Thermophysiological wear comfort of viscose and tencel socks

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Abstract:

Men's socks were designed and manufactured in multiple plated single jersey structure using 20 tex viscose and Tencel yarn, 156 and 220 dtex multifilament PA 6.6 yarn and 25 tex cotton yarn. Sock mass and sock thickness were determined, the height of the sock leg, the length of the sock foot and half of the leg circumference and half of the foot circumference were measured. Thermophysiological sock wear comfort was determined by measuring thermal resistance on the thermal foot manikin. The results revealed that the sock samples containing the ring spun yarn in the structure had higher thermal resistance than the socks containing rotor and air-jet spun yarns. The obtained difference of thermal resistance of the sock samples per type of the basic yarn was significant. The viscose socks made of ring spun yarns with an added coarser cotton yarn and PA 6.6 yarn had the highest thermal resistance, while the lowest thermal resistance was recorded for the Tencel rotor spun yarns.

Keywords:

wear comfort, socks, knitted fabric, thermal resistance, Thermal foot manikin

1. Introduction

The thermal comfort of the foot is influenced by the transfer of heat and moisture within the clothing system. Foot comfort has a great influence on overall body comfort. The feet are located in a closed system formed by the socks covered by the shoes, making it much more difficult to achieve thermal comfort or neutrality and dryness. When sweat evaporation increases, the relative humidity of the microclimate increases. A feeling of discomfort is caused by the inability of clothing, socks or shoes to transfer vapour or liquid to the environment [1, 2]. Impermeable footwear and the inability of socks to conduct sweat to the outside leads to the accumulation of sweat within a closed system (shoe + sock), creating a feeling of moisture. The amount of sweat depends on the environmental conditions, physical activity, the individual characteristics of the person and the type of textile materials used in the manufacture of shoes and socks [3]. In cold environments, sweat that has accumulated in the so-called closed system around the feet - with the exception of cold and damp feet - can cause foot injuries due to softer skin and health problems as a result from the presence of microorganisms [3-5]. Cotton and regenerated cellulose fibres are the most common materials used for clothing worn next to the skin such as socks, underwear and sportswear. Thermal resistance is the main parameter that affects the thermal comfort of clothing systems. It is measured on a hot plate or thermal manikin or thermal foot [6-8]. The influence of fibre type on thermal resistance becomes apparent in wet materials. The water fills the spaces that have been filled with air by increasing the transfer of moisture. The geometric characteristics of woven and knitted fabrics affect thermal resistance, air permeability and water vapour, while moisture transfer is influenced by fibre characteristics [9]. A study by Frydrych et al. compares the thermal comfort properties of fibres. It was found that Tencel® has lower thermal conductivity and absorption, but higher thermal diffusion and air permeability than cotton [10]. However, when comparing the thermal conductivity of Tencel® with other regenerated cellulose fibres, a higher thermal conductivity was found than with Modal and viscose fibres [11]. Stanković et al. (2008) concluded that the order of thermal resistance values of cellulose knitted fabrics starting from the maximum is: cotton, linen, viscose, linen/viscose, linen/cotton [12]. In a study by Gün (2011), the maximum values of thermal resistance among cellulosic materials were determined for modal fabrics and the minimum values for micromodal fabrics [13]. Thermal resistance is defined as the ability of the material to resist a heat flow across it. The scope of literature research on thermophysiological properties of manufactured socks is very limited. Most of the literature investigates the thermophysiological properties of the knitted fabrics of which socks are made [14, 15]. The group of authors Čiukas et al. conducted a thermal conductivity study of 30 types of knitted fabrics made of different fibre types, with or without the addition of textured PA and elastane thread (Lycra). The obtained values of the thermal conductivity coefficient range from 0.028 to 0.0644 W/(m °C), while the values of thermal resistance range from 0.0119 to 0.0401 m² °C W-1 [16, 17]. The results of a study by Gun et al. prove that the knitted in elastane thread has a significant effect on thermal conductivity [18]. The thermal resistance of a knitted fabric depends on the thickness and mass of the fabric as well as on its porosity [19]. Heat is transferred in humans through evaporation of sweat. Increased sweating causes a sudden increase in body heat loss by raising the ambient temperature above the comfortable body temperature [20]. Heat transfer by evaporation from the skin surface depends on the amount of moisture on the skin and the difference between the water vapour pressure on the skin and the environment [21]. Under normal conditions, heat loss occurs between 50 and 70 kJ/h, or 450 to 600 ml of sweat evaporates daily [20]. The aim of this paper is to investigate the influence of the type and different raw material composition of yarns added to basic viscose and Tencel yarns in socks which influence thermal resistance as one of the most important thermo-physiological parameters of wear comfort.

2. Experimental part

2. 1. Materials and methods

For the purposes of this paper sock samples made of viscose (Viscose® - V) and lyocell (Tencel® - T) fibres with the addition of cotton (PR) and polyamide (PA) yarns of different counts (Table 1) were used. The basic yarns were spun on a ring spinner (designated as R), rotor spinner (designated as RO) and air-jet spinner (designated as AJ). The yarns are intended for knitting (Fig. 1). Men's viscose socks size 42 were designed and manufactured on an automatic sock knitting machine with a cylinder diameter of 95 mm (3 ¾ inches) which knits with 108 needles. Socks were manufactured of 20 tex viscose yarn, 156 and 220 dtex filament PA 6.6 yarn and 25 tex cotton yarn in multiple plated single jersey structure. The sock cuff contains a knitted in elastane yarn.

The average weight of socks was determined by individual weighing of four socks, and the mean value of the weight of one sock was calculated [22]. The sock thickness was measured using a thickness gauge (model 2000-U, HESS MBV GmbH, Sonsbeck, Germany, ISO 9073-2) in ten different places. One plate was inserted into the sock leg, and the other two plates were placed on the outside of the sock, and the thickness of the "sandwich" was measured. Subtracting the thickness of the plates (3 plates 3 mm) from the thickness of the sandwich gives the sock thickness. The thickness of the sock knitted fabric is half the thickness of the sock [22]. The sock dimensions were measured in such a way that the socks were straightened out on a flat surface, and the length measurement instrument was used to measure the length with a reading accuracy of 1 mm. [22]. The method of measuring sock dimensions is shown in Figure 2.

Tab. 1 Abbreviations and description of sock samples

Samples	Abbreviations	Yarns	Yarn label	Knitting
*VR – Viscose ring spun yarn	VR_A	Viscose and polyamide yarns	Viscose 20 tex x 3 + PA 6.6 156 dtex f68 x 1	Knitted with four yarns in a row
	VR_B		Viscose 20 tex x 3 + PA 6.6 220 dtex f68 x 1	
	VR_C	Viscose, cotton and polyamide yarns	Viscose 20 tex x 2 + cotton 25 tex x 1 + PA 6.6 220 f68 dtex x 1	
VRO – Viscose rotor spun yarn	VRO_A	Viscose and polyamide yarns	Viscose 20 tex x 3 + PA 6.6 156 dtex f68 x 1	Knitted with four yarns in a row
	VRO_B		Viscose 20 tex x 3 + PA 6.6 220 dtex f68 x 1	
	VRO_C	Viscose, cotton and polyamide yarns	Viscose 20 tex x 2 + cotton 25 tex x 1 + PA 6.6 220 dtex f68 x 1	
VAJ – Viscose air-jet spun yarn	VAJ_A	Viscose and polyamide yarns	Viscose 20 tex x 3 + PA 6.6 156 dtex f68 x 1	Knitted with four yarns in a row
	VAJ_B		Viscose 20 tex x 3 + PA 6.6 220 dtex f68 x 1	
	VAJ_C	Viscose, cotton and polyamide yarns	Viscose 20 tex x 2 + cotton 25 tex x 1 + PA 6.6 220 dtex f68 x 1	
TR – Tencel ring spun yarn	TR_A	Tencel and polyamide yarns	Tencel 20 tex x 3 + PA 6.6 156 dtex f68 x 1	Knitted with four yarns in a row
	TR_B		Tencel 20 tex x 3 + PA 6.6 220 dtex f68 x 1	
	TR_C	Tencel, cotton and polyamide yarns	Tencel 20 tex x 2 + cotton 25 tex x 1 + PA 6.6 220 dtex f68 x 1	
TRO – Tencel rotor spun yarn	TRO_A	Tencel and polyamide yarns	Tencel 20 tex x 3 + PA 6.6 156 dtex f68 x 1	Knitted with four yarns in a row
	TRO_B		Tencel 20 tex x 3 + PA 6.6 220 dtex f68 x 1	
	TRO_C	Tencel, cotton and polyamide yarns	Tencel 20 tex x 2 + cotton 25 tex x 1 + PA 6.6 220 dtex f68 x 1	
TAJ – Tencel air-jet spun yarn	TAJ_A	Tencel and polyamide yarns	Tencel 20 tex x 3 + PA 6.6 156 dtex f68 x 1	Knitted with four yarns in a row
	TAJ_B		Tencel 20 tex x 3 + PA 6.6 220 dtex f68 x 1	
	TAJ_C	Tencel, cotton and polyamide yarns	Tencel 20 tex x 2 + cotton 25 tex x 1 + PA 6.6 220 dtex f68 x 1	

PR – cotton ring yarn; *VR – results published in the literature [21]

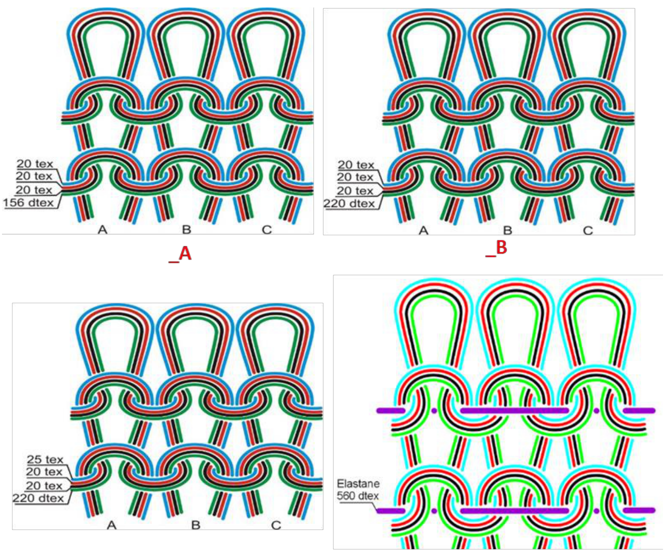

Fig. 1 View of the yarn in the structure of the leg and cuff of the sock; group of sock samples A, group of sock samples B, group of sock samples C

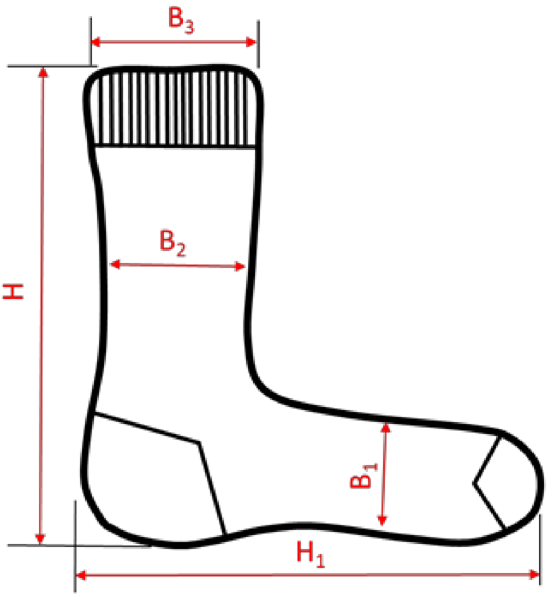

Fig. 2 Sock shape with main measurements, H – sock length, H1 – length of the sock foot, B1- half the foot circumference, B2 – half the circumference of the length H, B3 – half the circumference at the ankle height [21, 22]

2. 2. Determination of thermal resistance on the thermal foot manikin

Two objective parameters for the evaluation of thermophysiological properties are heat transfer resistance (thermal resistance) and water vapour resistance. Thermal resistance Rct (m² °C W^{-1}) generally depends on the measured sample thickness d (mm) and its thermal conductivity λ (W (°C m)$^{-1}$). It is calculated according to the expression:

$$R_{ct} = \frac{d}{\lambda} \qquad (1)$$

Thermal resistance of socks was measured on the thermal foot manikin which is divided into 13 segments (Fig 3). Each segment is separately heated at 35 °C [21, 23, 24]. Figure 4 shows the interface of the thermal foot manikin control unit with data display. The socks are placed on the thermal foot manikin, so as to cover the whole measuring surface, i.e. all segments (Fig. 3). The procedure for measuring thermal resistance is as follows: the basic sock is stabilized for 20-30 minutes, and then Rct0 is measured. A sock sample is placed, and a 20-30 minute re-stabilization period is applied after which Rctu is measured. This procedure is repeated for each sock sample. Thus, the thermal foot manikin measures the resistance of the device with the basic sock (Rct0) and the total resistance of the device, the basic sock and the sample (Rctu). The thermal resistance of the tested sock sample Rct is obtained from the difference Rctu and Rct0 according to the expression [21]:

$$R_{ct} = R_{ctu} - R_{ct0} \qquad (2)$$

Since a certain amount of elongation of sock samples occurs after they have been placed on the thermal foot manikin, the method of measuring the unstretched sock and the resulting elongation of the sock is shown in Fig. 5. It is important to emphasize that the measurement of a stretched sock on the thermal foot manikin is measured along a curve (Fig. 5). The measurement procedure is described in detail in the literature [21]. The relative elongation of the sock on the part of the foot εs (%) is the elongation

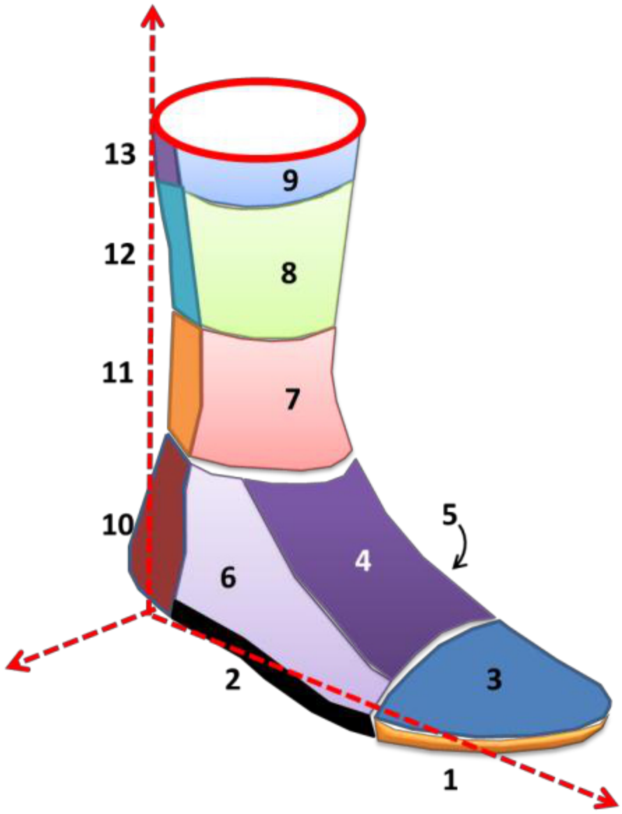

Fig. 3 Thermal foot manikin divided into 13 segments [23]

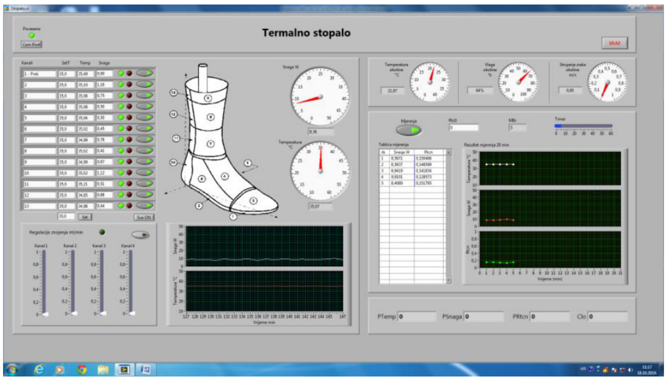

Fig. 4 Interface of the Thermal foot manikin control unit

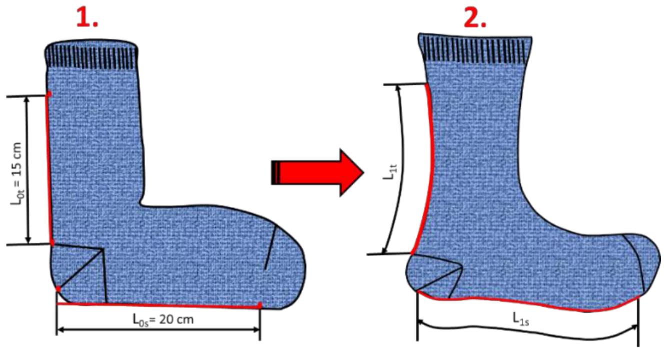

Fig. 5 Sample marking for measuring geometrical parameters of the unstretched and stretched sock along the curve

in the wale direction, which occurs by placing the sock on the thermal foot manikin, and it is calculated according to the expression [21]:

$$\varepsilon_s = \frac{\Delta L_s}{L_{0s}} = \frac{L_{1s} - L_{0s}}{L_{0s}} \cdot 100 \qquad (3)$$

The relative elongation on the part of the sock leg εt (%) is also calculated by measuring the elongation in the wale direction on the sock leg using the expression [21]:

$$\varepsilon_t = \frac{\Delta L_t}{L_{0t}} = \frac{L_{1t} - L_{0t}}{L_{0t}} \cdot 100 \qquad (4)$$

where: ΔLs, ΔLt – the absolute elongation of socks in the foot and the leg, L1s, L1t - the measured values after placing the sock on the thermal foot manikin in the wale direction, L0s, L0t - initial values of measuring the sock in the wale direction in the foot and the leg before placing the sock on the thermal foot manikin (L0t = 150 mm, L0s = 200 mm) [21].

3. Results and discussion

Sock dimensions

The height of the leg of the sock, the length of the foot of the sock, and half the leg circumference and half the circumference of the foot of the sock were measured. The dimensions of the sock samples, according to Fig. 1, are presented in Tables 2 and 3 and Figs 6-8. 5 measurements were taken at different locations on each of the 4 socks per sample. The range of deviation from the mean value was determined with a reliability of 95%. The total height of the sock (H) ranges from 233 mm for the VR_B sample to 253 mm for the TAJ_C sample (Table 2, Fig. 6). Comparing the mean values of

Tab. 2 Dimensions of sock samples as shown in Figure 1

Samples		H (mm)	H_1 (mm)	B_1 (mm)	B_2 (mm)	B_3 (mm)
*VR	VR_A	235 ± 3	274 ± 2	92 ± 1	87 ± 0	85 ± 0
	VR_B	233 ± 5	272 ± 2	93 ± 1	88 ± 1	86 ± 1
	VR_C	242 ± 3	273 ± 4	93 ± 1	89 ± 1	85 ± 1
VRO	VRO_A	251 ± 2	276 ± 5	91 ± 1	86 ± 1	84 ± 0
	VRO_B	251 ± 3	276 ± 4	93 ± 1	89 ± 1	85 ± 1
	VRO_C	248 ± 4	276 ± 2	95 ± 1	90 ± 0	86 ± 1
VAJ	VAJ_A	243 ± 4	278 ± 2	92 ± 1	87 ± 3	84 ± 1
	VAJ_B	249 ± 1	278 ± 1	93 ± 1	90 ± 1	84 ± 0
	VAJ_C	249 ± 3	279 ± 2	94 ± 1	91 ± 1	86 ± 1
TR	TR_A	244 ± 2	274 ± 3	93 ± 1	87 ± 1	85 ± 1
	TR_B	246 ± 2	276 ± 3	94 ± 1	88 ± 0	85 ± 0
	TR_C	244 ± 4	273 ± 5	93 ± 2	89 ± 2	86 ± 1
TRO	TRO_A	249 ± 2	279 ± 1	93 ± 1	88 ± 1	85 ± 1
	TRO_B	252 ± 3	276 ± 2	94 ± 1	91 ± 1	85 ± 1
	TRO_C	249 ± 2	276 ± 2	95 ± 0	91 ± 1	86 ± 1
TAJ	TAJ_A	242 ± 2	268 ± 2	89 ± 1	86 ± 1	84 ± 1
	TAJ_B	252 ± 2	268 ± 2	95 ± 1	91 ± 1	85 ± 1
	TAJ_C	253 ± 4	277 ± 5	95 ± 1	92 ± 1	85 ± 1

*VR – results published in the literature [21] the height of the leg of the sock H and the length of the foot H1 for the group of yarn samples marked VR, VRO and VAJ shows the influence of the type of the basic yarn (R, RO, AJ) and the type of the raw materials (V, T, PR, PA) on sock dimensions. For example, the greatest difference obtained in the sock samples containing the basic viscose yarn in the height of the leg was 5.5% and it was determined between VR and VRO (Fig. 7). The largest difference in the height of the leg of the sock in the samples containing the basic tencel yarn is 2%, and practically negligible (Fig. 6). Furthermore, the influence of viscose and Tencel as the basic raw material and other raw materials in the sock samples is negligibly small and amounts to 1.2% (Fig. 8).

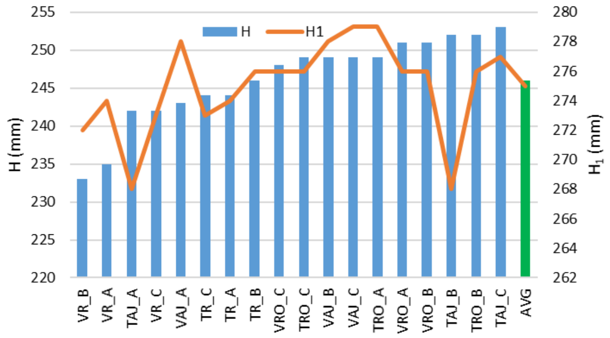

Fig. 6 Comparison of the height of the leg of the sock (H) and the length of the foot (H1)

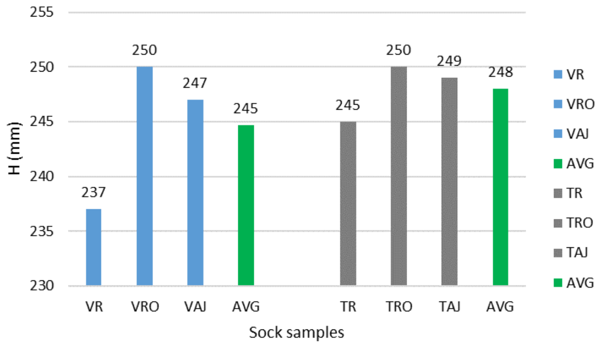

Fig. 7 Mean values of the height of the leg of the sock (H) for the group of samples

With regard to the length of the sock foot (H1), Table 2, Fig. 7, very small differences were found which are practically negligible. In other words, the influence of raw material and yarn type on the structure of the socks is not significant.

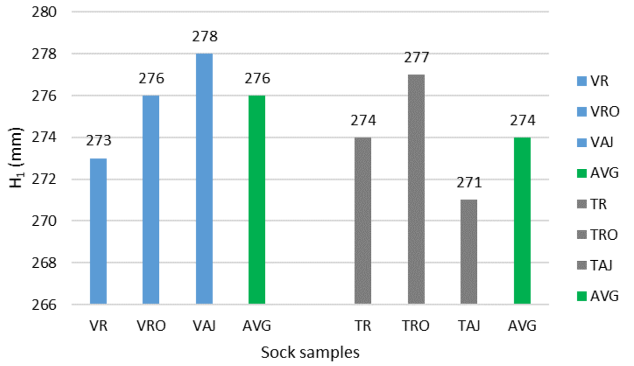

Fig. 8 Mean values of the length of the leg of the sock (H1) for the group of samples

Mass and thickness of socks

The results of the mass and thickness of the socks are presented in Table 3 and Figs. 9-12. 5 measurements of mass and thickness were performed in different places on each of 4 socks per sample. The range of deviation from the mean value was determined with a reliability of 95%. The greatest difference in the mass of viscose socks was found between the samples dominated by the rotor spun yarn (VRO_A) compared with the knitted fabric, where the ring spun yarn (VR_A) is dominant and amounts to 4.8% (Tab. 3, Fig. 9, 10). The mass of viscose socks made of the rotor spun and air-spun yarn is significantly uniform and is greater than the mass of ring spun yarn samples. The mass of viscose socks containing the rotor and air-jet spun yarn is significant. Although the difference in the mass of socks is less than 5%, some differences were obtained, and the reason may be the difference in the structure of ring spun yarns (R), rotor spun yarns (RO) and air-jet spun yarns (AJ).

Tab. 3 Knitted fabric thickness of the sock and mass of socks samples

		Mass of the sock (g/piece)	Sock thickenss (mm)
*VR	VR_A	18.7 ± 0.0	1.20 ± 0.02
	VR_B	20.9 ± 0.1	1.28 ± 0.01
	VR_C	22.7 ± 0.0	1.37 ± 0.02
VRO	VRO_A	19.6 ± 0.1	1.18 ± 0.01
	VRO_B	21.8 ± 0.0	1.27 ± 0.01
	VRO_C	23.1 ± 0.0	1.37 ± 0.02
VAJ	VAJ_A	19.4 ± 0.0	1.26 ± 0.01
	VAJ_B	21.6 ± 0.0	1.27 ± 0.01
	VAJ_C	23.2 ± 0.0	1.37 ± 0.02
TR	TR_A	19.1 ± 0.0	1.24 ± 0.01
	TR_B	21.4 ± 0.0	1.33 ± 0.01
	TR_C	22.8 ± 0.1	1.43 ± 0.02
TRO	TRO_A	19.3 ± 0.0	1.21 ± 0.02
	TRO_B	21.7 ± 0.0	1.32 ± 0.01
	TRO_C	23.2 ± 0.1	1.43 ± 0.01
TAJ	TAJ_A	19.7 ± 0.1	1.22 ± 0.01
	TAJ_B	21.8 ± 0.0	1.33 ± 0.02
	TAJ_C	23.3 ± 0.1	1.42 ± 0.01

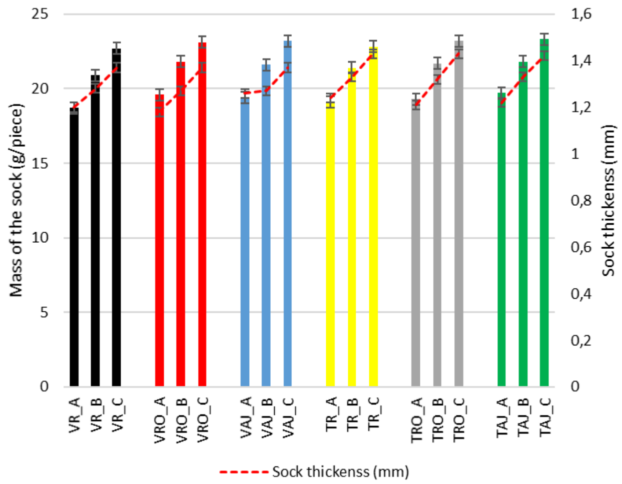

Fig. 9 Comparison of mass and thickness of socks

In the case of Tencel sock samples, the largest difference of 3.1% was obtained between the samples of air-jet spun yarn (TAJ_A) and ring spun yarn (TR_A) and here, as in the case of viscose sock samples, the lowest mass was found in samples of ring spun yarns.

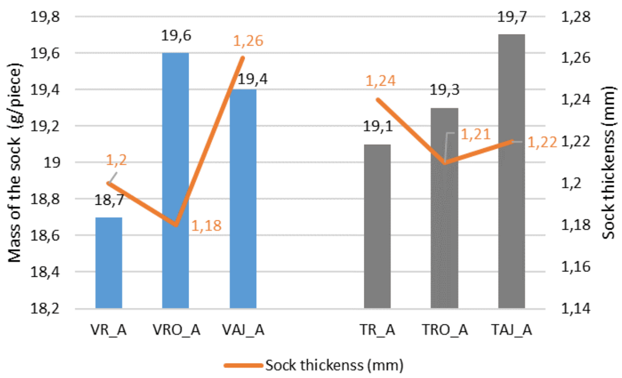

Fig. 10 Comparison between the mass and thickness of the socks of the group A samples

The group B samples, where coarser polyamide yarn (PA 6.6 220 dtex) was used in contrast to the group A samples, show the same trend in the mass of the socks, i.e. the biggest difference is less than 5%. Knitted fabric samples made of the ring spun yarn have a lower mass than samples made of rotor or air-jet spun yarn (Figs. 9, 11).

Sock samples with a coarser 25 tex cotton yarn instead of a single viscose thread show the same trend as sock samples of group A and B (Fig. 9, 12). Thus, the largest difference in mass, both in viscose and tencel socks, between the samples of socks containing the air-jet spun yarn and the samples containing the ring spun yarn is 2.2% (Fig. 12). There are no differences in the thickness of the sock samples of group A between viscose and tencel knitted fabrics containing 156 dtex PA 6.6 yarn (equal to the mean value of 1.21 mm).

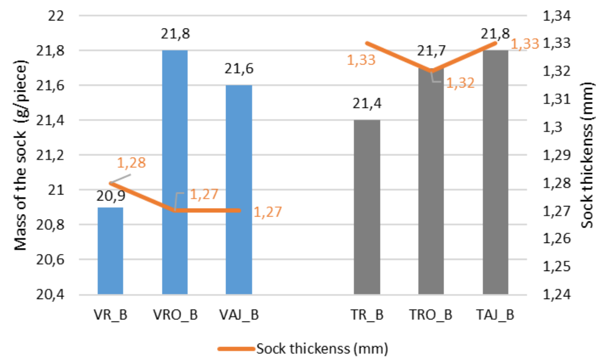

Fig. 11 Comparison between the sock mass and thickness of sample groups B

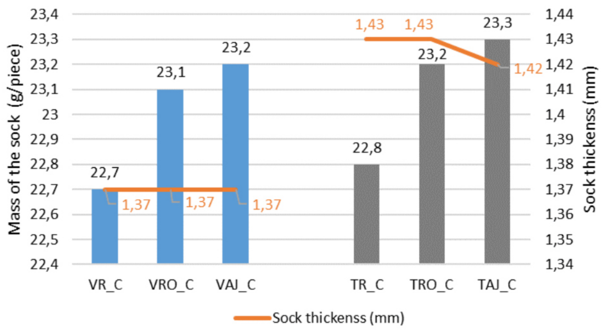

Fig. 12 Comparison between the sock mass and thickness of sample groups C

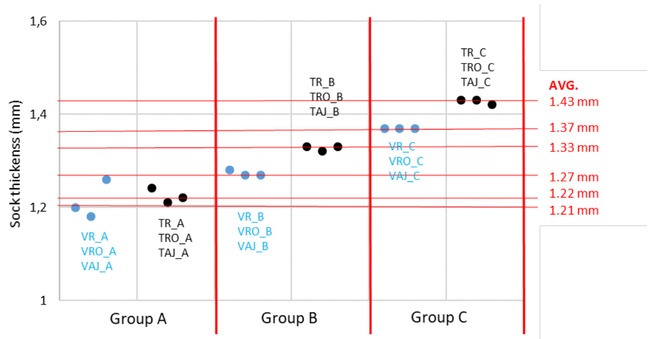

Fig. 13 Sock thickness per sample groups A. B and C

Thickness of sock samples of viscose + PA 156 dtex and tencel + PA 156 dtex (group A samples)

Sock samples made of viscose yarn + PA 156 dtex yarn differ in thickness by a maximum of 6.8% (VR_A and VAJ_A), Figs. 10, 13. The mean values of the thickness of viscose and tencel socks are practically indistinguishable from each other amounting to 1.21 mm and 1.22 mm, so that there is no influence of the raw material on the sock thickness. In addition, sock samples made of Tencel + PA 156 dtex yarns show the biggest difference in thickness of 2.5% (TR_A and TRO_A). This difference is practically negligible.

Thickness of sock samples of viscose + PA 220 dtex and tencel + PA 220 dtex (group B samples)

The difference in the thickness of the socks made of the viscose yarn with an added 220 dtex coarser PA yarn using different types of yarn (R, RO, AJ) is negligibly small (Figs. 11, 13). An equally small difference was obtained in the samples of Tencel socks by adding a coarser PA yarn with a count of 220 dtex using different types of yarn (R, RO, AJ). The difference in the mean value of the thickness of the viscose and tencel sock samples is 4.7%, which can be regarded as random.

Thickness of viscose sock samples + PK + PA 220 dtex and tencel + PK + PA 220 dtex (group C samples)

The difference in the thickness of the socks made of the viscose yarn with an added 25 tex cotton yarn and 220 dtex coarser PA yarn is practically non-existent (Figs. 12, 13). Similarly, the difference in the thickness of the socks made of the tencel yarn with an added 25 tex cotton yarn and PA 220 dtex yarn is practically negligible. The difference in the thickness of socks for knits that differ in the basic yarn viscose and tencel is 4.4% and it can be regarded as random.

Sock thickness per sample groups A. B and C

The difference in the mean values of the thickness of the sock samples between groups of samples A, B and C ranged from 6.6% (groups B and A) to 14.8% (sample groups C and A). The obtained difference in thickness is a consequence of a higher percentage of the coarser 20 dtex PA yarn (sample group B) or 25 tex cotton yarn and coarser 220 dtex PA yarn (sample group C). The results of the calculated elongation according to formulas 3 and 4 are shown in Table 4 and Figs. 14, 15.

The elongation of the foot on the Thermal foot manikin of all sock samples ranges from 0% to 5.85%, while the elongation of the leg of the socks lies in the range from 2.87% to 15.80% (Table 4, Fig. 14).

The effect of the coarser 220 dtex PA multifilament yarn used in sock samples of group B compared to group A, where a finer 156 dtex PA multifilament yarn (group A) was used on the elongation of the foot and leg

Tab. 4 Results of the elongation of the sock samples on the thermal foot manikin

		L_{1s} (mm)	SD (mm)	CV (%)	ε_s (%)	L_{1t} (mm)	SD (mm)	CV (%)	ε_t (%)
*VR	VR_A	207.7	3.79	1.82	3.85	166.3	4.04	2.43	10.57
	VR_B	204.0	1.41	0.69	2.00	166.0	4.24	2.56	10.67
	VR_C	204.3	3.06	1.50	2.15	158.3	2.52	1.60	5.53
VRO	VRO_A	205.3	0.58	0.28	2.65	171.7	2.89	1.68	14.47
	VRO_B	211.7	2.89	1.36	5.85	168.7	1.16	0.70	12.47
	VRO_C	203.7	1.53	0.75	1.85	173.7	3.22	1.85	15.80
VAJ	VAJ_A	203.3	2.89	1.42	1.65	161.3	1.53	0.95	7.53
	VAJ_B	205.7	1.16	0.56	2.85	157.0	2.65	1.69	4.67
	VAJ_C	203.7	2.31	1.13	1.85	163.3	2.89	1.77	8.87
TR	TR_A	210.0	0	0	5.00	168.3	2.89	1.72	12.20
	TR_B	209.3	1.16	0.55	4.65	164.7	0.58	0.35	9.80
	TR_C	205.7	2.52	1.22	2.85	169.0	4.58	2.71	12.67
TRO	TRO_A	200.0	0	0	0	156.0	1.00	0.64	4.00
	TRO_B	205.3	5.03	2.45	2.65	163.3	2.89	1.77	8.87
	TRO_C	204.3	0.58	0.28	2.15	160.0	0	0	6.67
TAJ	TAJ_A	205.0	0	0	2.50	161.7	2.52	1.56	7.80
	TAJ_B	205.0	0.58	0.28	2.50	154.3	1.15	0.75	2.87
	TAJ_C	205.0	0	0	2.50	164.7	0.58	0.35	9.80

*VR – results published in the literature [21]

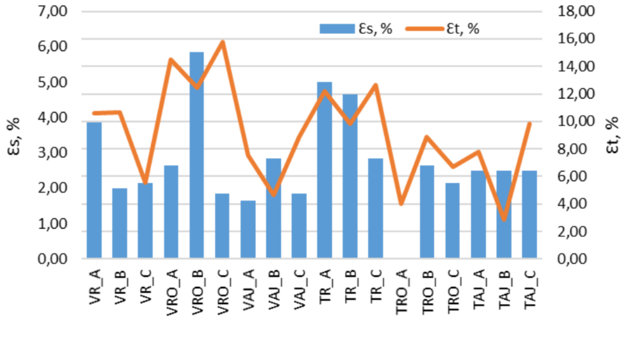

Fig. 14 Elongation of the foot (εs) and the leg (εt) of the samples of viscose and tencel socks

of the sock is low, which is confirmed by their average elongation values (7.7% and 9.4%, Fig. 15). The elongation of the leg of the socks of group C, where instead of one viscose or tencel yarn a coarser 25 tex cotton yarn was added, is 9.9% and is slightly higher than the elongation of group A and group B. As the differences in the mean values of the elongation of the sock leg between the groups are still small, it can be said that they are not influenced by the raw material (Figure 15).

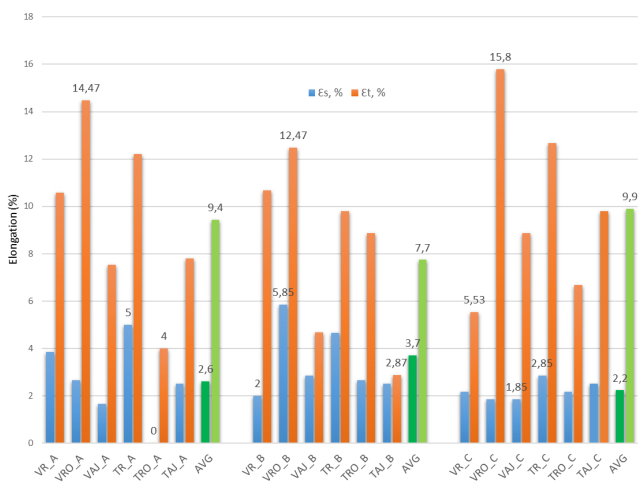

Fig. 15 Elongation of the foot (εs) and the leg (εt) of the viscose and tencel sock samples according to sock groups A, B and C

The elongation of the leg of the sock having a basic viscose air-jet spun yarn ranges from 4.7% (VAJ_B) to 15.8% of the sample of the viscose rotor spun yarn (VRO_C). Average leg values of the sock range from 7.0% for samples with the air-jet spun yarn to 14.2% for samples with the rotor spun yarn (Fig. 16). The values of the foot elongation of the sock samples range from 1.7% for the samples containing the air-jet spun yarn (VAJ_A) to 5.9% for the samples containing the rotor spun yarn (Table 4, Fig. 16). The average values of foot elongation differ slightly from each other and are a consequence of random nature. The cause of the difference in stretching the leg and foot of the sock is that the specimens stretch to a certain extent to cover the entire measuring surface of the Thermal Foot manikin. Care is taken to ensure that the heel of the sock covers the heel of the Thermal Foot manikin and the rest of the sock covers the entire leg of the Thermal Foot manikin. It was practically confirmed that it was necessary to stretch the leg of the sock more. Figure 16 (Table 4) shows that the leg elongation in the samples made of the basis Tencel yarn ranges from 2.9% for the sample made of the air-jet spun yarn (TAJ_B) to 12.7% for the sample made of the ring spun yarn (TR_C). The difference in the mean values of the elongation of the leg of the basic sock made of the basic tencel yarn is smaller than in the elongation of the leg of the samples of the basic viscose yarn. The difference in elongation is by 5.1% lower in value. Assuming that the difference in elongation is statistically insignificant, it can be said that the type of basic yarn (ring, rotor and airspun yarn) does not influence the elongation of the body of the sock samples. Assuming that the difference in elongation is statistically insignificant, it can be stated that the type of the basic yarn (ring-, rotor- and air-jet spun yarn) does not influence the elongation of the leg of the sock samples. The elongation of the foot of the sock samples made of the basic Tencel yarn is low and ranges from 0%

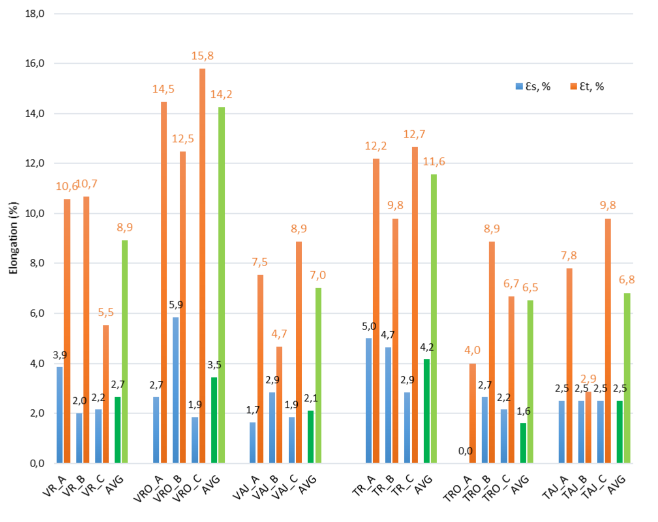

Fig. 16 Elongation of the foot (εs) and leg (εt) of viscose and tencel sock samples according to yarn type

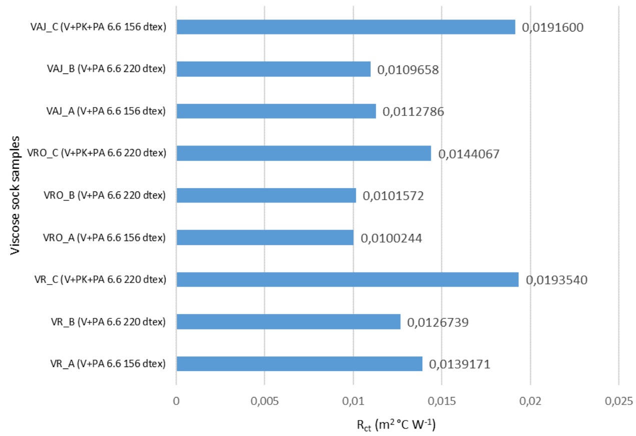

Fig. 17 Thermal resistance of viscose sock samples

(TRO_A) to 5.0% (TR_A). The differences in the elongation of the foot of individual samples are numerically small as well as the differences in the mean values.

Thermal resistance

Three thermal resistance measurements were performed for each sample. The samples were left for 24 hours at standard conditions of 20 ± 2 ° C, 65 ± 5% before measurement. The measurement results are presented in Table 5, where the mean value, standard deviation and coefficient of variation were calculated for each of the samples. A comparison of the results of thermal resistance of the samples is presented in Figures 17-20.

Sock samples made of basic viscose yarn

Socks of greater thickness and mass made of basic viscose ring spun yarn have higher thermal resistance (0.0193540 m^2 °C W^{-1}) compared to socks of lesser thickness and mass (0.0139171 m^2 °C W^{-1} or 0.0126739 m^2 °C W^{-1}), which is shown in Table 5 and Fig. 17. The difference in thermal resistance between the samples ranges from 9.8% to 52.7%. The influence of the raw material type on resistance is certainly included in the obtained values especially in the sample VR_C where cotton ring spun yarns were used instead of the viscose ring spun yarn. Cotton is known to have higher thermal conductivity (0.461 W m^{-1} °C^{-1}) than viscose (0.289 W m^{-1} °C^{-1}) [24].

Socks containing the base viscose rotor spun yarn of greater mass and thickness also have higher thermal resistance (0.0144067 m^2 °C W^{-1}) compared to the other two samples of lesser thickness and mass (Table 5, Fig. 17). The largest difference in thermal resistance achieved between the samples is 41.8% (Table 5, Fig. 17). Here too, as in the case of the sock samples made of the basic viscose ring spun yarn (VR_C), the influence of the cotton yarn of a lower count (25 tex) and its different thermal conductivity is certainly contained in the higher value of thermal resistance achieved (VRO_C, Fig. 17). In the case of sock samples containing the air-

Tab. 5 Results of thermal resistance (Rct) for samples of different socks

Samples		Rct (m^2 °C W^{-1})	CV (%)	Sock thickenss (mm)	Elongation of the leg (%)	Mass of the sock (g/kom)
*VR	VR_A	0.0139171	12.9	1.20	10.57	18.7
	VR_B	0.0126739	18.8	1.28	10.67	20.9
	VR_C	0.0193540	17.6	1.37	5.53	22.7
	AVG	**0.0153150**		**1.28**	**8.92**	**20.77**
VRO	VRO_A	0.0100244	19.6	1.18	14.47	19.6
	VRO_B	0.0101572	20.9	1.27	12.47	21.8
	VRO_C	0.0144067	13.4	1.37	15.80	23.1
	AVG	**0.0115294**		**1.27**	**14.25**	**21.5**
VAJ	VAJ_A	0.0112786	5.3	1.26	7.53	19.4
	VAJ_B	0.0109658	30.4	1.27	4.67	21.6
	VAJ_C	0.0191600	18.8	1.37	8.87	23.2
	AVG	**0.0138015**		**1.30**	**7.02**	**21.4**
TR	TR_A	0.0085398	31.8	1.24	12.20	19.1
	TR_B	0.0105169	10.4	1.33	9.80	21.4
	TR_C	0.0098625	23.1	1.43	12.67	22.8
	AVG	**0.0096397**		**1.33**	**11.56**	**21.10**
TRO	TRO_A	0.0070991	21.8	1.21	4.00	19.3
	TRO_B	0.0099896	3.7	1.32	8.87	21.7
	TRO_C	0.0149783	31.7	1.43	6.67	23.2
	AVG	**0.0106890**		**1.32**	**6.51**	**21.4**
TAJ	TAJ_A	0.0105655	23.2	1.22	7.80	19.7
	TAJ_B	0.0156811	34.3	1.33	2.87	21.8
	TAJ_C	0.0118242	6.3	1.42	9.80	23.3
	AVG	**0.0126903**		**1.32**	**6.82**	**21.6**

Rct – themal resistance (m^2 °C W^{-1}), SD – standard deviation (m^2 °C W^{-1}), CV – coefficient variation (%), AVG – Average, * [21]

jet spun viscose yarn thermal resistance is also higher here for the samples of greater thickness and mass (0.0191600 m^2 °C W^{-1}) compared to samples oflesser thickness and mass (0.0112786 or 0.0109658 m^2 °C W^{-1}, Table 5, Fig. 17). The mean values of thermal resistance according to the type of basic viscose yarn (P - ring, RO - rotor and AJ air-jet spun yarn, Tab. 5, Fig. 17) differ from each other. The highest value of thermal resistance was obtained for the samples containing the basic ring spun yarn (0.0153150 m^2 °C W^{-1}), and the lowest for samples of socks containing the basic rotor spun yarn (0.0115294 m^2 °C W^{-1}).

Sock samples made of the basic Tencel yarn

In the case of socks made of the basic tencel yarn, it can be seen that the lowest thermal resistance was obtained for the samples of the lowest thickness and mass (samples TR_A, TRO_A, TAJ_A, Tabele 5, Figs. 18). The mean values of thermal resistance of individual groups of samples containing different types of the basic yarn (R - ring, RO - rotor and AJ - air-jet spun yarn) differ from each other, ranging from 0.096397 to 0.0126903 m^2 °C W^{-1}.

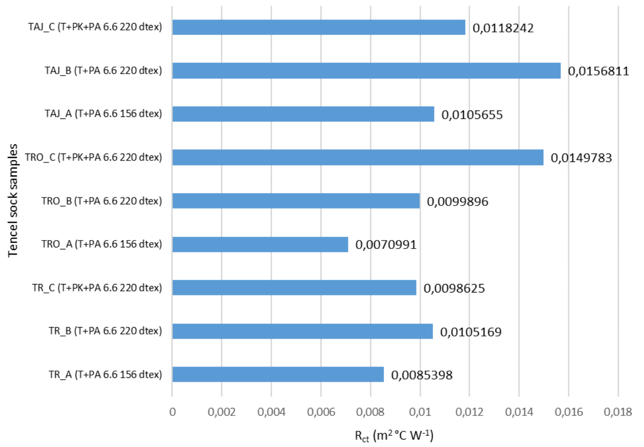

Fig. 18 Thermal resistance of tencel sock samples

The mean value of thermal resistance of socks made of the basic viscose yarn (all types of yarn, 0.013548633 m^2 °C W^{-1}) is higher than the mean value of thermal resistance of the basic tencel yarn (all types of yarn, 0.011006333 m^2 °C W^{-1}). The difference in the mean value of thermal resistance of the samples made of the basic viscose and Tencel yarn is 23.1% (Tab. 5, Fig. 19) and is certainly significant. In the case of Tencel sock samples, the thermal resistance results obtained differ from those of the basic viscose yarn samples. Although the mean values of the mass of socks by yarn type (R, RO, AJ) differ slightly (the difference is less than 0.8 g), the difference obtained for the thermal resistance of the samples per basic yarn type is still significant. The average elongation of the leg of the sock on the thermal foot manikin in the samples containing Tencel ring spun yarn is 11.6%, being higher than the elongation of the leg of the sock made of the basic viscose yarn (8.9%). structure, which may be the reason why the sample made of the basic Tencel ring spun yarn had a lower value of thermal resistance topline (0.0096397 m^2 °C W^{-1}).

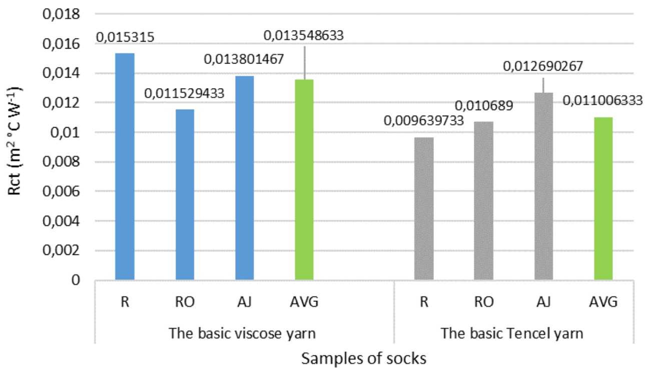

Fig. 19 Thermal resistance of sock samples depending on raw material and the type of basic yarn (R, RO, AJ)

The results of thermal resistance of socks depending on the type of the basic yarn (R, RO, AJ) are presented in Fig. 20. Sock samples containing the ring-spun yarn in the structure exhibit higher thermal resistance (0.0139171 m^2 °C W^{-1}) compared to the samples containing rotor and air-jet yarns (0.0100244 or 0.0112786 m^2 °C W^{-1}), Table 5, Fig. 20. Analogous results were obtained for sock samples containing the basic Tencel yarn. There is a difference in the mean values of thermal resistance, and a higher resistance was found in the samples of the basic viscose yarn.

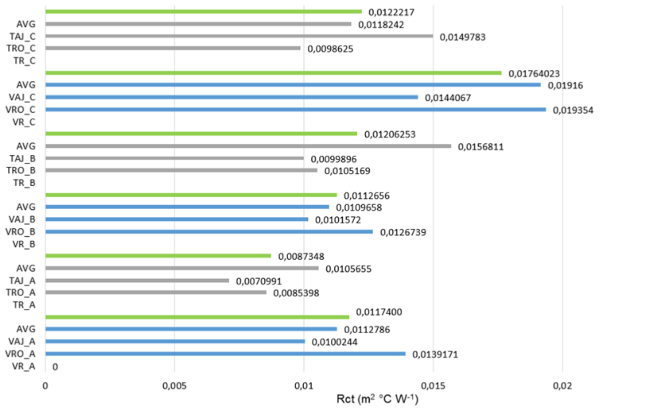

Fig. 20 Thermal resistance of viscose and Tencel socks of group A, B, C

In the case of sock samples containing the basic viscose ring spun yarn and the coarser PA multifilament yarn (VR_B), the highest thermal resistance (0.0126739 m^2 °C W^{-1}, Table 5, Fig. 20) was obtained, and the lowest in the sample made of the rotor spun yarn VRO_B (0.0101572 m^2 °C W^{-1}). Sock samples containing the basic viscose yarn with the addition of cotton yarn have different values of thermal resistance. The highest resistance was found in the sample containing the ring spun yarn VR_C (0.019354 m^2 °C W^{-1}), and the lowest in the sample containing the rotor spun yarn VRO_C (0.0144067 m^2 °C W^{-1}, Table 5, Fig. 20). In the case of samples containing the basic Tencel yarn, the thermal resistance values do not follow the values of the samples containing the basic viscose yarn and are on average lower.

4. Conclusion

The sock structure under the same knitting conditions depends on the number of yarns, yarn type (ring-spun, rotor-spun and air-jet spun), the type of raw material (viscose, Tencel, cotton, PA) and yarn count. Coarser yarns (cotton and PA) knitted into the samples of Viscose and Tencel socks result in a greater sock thickness and mass. The elongation of socks was determined on the thermal foot manikin during measuring thermal resistance of the socks in the area of the leg of the sock. It is higher in all samples and ranges from 2.87% to 15.80%, while the elongation in the foot area is lower in all samples and ranges from 0% to 5.85%. The cause of a greater sock leg elongation is the way how sock samples are placed on the thermal foot measurement area. The foot is covered so that the heel of the sock completely and properly covers the heel of the Thermal foot manikin, and the leg of the sock is stretched to cover all the remaining segments. Socks made of viscose ring spun yarns with the addition of 25 tex coarser cotton yarn and coarser PA 6.6 have the highest thermal resistance (VR_C, 0.0193540 m^2 °C W^{-1}), while socks made of the 20 tex tencel rotor spun yarn with the addition of one 156 dtex PA 6.6 yarn (TRO_A, 0.0070991 m^2 °C W^{-1}) has the lowest thermal resistance. Sock samples containing ring-spun yarn in the structure have higher thermal resistance compared to samples containing rotor and air-spun yarn. In the basic tencel yarn socks, the highest thermal was obtained in the samples made of air-spun yarn (0.012690267 m^2 °C W^{-1}). The mean thermal resistance of socks made of basic viscose yarn (all yarn types, 0.013548633 m^2 °C W^{-1}) is higher than the mean thermal resistance of basic Tencel yarn (all yarn types, 0.011006333 m^2 °C W^{-1}), and the difference is significant with 23.1%. Although the mean values of the mass of the socks by yarn type (R, RO, AJ) differ slightly (the difference is less than 0.8 g), the difference obtained in the thermal resistance of the samples by type of the basic yarn is nevertheless significant. Therefore, the type of yarn in these samples affects the thermal resistance of the socks. In samples containing theTencel ring spun yarn, the mean elongation of the sock leg on the thermal foot manikin was 11.6% and was higher than the elongation of the sock leg made of the basic viscose yarn (8.9%). Higher elongation reduces the thickness of the sock and changes its structure, which may be the reason why the sample made of the basic Tencel ring yarn spun yarn had a lower value of thermal resistance (0.0096397 m^2 °C W^{-1}) than the sample of the basic viscose ring spun yarn (0.0153150 m^2 °C W^{-1}). The influence of the type of raw material is certainly included in the obtained values of thermal resistance, especially in the group of samples containing cotton yarn instead of viscose yarn, as the thermal conductivity of cotton (0.461 W m^{-1} °C^{-1}) differs significantly from viscose.

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