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Investigation of the Air Permeability of Socks Knitted from Yarns with Peculiar Properties

Abstract
This paper presents a study on the air permeability of socks manufactured using the yarns of new kinds of fibres, such as soybean, bamboo, cotton/seacells and bamboo/flax. The air permeability of plain pure knits and plated knits of textured polyamide (PA) and elastane (Lycra) wrapped with textured polyamide threads was investigated. It was determined that higher air permeability is characteristic for knits produced from natural yarns, a lower permeability for knits with textured PA, and the lowest for knits with Lycra threads. Textured PA or Lycra threads change the structure of plated knits as the construction of such knits are thicker and tighter. The variation in air permeability depending on the area density, linear density, loop length and tightness factor of plain and plated plain knits was discused.

Key words: *natural yarns, bamboo yarns, soybean yarns, cotton/seacell, bamboo/flax, air permeability, plated socks, linear density, area density, loop length, tightness factor.*

Introduction

With the growing demand for more comfortable, healthier and environmentally friendly products, efforts in research and development in the textile industry have focused on the utilisation of renewable and biodegradable resources. As a result a new kind of bamboo and soybean protein fibres, which are an alternative to conventional ones, and cotton have gained importance in apparel manufacturing. Information about the manufacturing process for regenerated bamboo fibre, application areas and characteristics is supported by investigations conducted by N. Erdumlu and B. Ozipek on yarn properties produced from regenerated bamboo fibre in the ring yarn manufacturing process using different counts [1]. In order to make comfortable socks, not only cotton yarns are used: yarns of soya, bamboo, seacells and their blends with traditional fibres such as cotton and flax are also utilised. These fibres have a good influence on humans. Bamboo fibres are naturally antibacterial and biodegradable and have a high moisture absorption capacity, softness, brightness as well as UV protective properties [1]. Soybean protein fibre is also naturally antibacterial, has good mechanical and physical performances, a soft and smooth handle, good moisture absorption and permeability, and is used especially for skin - contact [2]. Seacell fibre is saturated with various minerals, microelements and vitamins. When in contact with this fibre, the skin feels a crème-effect. Seacell protects the skin, has antiphlogistic and antiallergic properties and is not irritative for the skin [3].

Air permeability is a vital quality in such end-use applications as sport garments, underwear products, t–shirts, socks and others. Air permeability, being a bio-physical feature of textiles, determines the ability of a fabric to carry out gaseous substances, significantly influences the thermal comfort of the human body and secures the support of proper body temperature [4]. It is logical to expect that fabric structure has an impact on air permeability, namely the porosity. However, there is limited experimental proof in the literature that can correlate these properties [5]. It was determined that the loop length of a knitted jersey has more influence on porosity than the stitch density and the thickness. Porosity is affected by the yarn number or yarn count number. It was noted that an increase in the yarn number influences porosity by decreasing the space and volume of pores and flattening yarns on the surface [6]. Thus far there have no any investigations on blended yarns.

There are a lack of researches comparing the influence of raw material and the knitted fabric structure on bio – physical properties, particularly on air or water vapour permeability. B. Wilbik-Halgas et al. investigated air and water permeability in double - layered knitted fabrics with different raw materials and found that air permeability, in contrast to water vapour permeability, is a function of the knitted fabric thickness and surface porosity. They emphasised that surface porosity correlates more with air permeability than knitted fabric thickness [7]. Research of R. Baltakytė and S. Petrulytė determined the influence of the kind of impact (water/heat/mechanical/chemical) and concluded that the process has a significant effect on the air permeability of woven terry fabrics [8]. The air permeability decreases considerably after finishing operations due to the blocking up of the fabric‘s pores. A significant difference exists in the air permeability of different fabric softener treatments, fabric types and in the number of laundering cycles [9, 10].

So far there have been no investigations on plain knits for socks from natural yarns and plated knitted socks of textured polyamide (PA) and elastane (Lycra) wrapped with textured polyamide thread. The aim of this investigation was to determine what kind of yarns or composite thereof allows to obtain comfortable knits for socks. During the wearing of such socks, we could feel cool when it is hot outside or feel warm when it is cold.This paper investigates the air permeability of knitted socks not only from conventional cotton yarns but also from other new 21st century pure yarns, such as bamboo, soybean protein fibres, blended yarns like cotton – seacells, and bamboo - flax.

Object of investigation

Socks are commonly knitted in a plain pattern from cotton yarns plated with textured polyamide (PA) or elastane wrapped with textured polyamide threads (Lycra).

Experimental samples were knitted using pure yarns from such fibres as 100% Cotton (C - 14 tex), 100% Bamboo (B - 14 tex), 100% Soybean protein (S - 14 tex), and blended yarns: 75% Cotton/25% seacell (CS - 19 tex), 80% Bamboo/20% flax (BF - 24 tex). Also, plated knits of textured polyamide PA (20 tex) or elastane (Lycra 2.2 tex) wrapped with textured polyamide threads (PA 7.8 tex) were used. Knits for socks were manufactured from pure 28 tex and 42 tex yarns (knitted from two or three yarns per loop when the linear density is 14 tex). Plated knits were manufactured using 24 tex and 38 tex yarns (combination of one or two pure yarns (14 tex) and Lycra thread). Plated knits with textured PA were manufactured from 34 tex and 48 tex yarns (same combination as with Lycra). Using the same manufacturing method, samples were knitted from blended yarns of cotton – seacell and bamboo – flax yarns and its combination with Lycra, and textured PA threads. Single jersey knits were manufactured on a 14 gauge, 168 needle and 3¾” diameter Matec - Techno New socks knitting machine. The knitted samples were kept in a steam box for 20 minutes. Before investigation, the test knits were conditioned in standard conditions: relative humidity (65±2)%, temperature (20±2)°C. The variants of the knitted samples are presented in ***Table 1***.

Table 1. *Variants of the plain knitted samples and their structural parameters.*

Indication of knitted sample variant		Total yarn linear density, tex	Course density, cm^{-1}	Wale density, cm^{-1}	Area density M, g/m^2
CL	Cotton 14 tex + Lycra 10 tex	24	17.0	10.0	236
BL	Bamboo 14 tex + Lycra 10 tex	24	17.0	10.0	287
SL	Soy 14 tex + Lycra 10 tex	24	17.0	10.0	280
CSL	Cotton + Seacell 19 tex + Lycra 10 tex	19	16.0	10.0	250
BFL	Bamboo + flax 24 tex + Lycra 10 tex	34	14.0	10.0	290
CC	Cotton 14 tex + Cotton 14 tex	28	7.4	6.3	88
BB	Bamboo 14 tex + Bamboo 14 tex	28	7.4	6.2	91
SS	Soy 14 tex + Soy 14 tex	28	7.4	6.2	94
CSCS	Cotton+Seacell 19 tex + Cotton+Seacell 19 tex	38	7.4	7.0	132
BFBF	Bamboo+flax 24 tex + Bamboo+flax 24 tex	48	7.4	7.0	144
CPA	Cotton 14 tex/ PA 20 tex	34	10.0	8.3	192
BPA	Bamboo 14 tex/ PA 20 tex	34	10.0	8.3	201
SPA	Soy 14 tex/ PA 20 tex	34	9.8	8.3	188
CSPA	Cotton+Seacell 19 tex /PA 20 tex	39	9.4	8.0	193
BFPA	Bamboo+flax 24 tex /PA 20 tex	44	9.4	8.0	210
CCL	Cotton 14 tex + Cotton 14 tex + Lycra 10 tex	38	13.0	10.0	293
BBL	Bamboo 14 tex + Bamboo 14 tex + Lycra 10 tex	38	15.0	10.0	321
SSL	Soy 14 tex + Soy 14 tex + Lycra 10 tex	38	16.0	10.0	338
CSCSL	Cotton+Seacell 19 tex +Cotton+Seacell 19 tex + Lycra 10 tex	48	14.0	9.0	363
BFBFL	Bamboo+flax 24 tex + Bamboo+flax 24 tex + Lycra 10 tex	58	16.0	9.0	380
CCC	Cotton 14 tex + Cotton 14 tex + Cotton 14 tex	42	7.8	7.7	156
BBB	Bamboo 14 tex + Bamboo 14 tex + Bamboo 14 tex	42	7.2	7.0	164
SSS	Soy 14 tex + Soy 14 tex + Soy14 tex	42	7.4	7.1	152
CSCSCS	Cotton+Seacell 19 tex + Cotton+Seacell 19 tex + Cotton+Seacell 19 tex	57	8.0	7.4	220
BFBFBF	Bamboo+flax 24 tex + Bamboo+flax 24 tex + Bamboo+flax 24 tex	72	8.0	7.4	213
CCPA	Cotton 14 tex+ Cotton 14 tex/PA 20 tex	48	10.0	8.2	248
BBPA	Bamboo 14 tex + Bamboo 14 tex/ PA 20 tex	48	10.0	8.2	269
SSPA	Soy 14 tex + Soy 14 tex/ PA 20 tex	48	9.4	8.0	244
CSCSPA	Cotton+Seacell 19 tex + Cotton+Seacell 19 tex/ PA 20 tex	58	9.1	8.0	272
BFBFPA	Bamboo+flax 24 tex + Bamboo+flax 24 tex/ PA 20 tex	68	9.4	7.8	292

Methods of test and calculations

In this research air permeability tests of the knits investigated were conducted according to EN ISO 9237: 1997 [11]. The air permeability was measured using an L14DR air permeability tester (Karl Schroder KG, Germany) with a head area of 5 cm^2. In order to get comparable results, coeficient 4 was multiplied with a specified area. The airflow rate was measured over 20 tests per sample variant. The airflow rate determines the air permeability of test specimens, hence after the tests, the values of air permeability were calculated using equation [11]:

$$R = \frac{q_v}{A} \cdot 167 \qquad (1)$$

where:
R – air permeability in mm/s;
q_v – mean of airflow yield in dm^3/min;
A – specified area in cm^2.

The courses and wale density of the samples were calculated in the direction of the length and width of the knits at a 10 cm distance, and evaluated per cm. The area density of the samples was obtained from measurements of 10 × 10 cm samples, which is reported in g/m^2. The yarn count was estimated before knitting. The stitch length l of a plain knitted sock was determined from the area density, which may be calculated using expression [12]:

$$l = \frac{M \cdot A \cdot B}{T} \qquad (2)$$

where:
l – stitch length in mm;

M – area density of knitted sample in g/m²;
A – wale spacing of knitted sample in mm;
B – course spacing of knitted sample in mm;
T – linear density of yarns in tex.

It is known that the majority of knit features depend on the loop length and yarn linear density. The tightness of knits was characterised by the tightness factor (*TF*). It is know that *TF* is a ratio of the area covered by the yarns in one loop to the area occupied by the loop [12]. It is also an indication of the relative looseness or tightness of the plain knitted weft structure. For determination of *TF* the following formula was used [12 – 16]:

$$F = \frac{\sqrt{T}}{l} \quad (3)$$

where:
T – the yarn linear density in tex;
l – the loop length of knitted samples in mm.

Experimental results

All experimental results are presented in ***Table 2***.

We investigated the main characteristics of the knits that have an impact on air permeability: the linear density of the yarns, area density, loop length, the tightness factor and raw material of the yarns. Regarding air permeability, the range of values obtained is significant, ranging from 152.8 – 1812.8 mm/s. Obviously air permeability decreases if the area density increases due to the knit structure becoming thicker, a result of which being worse air flow. As can be seen in ***Figure 1***, knits with textured PA or

Table 2. *Variants of the plain knitted samples and their calculated parameters*

Indication of knitted sample variant	Loop length l, mm	Tightness factor, TF	Air permeability, mm/s	Coefficient of variation of air permeability,%	Relative error, %
CL	5.71	8.63	254.8	2.91	0.65
BL	7.03	6.96	192.9	4.42	0.99
SL	6.86	7.14	188.7	4.16	0.93
CSL	5.39	10.0	237.1	2.89	0.65
BFL	6.09	9.57	205.4	3.82	0.85
CC	6.60	8.10	1519.7	0.80	0.18
BB	7.08	7.47	1639.9	0.78	0.17
SS	7.32	7.23	1812.8	0.47	0.11
CSCS	6.71	9.19	1010.4	0.85	0.19
BFBF	5.79	11.96	1074.6	0.76	0.17
CPA	6.74	8.68	293.9	4.67	1.04
BPA	7.12	8.19	293.9	2.37	0.53
SPA	6.80	8.58	377.4	4.85	1.08
CSPA	6.58	9.49	349.0	3.44	0.77
BFPA	6.35	10.45	359.9	3.52	0.79
CCL	5.84	10.64	212.9	3.48	0.78
BBL	5.63	10.95	158.7	4.80	1.10
SSL	5.56	11.09	152.8	4.00	0.90
CSCSL	5.40	12.83	177.9	4.59	1.03
BFBFL	4.09	18.60	157.8	4.82	1.08
CCC	6.48	10.12	729.0	2.81	0.63
BBB	7.54	8.60	884.3	2.70	0.61
SSS	6.99	9.28	1021.2	2.45	0.55
CSCSCS	6.52	11.58	506.9	1.61	0.36
BFBFBF	5.00	16.98	458.4	1.86	0.42
CCPA	6.22	11.20	190.8	4.08	0.91
BBPA	6.83	10.14	207.1	3.84	0.86
SSPA	6.76	10.25	242.2	4.75	1.06
CSCSPA	6.44	11.82	229.6	4.00	0.89
BFBFPA	5.86	14.08	206.6	4.17	0.93

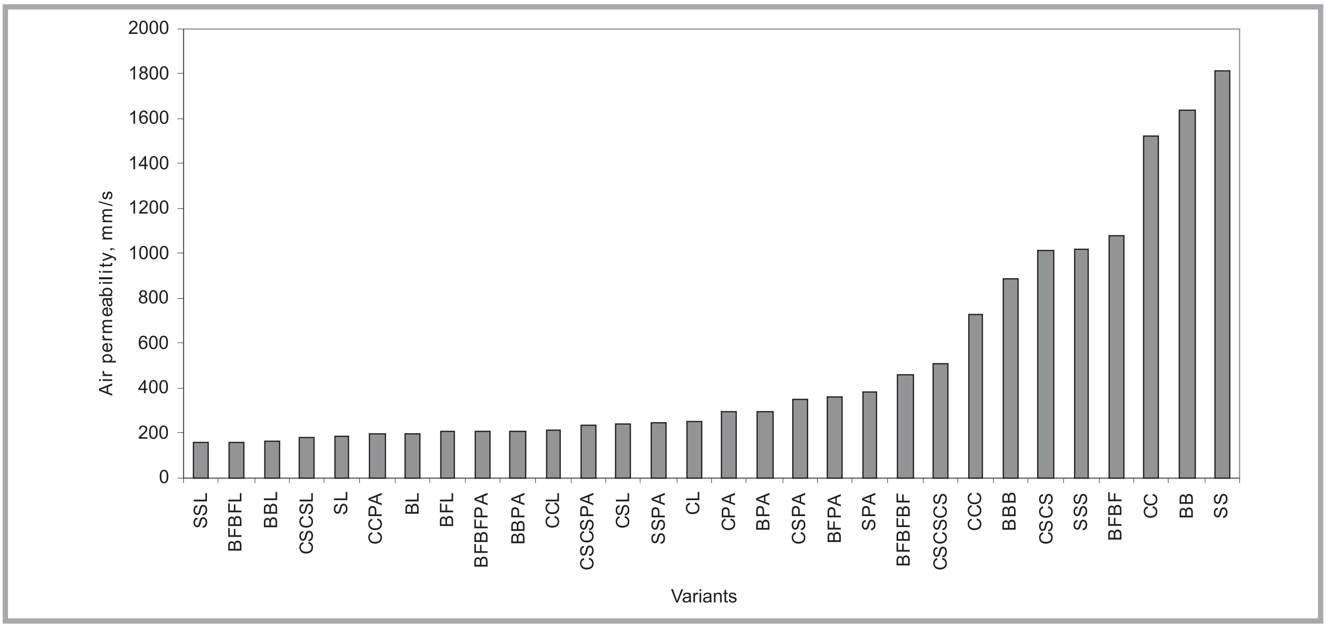

Figure 1. *Air permeability of samples of knitted socks, as denoted in Table 1.*

Lycra threads have lower air permeability (ranging from 152.8 – 359.9 mm/s). The highest values are shown by knits manufactured from two pure yarns: cotton - seacells (1010.4 mm/s), bamboo - flax (1074.6 mm/s), cotton (1519.7 mm/s), bamboo (1639.9 mm/s), soybean (1812.8 mm/s).

To describe the results in terms of air permeability dependence on area density, a polynomial equation was used because it shows the highest determination coefficient. In ***Figure 2*** the dependence of air permeability on the area density of knits from cotton, bamboo and soybean is presented; the determination coefficient of the equation obtained is R^2 = 0.989 (cotton), R^2 = 0.974 (bamboo), and R^2 = 0.976 (soybean). In order to obtain these dependences, all plain and plated knits for each fibres were used. As mentioned earlier, these results confirm that the air permeability decreases with the increasing area density of the samples. A comparison was made of the knits manufactured from different (cotton, bamboo, soy) fibres but with the same linear density (14 tex). Results of the air permeability of knits for socks manufactured using two or three pure yarns per loop (linear density 28 tex and 42 tex), as well as a combination with textured polymide PA or Lycra threads are presented in ***Figure 3***. When samples were manufactured from 28 tex or 42 tex yarns of pure fibre, the highest air permeability was for the knit from soy. Samples knitted with the same linear density of cotton yarns showed lower air permeability than those manufactured from bamboo, which was even lower than soy knits.

Results of samples knitted from a combination with PA threads show lower air permeability than knits from pure yarns. When samples were manufactured from a combination of one pure yarn and one textured polyamide thread (linear density 34 tex), the highest air permeability was for knits manufactured from one soy yarn and one polyamide thread, which was 28% higher than the air permeability of samples knitted from a combination of one cotton yarn and one textured polyamide thread, and higher than that of a combination of bamboo yarn and textured PA. The air permeability of knits from cotton and polyamide and from bamboo and polyamide is the same. When samples were manufactured from a combination of two pure yarns and one textured polyamide thread (linear density 48 tex), the highest air permeability was also in knits from two soy yarns and polyamide, which was 27% higher than the air permeability of samples manufactured from cotton and textured polyamide, and compared with that from a combination of bamboo and textured PA, the difference was not so apparent. Knits made from a combination of cotton yarns and textured PA did not differ so distinctly from those made with bamboo yarns and polyamide.

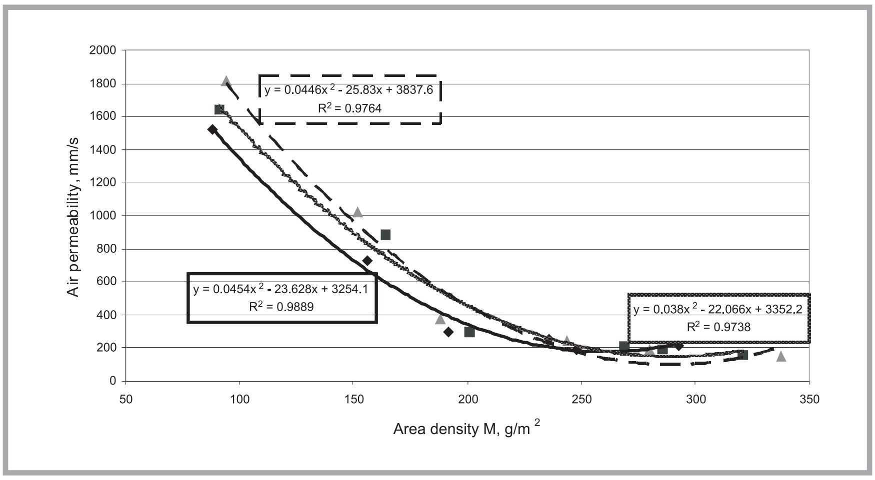

***Figure 2**. Air permeability as a function of the area density of all the cotton (♦), bamboo (■) and soybean (▲) knit variants.*

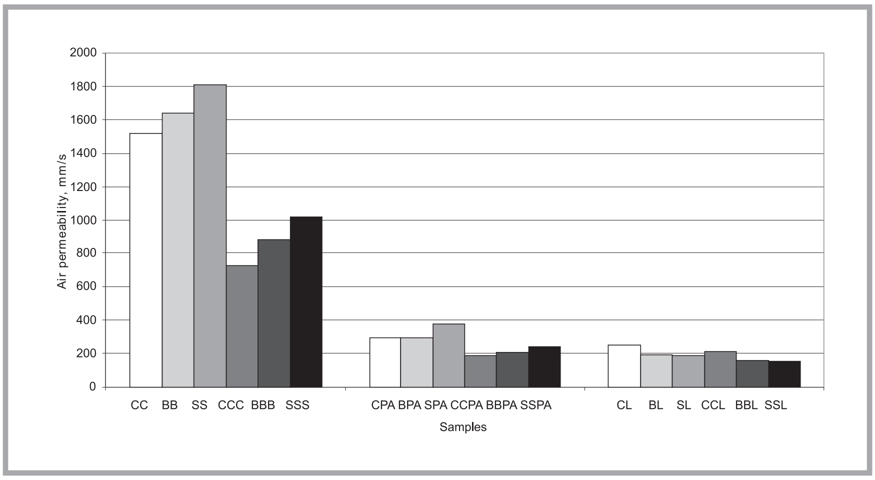

***Figure 3**. Air permeability of knits manufactured from two or three pure yarns of cotton, bamboo, soybean (28 tex and 42 tex) and its combination with textured PA (34 tex and 48 tex) and Lycra (24 tex and 38 tex) threads.*

From results we can see that Lycra thread decreases air permeability much more than textured PA. When samples were manufactured from a combination of one pure yarn and one Lycra thread (linear density 24 tex), the highest air permeability was shown by knits manufactured from a combination of cotton and Lycra, which was 24% higher than samples manufactured from a combination of bamboo and Lycra and 26% higher than knits from soy and Lycra thread. When samples were manufactured from a combination of two pure yarns and one Lycra thread (linear density 38 tex), as in the combination with one pure yarn and Lycra thread, the highest air permeability was shown by knits manufactured from a combination of cotton and Lycra, which was 25% higher than knits from a combination of bamboo yarns and one Lycra thread and 28% than samples knitted from a combination of soy yarns and Lycra thread.

Also, a comparison was made of the knits made from the same fiber but with a different linear density. Comparing knits from two or three pure yarns, it is obvious that the area density increases and the air permeability decreases in all the variants of knits. When knitted samples are manufactured from the yarns investigated including textured PA or Lycra, the air permeability decreases as well. As the yarns investigated are single, the loop length is longer and air flows more easily. Stretch textured polyamide and Lycra thread make the sample more tightly knitted, the loop length shorter and the air flow worse. Comparing knits manufactured from pure yarns and knits with textured PA, it is evident that the air permeability decreases by about 78%. Comparing knits manufactured from pure yarns and knits with Lycra, the air permeability decreases by about 83%, being much more than with textured PA. The same trend in air permeability variation was noted of knits manufactured from blended cotton - seacell and bamboo - flax yarns. The air permeability of all the knit variants manufactured from cotton - seacell yarns did not differ so distinctly from knits of bamboo - flax. Comparing the knits manufactured from pure yarns and knits with textured PA or Lycra threads, the air permeability decreases by about 60% and 72%, respectively.

Verification of the correlation between the air permeability and tightness factor TF or loop length l was performed. There was not any correlation for all the plated knit variants with textured PA and elastane Lycra threads, which could be explained by the diverse porosity of knits manufactured from threads (PA or Lycra) with high stretch and bulk properties. A weak correlation exists between the air permeability and the tightness factor only for knits manufactured from pure yarns.

Conclusions

The research on the air permeability of cotton, bamboo, soybean, cotton - seacell, bamboo - and flax knitted socks with different stucture parameters and raw material compositions can be summarised as follows:

- It was determined that higher air permeability is characteristic for knits manufactured only from pure yarns, a lower *permeability* for knits with textured PA, and the lowest for knits with Lycra threads. The air permeability of knits depends on the linear density and raw material composition. Textured PA increases air permeability compared with Lycra thread. By interchanging these stretch threads, we can control the area density, loop length and, most importantly, air permeability.
- Air permeability decreases with an increase in area density of samples; therefore, there is a good relation between area density and air permeability for all the kinds of knits examined. The experimental results are best described by a polynomial equation for the function of air permeability to area density. The determination coefficients of the equations obtained is $R^2 = 0.989$ (cotton), $R^2 = 0.974$ (bamboo) and $R^2 = 0.976$ (soybean).
- There was no correlation between the air permeability, tightness factor and loop length of knits manufactured from compositions with textured PA and Lycra threads. A weak correlation exists between the air permeability and tightness factor of knits manufactured from pure yarns.
- Cotton – seacell fibre reduces the air permeability of the knits examined compared with knits manufactured from pure cotton yarns, where the linear density is the same. Bamboo – flax fibre reduces the air permeability of the knits tested compared with knits manufacutred from pure bamboo yarns, where the linear density is the same.
- For warm season socks, knits from natural yarns would be used as they are characterised by higher air permeability, creating a cool feeling for the wearer.. For cold season socks, plated knitted structures of textured polyamide (PA) and elastane wrapped with textured polyamide threads (Lycra) would be used as they are characterised by lower air permeability, creating a warm feeling for the wearer.

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