 minutes and its ranking was obtained as piquet (B), terry (C) and single jersey (A) starting from the maximum. As it can be seen in Figure 5, all standard and modified PP fabrics (PP and MPP) transferred the minimum amount of liquid (ranging from 0.48% to 2.31%) to the outer dry layer proportional to their low absorption capacities and short drying periods. The greater amount of liquid was transferred by MPP Polycolon® when compared to standard PP and by piquet fabrics among other knit types confirming their absorption capacity results.

Moisture on the skin or clothing increases the heat loss of the body and also affects its overall performance and endurance. The drying ability of the knitted fabric is primarily affected by the mass per unit area and thickness [37]. The mentioned phenomenon is valid also for this study that terry fabrics with the maximum weight values (PES and MPES) dried within longer periods in spite of their lower absorption capacities than piquet fabrics (cf. Figure 6). Minimum drying periods belonged to polypropylene single jersey fabrics as expected, followed by polyester fabrics. According to slope calculations (cf. Table 6), terry fabrics made of MPES had the maximum drying speed (0.87), followed

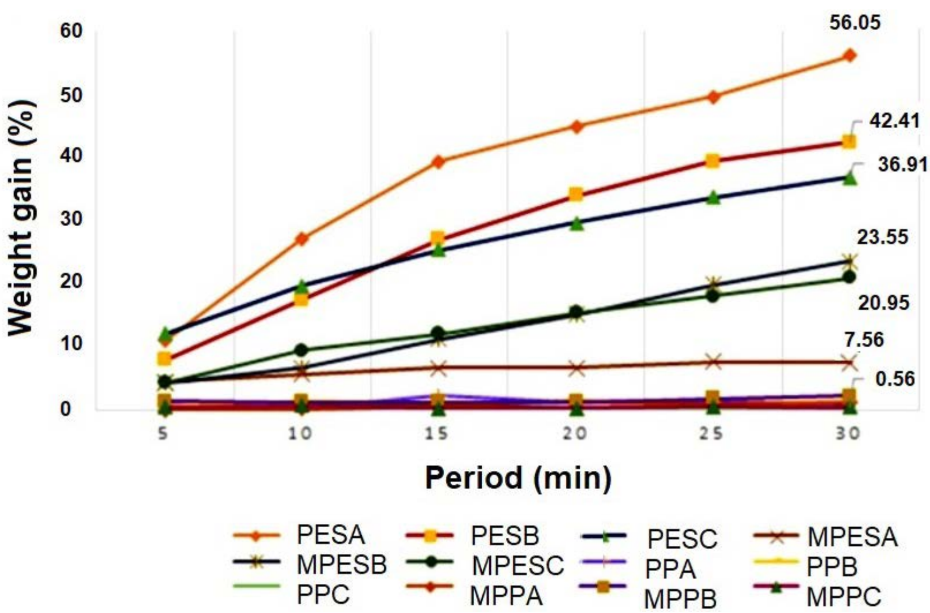


Figure 5: Transferred liquid from wet to dry fabric (weight gain) under pressure (A: single jersey, B: piquet, C: terry)

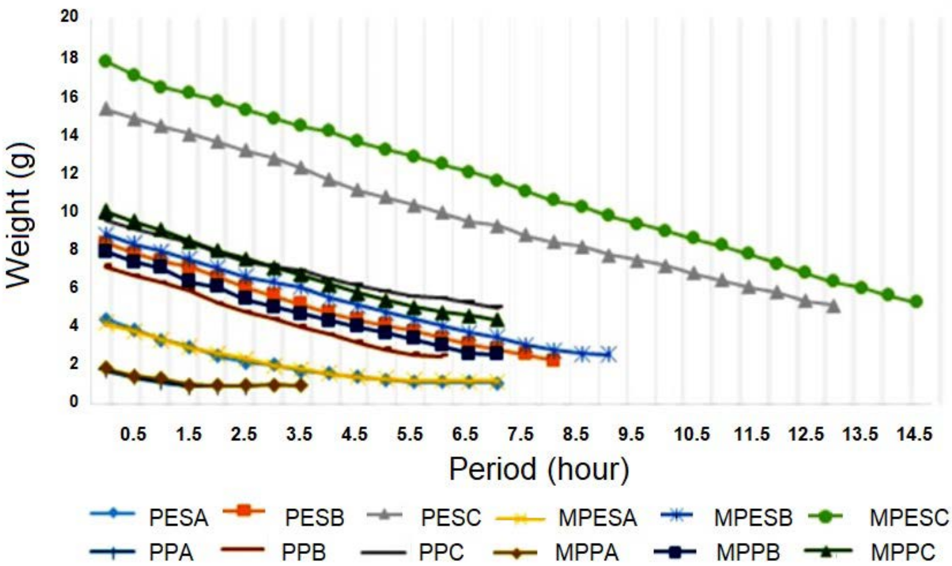


Figure 6: Drying periods (A: single jersey, B: piquet, C: terry)

by MPP Polycolon® (0.81). The drying speed values increased starting from single jersey fabrics (A), followed by piquet (B) and terry fabrics for all materials except for PP. The minimum drying speed belonged to single jersey MPP fabric (0.25) followed by single jersey PP fabric (0.34), MPES (0.44) and PES (0.48) fabrics. It was concluded that drying periods are related more to weight and absorption capacities of fabrics.

According to the correlation analysis results, air permeability is negatively correlated with weight and thickness as expected. The denser the fabric, the less air passes through it. The absorption period (drop) test results are correlated with surface and porosity properties, which shows the effect of surface and structural features on surface energy, hence absorbency of the fabric. Other significant correlation coefficients are compiled in Table 7.

4 Conclusion

Sports socks have a decisive influence on comfort and performance of sports people. The perceived comfort, mainly affected by temperature and dampness feelings, depends on the fibre content and construction of socks. Moreover, frictional deformation occurring on foot skin, perceived by mechanoreceptors, is also important for sports performance. During walking or running, besides cyclic pressure, friction and shear forces resulting from forward or sideways momentum of the athlete, increased moisture level and temperature within sports shoes are the main reasons for foot blisters. Therefore, in this study, friction, permeability and liquid transfer characteristics of socks fabrics produced from standard and modified forms of polyester and polypropylene fabrics in different

Table 7: Correlation analysis results

Property	Weight	Thickness	Water vapour perm.	Static friction coeff.	Kinetic friction coeff.	Porosity
Weight		0.904 b)				
Air permeability	−0.699 a)	−0.837 b)				
Absorption period (Drop)				0.661 a)	0.630 a)	0.645 a)
Absorption capacity			0.678 a)			
Static friction coeff.					0.975 b)	

a), b): significant for p = 0.05, p = 0.01 in turn structures (single jersey, piquet and terry) were investigated. According to the results, both standard and modified polypropylene Polycolon® gave lighter and bulkier fabrics, which is an advantage for permeability, hence drying performance of the socks. Polypropylene fabrics also created lower friction coefficients, meaning less deformation on wet skin when compared to polyester. Polyester, especially the standard one, has a bigger potential for skin deformation, the effect of fabric structure here being greater. The modified forms of polyester and polypropylene (Thermocool® and Polycolon®) had worse performances for air permeability, which may be related to their higher fibre surface areas. For liquid absorption, polyester was advantageous, but piquet and terry structures of polypropylene did not absorb liquid. The modified polyester Thermocool® did not have a superiority for liquid absorption, but it transferred liquid better for piquet and terry structures. While the absorption capacity is related to the regain capacity of the fibre and fabric density, besides its lower capacity, polypropylene had better performances in piquet structure which is also the case for wetback performance. Polycolon® had better wetback performance when compared to standard polypropylene, which was not the case for polyester. Both Thermocool® and Polycolon® had better performances for drying periods. Yarn linear densities of polyester and polypropylene fabrics surely had influence on fabric density, porosity and hence permeability characteristics, which can be accepted as a weakness of this study. In conclusion, polypropylene, especially modified form Polycolon® and piquet structures, can be suggested for plantar and lateral foot parts where blisters occur during running under high moisture and temperature conditions.

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