Influence of structural and constructional parameters of knitted fabrics on the thermal properties of men's socks

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Abstract

The research is focused on determining the influence of structural and constructional parameters of rib knitted fabrics on the thermal properties of men's socks. Men's socks are made in three different pattern constructions of three types of basic yarns: bamboo, cotton and a cotton/polyester blend with the additional filament polyamide yarn and wrapped rubber wire for the so-called render socks. For all analyzed sock rib patterns, the most important structural parameters of the yarn and construction parameters of the knitted fabrics were determined. Thermal properties of socks such as the cool touch feeling property, thermal conductivity, heat retention coefficient and thermal resistance were determined by using Thermal Labo and Thermal Mannequin measuring devices. The structural and constructional parameters of knitted fabrics were shown to affect the investigated thermal properties of the socks, making them more or less insulating or heat conducting. Values of the warm-cold feeling parameter as well as thermal conductivity vary depending on the construction pattern, showing a decrease as the number of face loops is increased i.e. in the sequence R1:1> R3:1> R7:1. The ability to retain heat decreases in the opposite sequence R7:1 > R3:1 > R1:1. The highest values of heat retention were determined for R7:1 rib knitted socks by both methods. A regression equation has been established with thickness, loop length, mass per unit area and porosity as independent variables, and thermal resistance (determined by the Thermo Labo method) as the dependent variable. The loop length and mass per unit area were shown to contribute significantly to the model.

Keywords: yarn; rib knitted fabric; thermal insulation.

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1. INTRODUCTION

Socks are among the basic clothing items used in everyday life and are one of the most common products created by knitting. Socks not only serve to protect body parts from the cold, but nowadays they are an important fashion detail, which can visually improve the complete look of clothes. As a garment for the feet, they serve to absorb and remove moisture and sweat, preventing wet feet inconveniences, thus providing the necessary thermal and physiological comfort with the ability to adapt to the feet and leg shape [1].

In the sock production, along with polyamide, polyester and elastomeric (lycra, spandex) fibers, cotton, acrylic, viscose, linen, wool and their blends are used, as well as luxury fibers such as silk, cashmere and mohair. The most desirable are natural fibers such as cotton and wool, which have a very high ability to absorb moisture. Since the strength of natural fibers is low, the strength of socks is usually achieved by using synthetic fibers such as polyamide, polyester, acrylic and elastomeric fibers. Polyamide fibers have high dimensional stability and wear resistance, while acrylic fibers exhibit a long service life and provide softness and volume to socks. Daily wear socks are usually made of cotton for softness and comfort, while wool or acrylic fibers are more desirable for winter socks in order to warm the feet [2,3].

Knitted structures used in socks must be of adequate elasticity to fit the feet and legs. Rib knitted fabric, as well as smooth plain knitted goods are mainly used to produce socks. These structures are desirable because they provide

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elasticity and the ability to return to their original shape. The rubber part, so-called sock render, knitted on the upper part of the sock, prevents the sock from slipping down and is made of elastic threads. This rubber elastic part of the sock is usually 3 to 5 cm wide and is supported by a wrapped rubber wire or elastane (lycra). To ensure a long lifespan in the heel and toe area, a double heel is usually made, using fibers such as polyamide and cotton. Sometimes knitted structures made of fine and tough cotton yarns are used, which improve durability [2,3]. Also, in addition to the type of fibers, two special types of yarns with thermoregulatory effects, (*e.g*. Outlast and Coolmax) significantly affect characteristics and structure of the knit, especially in terms of thermal properties and air permeability. With 100 % pure fiber structures, similar values of thermal resistance were recorded for elastane or polyester, while slightly higher values were recorded for polyamide textiles [4,5].

Furthermore, it was observed that changing the stitch type affects the air permeability and thermal resistance properties of single knits. Increasing the porosity of a fabric by increasing the percentage of stressed seams results in an increase in air permeability of the fabric. Greater permeability can be achieved by alternating knitting and looping. The fabric thermal resistance depends primarily on air that is enclosed within the knitting structure. The most important factor affecting thermal resistance is the thickness of single knitted fabric [6].

Thermal-physiological comfort of socks depends on the type of yarn or fibers and their characteristics, density, thickness, bulk density, and porosity of the knit. Of the thermal-physiological properties, thermal conductivity, water retention capacity, air permeability and water vapor permeability stand out [7,8].

According to the available literature data, as well as in scientific discussions, certain shortcomings were observed leading to the idea for this research in the field of ribbed knitted socks. This research is based on carefully designed non-commercial knitwear patterns from specially selected yarns, suitable for sock production. Bearing in mind that the comfort and convenience of socks have very complex properties, this research aims to confirm the use of rib knitted socks with new findings in order to define characteristics needed to increase the thermal and physiological comfort. For this purpose, the effects of structural and constructional parameters of rib knits on the thermal and physiological comfort of men's socks intended for everyday use were investigated with the goal of engineering design of rib knits for socks for certain purposes.

2. EXPERIMENTAL

2. 1. Materials

Men's socks are made of three types of basic yarns (bamboo, cotton and a blended cotton/polyester yarn purchased from BIM tex, Leskovac), which are knit into each row along the entire length of the socks. Together with the basic yarn (dominant yarn with the highest percentage share in the raw material composition), filament PA 6.6 yarn (purchased from BIM tex, Leskovac) is also knitted at the beginning of sock knitting, the so-called render of socks, a wrapped rubber thread was introduced.

The raw material compositions and basic structural characteristics of yarns for making socks are shown in Table 1. These are single yarns, except polyamide, which is a two-folded multifilament yarn. The Z- and S-twist alternate, except for the rubber wire which had to be stabilized. The rubber yarn is present in the smallest amount of only 1 ± 3 mass.% in the composition of the sock, it is wrapped in two layers with the polyamide yarn of linear density of 78 dtex and is used to make socks at the beginning, the so-called render socks, with the width of 3-5 cm. This wrapped rubber yarn serves to hold the sock along the lower part of the lower leg, to fit well, not to shear, but at the same time, not to tighten too much and be uncomfortable.

The socks are made in the same pattern construction, rib construction, (the face of the sock is made on the lower cylinder and the back on the upper cylinder), with different number of loops on the face (7, 3 and 1 loop) and the same number of loops on the back (1 loop) (designated as R1:1, R3:1, and R7:1, respectively).

2. 2. Methods

Determination of the basic characteristics of yarn for socks was realized according to the appropriate standards: linear density of yarn was determined according to the standard SRPS EN ISO 2060: 2012; number of turns according to SRPS EN ISO 2061: 2016 and breaking force and elongation at break according to SRPS EN ISO 2062: 2012.

Testing of the basic parameters of the structure of knitted socks was also carried out according to the appropriate standards: horizontal and vertical density was determined according to the standard SRPS EN 14971: 2012; length of yarn in a loop according to the standard SRPS EN 14970: 2014; knit thickness according to SRPS EN ISO 5084: 2013; mass per unit area of knitted fabric according to the standard SRPS EN 12127: 2014.

The bulk density of the knitted fabrics [9] was determined according to the equation (1):

$$\gamma = \frac{m}{h} \tag{1}$$

where *m* is the average mass per unit area of the knit and *h* is the thickness of the knit.

The porosity, *P* / %, of the knit [10] is calculated according to the equation (2):

$$P = \left(1 - \frac{m}{\rho h}\right)100 \tag{2}$$

where ρ is the density of yarn fibers.

Thermal properties of socks samples were measured by using the KES-F7 Thermo Labo Tester (Kato Tech Co., Ltd., Japan). For this purpose, the thermal conductivity λ, the heat retention coefficient α, the so-called warm-cold feeling q_{max}, and thermal resistance R_{ct} were measured, which allow functional and sensory evaluation of thermal properties of the knitted fabrics from the point of view of thermal comfort [11-13].

The thermal conductivity λ is determined according to equation (3):

$$\lambda = \frac{\phi h}{A \Delta T} \tag{3}$$

where ϕ is the heat flow, *A* is the area of the heat plate and ΔT is the temperature difference of sample.

The heat retention coefficient α is calculated on the basis of the measurement of the heat flux values without (W_0) and with the sample (W), expressed as a difference in these values in relation to the density of heat flux determined without the sample, equation (4):

$$\alpha = \frac{W_0 - W}{W_0}100 \tag{4}$$

The warm-cold feeling q_{max} / W·cm^{-2} is the measure of the maximum heat loss at the moment of simulation of skin contact with the fabric, which is the largest value of the instantaneous heat flow through the fabrics.

The thermal resistance R_{ct} is determined according to the standard ISO 11092:2014, equation (5) [11-13]:

$$R_{ct} = \frac{T_s - T_a}{H_c}A \tag{5}$$

where: T_s is the temperature of the measuring unit (skin temperature), T_a is the air temperature, *A* is the surface area of the measuring unit, and H_c is the dry heat flux, that flows through the material.

The thermal resistance was also determined by using the Thermal Mannequin (Faculty of Textile Technology, Croatia) according to the standard ISO 15831-2004. Measurements lasted for 20 min with collection of 10 measurements per minute with the average value printed at the end of each 1 min time interval. At the end of measurements, average values of temperature, power consumption, and total thermal resistance of the measured surfaces were automatically recorded. The so-called constant of the Thermal Mannequin, R_{ct0}, is determined by the following equation (6) [14,15]:

$$R_{ct0} = \frac{T_s - T_a}{H_0}A \tag{6}$$

where: R_{ct0} is the total thermal resistance of the empty surface of the measuring device together with the boundary layer of air along the surface (m^2 K·W^{-1}), *A* is the surface area on which measurements are performed, T_s is the surface temperature of the measured surfaces of the Thermal Mannequin, T_a is the ambient air temperature, and H_0 is the electric power required to heat the empty measured surface of the Thermal Mannequin (undressed mannequin).

After determining the constant R_{ct0}, the Thermal Mannequin was dressed in the selected garment and the operation of the device is monitored until a new thermal balance is achieved. After reaching the equilibrium, which can be detected by stabilization of the parameter values (numerically and by graphic representations), the thermal resistance R_{ctn} is determined according to the equation (7) [14,15]:

$$R_{ctn} = \frac{(T_a - T_s)A}{H_m} - R_{ct0} \tag{7}$$

where H_m is the supplied electric power required to maintain the temperature of the measured surfaces at the Thermal Mannequin. All measurements of thermal properties were performed at the Faculty of Textile Technology, Croatia.

2. 3. Yarn and socks characteristics

The data shown in tables 1 and 2 were obtained by measuring according to the specified standards at the institute Vunil d.o.o., Leskovac. Numerous values of the statistical parameter standard deviation are also shown in tables 1 and 2 (mean±standard deviation).

Table 1. Composition of raw materials and basic structural characteristics of yarns for making socks

Composition of raw materials of the socks		Content, %	Linear density, tex	Twist, m^{-1}	Breaking tenacity, cN·tex^{-1}	Elongation, at break, %
Bamboo socks	Bamboo* (BB)	75.46	30.75 ± 1.3	610±9.6	13.53±1.1	15.12±1.3
	Polyamide (PA)	23.52	4.57×2 ± 0.5	93±7.1	41.75±0.9	30.44±1.6
	Wrapped rubber wire	1.02	100.40 ± 1.7	-	4.21±0.6	368±9.9
Cotton socks	Cotton* (CO)	77.49	30.10 ± 0.9	618±9.3	14.47±0.9	4.76±0.7
	Polyamide (PA)	21.48	4.52×2 ± 0.4	96±7.0	39.60±0.9	28.96±1.5
	Wrapped rubber wire	1.03	100.80 ± 1.6	-	4.39±0.5	345±9.7
Cotton/ Polyester socks	CO/PES* 60/40 %	75.22	29.70 ± 0.8	623±9.2	14.10±1.2	6.04±0.8
	Polyamide (PA)	23.77	4.49×2 ± 0.5	98±7.2	41.77±0.8	32.43±1.7
	Wrapped rubber wire	1.01	100.30 ± 1.7	-	4.34±0.5	352.78±9.8

*Basic yarns

A two-cylinder sock machine was used to make the socks, made by “Lonati Bravo 856” (Lonati, Italy), 95 mm ($3^{3/4}$ inch) in diameter, with 168 needles, while a special sewing device - "Rosso 025 full tronic" (Rosso, Italy) - was used to close the toes.

All sock samples (30 per the sock type) were made in the size number 11 with basic parameters: foot length 28 cm, sock leaf length without render 16 cm and render width 4 cm, which corresponds to the size of footwear 42-43. Table 2 presents the results of the most important construction parameters of rib construction socks and different raw material compositions.

Table 2. Design parameters of rib knitted socks size 11 (42-43)

Sock mark (basic yarn-pattern construction mark)	Thickness, mm	Horizontal density, cm^{-1}	Vertical density, cm^{-1}	Loop length, mm	Mass per unit area, g·m^{-2}	Bulk density, g·cm^{-3}	Porosity, %
BB-R1:1	1.70 ± 0.04	14.2 ± 0.4	9.7 ± 0.2	6.4 ± 0.1	339.8 ± 5.3	0.20 ± 0.02	86.8 ± 1.1
CO-R1:1	1.75 ± 0.08	14.3 ± 0.4	9.6 ± 0.3	6.3 ± 0.2	377.4 ± 9.0	0.21 ± 0.01	86.1 ± 1.4
CO/PES-R1:1	1.69 ± 0.1	14.4 ± 0.8	9.5 ± 0.4	6.1 ± 0.3	307.7 ± 8.5	0.18 ± 0.02	87.7 ± 1.6
BB-R3:1	1.68 ± 0.1	11.2 ± 1.4	11.9 ± 1.3	5.4 ± 0.5	318.9 ± 8.1	0.19 ± 0.01	87.5 ± 1.8
CO-R3:1	1.72 ± 0.1	11.3 ± 1.2	11.8 ± 1.3	5.3 ± 0.4	335.9 ± 8.4	0.19 ± 0.01	87.4 ± 1.6
CO/PES-R3:1	1.67 ± 0.09	11.1 ± 1.2	12.0 ± 1.3	5.4 ± 0.4	307.1 ± 7.7	0.18 ± 0.01	87.6 ± 1.4
BB-R7:1	1.65 ± 0.08	10.9 ± 1.0	12.2 ± 1.3	4.7 ± 0.6	318.1 ± 9.8	0.19 ± 0.01	87.3 ± 1.8
CO-R7:1	1.69 ± 0.07	10.8 ± 1.1	12.3 ± 1.4	4.7 ± 0.6	339.9 ± 8.3	0.20 ± 0.02	87.0 ± 1.8
CO/PES-R7:1	1.61 ± 0.08	11.0 ± 0.8	12.1 ± 1.0	4.6 ± 0.8	297.7 ± 9.5	0.18 ± 0.01	87.5 ± 1.5

3. RESULTS AND DISCUSSION

Knitted fabric is a flat textile product made of a large number of interconnected loops that make up basic structural elements of the knit. These are very complicated structures with many elements that define the final functional properties and therefore should be investigated and defined.

Table 3 provides results of testing the thermal characteristics of socks by a Thermo Labo tester and a Thermal Mannequin. Higher values of the parameter warm-cold feeling, $q_{\max}$, represent a colder feeling and lower values a warmer feeling, *i.e.* a higher value means faster heat loss from the skin through the knit, while the knit leaves the impression of cooling [11]. According to the obtained results, it can be seen that $q_{\max}$ is highly dependent on the loop length and porosity. As the value for the mass per unit area or bulk density of the sock increases, q_{max} generally increases. Also, the values for q_{max}, vary depending on the pattern construction, showing a decrease in sequence, R1:1> R3:1> R7:1. The reason lies in the number of loops on the face (*i.e.* 1, 3 and 7 loops, respectively) and back (*i.e.* 1) and consequently the appearance of a more compact and even structure of rib construction, when the sock gives a warmer or cooler feeling.

Socks of the BB yarn give a greater sense of coolness, followed by articles of the CO yarn and finally of the CO/PES yarn. In this regard, it can be concluded that the sock marked BB-R1:1 is recommended for use in warmer days, *i.e.* in spring and summer. Socks with markings, CO/PES-R7:1 and CO-R7:1, proved to be a bit warmer, *i.e.* inducing lower feeling of cold on the skin, so they are recommended for wearing on colder days, *i.e.* in autumn and winter.

Thermal conductivity is one of the most important parameters for the insulating ability of a material and its measurement is based on the heat transfer from the warmer to the colder part, *i.e.* heat conduction. The increase in thermal conductivity signifies higher ability for heat transfer and lower thermal resistance [11-13]. It is noticeable that λ depends on the raw material composition of socks, pattern construction or loop length of the tested samples. For all socks of the same basic yarns, thermal conductivity decreases with the pattern construction order R1:1>R3:1>R7:1. Also, the values of λ are related to the loop length, thickness or the mass per unit area of the sock in proportional manner.

Considering the results for λ, it can be concluded that socks with base yarns of BB and CO achieve better heat conduction and are therefore recommended for use on warmer days, which is in line with the claim of the influence of the warm-cold feeling parameter.

The heat retention coefficient, α, decreases starting from R7:1 to R1:1 regardless of the raw material composition, which means that the construction and structure of the knitted fabrics are decisive factors that define the ability to retain heat. R7:1 sock retains more warm air in its volume as compared to socks with the other knitting patterns. While the CO/PES sock has the highest heat retention coefficient, the lowest α value was determined for the bamboo knits of any knitting pattern, which is explained by the structure and properties of the fibers used. Structure (surface morphology, fiber porosity, etc.) and fiber properties affect heat retention properties. For example, an interesting property is the thermal conductivity of individual fibers (*e.g.* for bamboo-like fibers the thermal conductivity is about 0.230 $W\cdot m^{-1}\cdot K^{-1}$; for cotton 0.464 $W\cdot m^{-1}\cdot K^{-1}$ and for polyester 0.141 $W\cdot m^{-1}\cdot K^{-1}$ [11]). Namely, considering the order of magnitude lower value for air of 0.026 $W\cdot m^{-1}\cdot K^{-1}$ [11] it is obvious that the thermal conductivity of textiles will be higher with the increase in the proportion of fibers in the volume of the material or the use of fibers with higher thermal conductivity.

The parameter thermal resistance of socks (determined by the Thermo Labo method), R_{ct}, varies according to the pattern construction, raw material composition or individual design parameters. In essence, the thermal resistance reflects the thermal insulation of the material and is greatest at rest because in that case the air under the sock is also at rest [12,13,16]. The highest values of R_{ct} were registered for R7:1 socks of rib construction marked R7:1, as well as for socks that have CO/PES as the basic yarn in the composition. Thus, the R7:1 rib knitted sock is the largest thermal insulator, while a sock marked R1:1 is the largest thermal conductor as also determined above and explained by a more compact and more even structure of R7:1 compared to the other patterns. The presence of 7 loops on the face and one loop on the back of the sock, implies a larger continuous contact surface and a more even number of contact points compared to the other rib knits (lower change of loops on the face and back), providing a larger area for skin contact, greater coverage and thus weaker heat dissipation. On the other hand, socks marked R3:1 and R1:1 have more frequent change of loops on the face and back, as well as a longer length of loops, which causes a special shape of rib knitted fabric that is more conductive. Socks that have the least values for thickness, loop length, mass per unit area or bulk density show the highest values for thermal resistance, which is not expected but is associated with a more dominant influence of other parameters that are decisive, *e.g.* by pattern construction or by the type of basic yarn.

It is interesting to consider the thermal resistance results of the socks determined by the Thermal Mannequin, R_{ctn}, where the socks are in a tense, slightly stretched state, similar to the wearing conditions. The R7:1 socks stand out providing significant resistance, while the lowest value of thermal resistance is registered for R1:1 socks. While the loop length values decrease in the sequence R1:1>R3:1>R7:1, there is a noticeable increase in the thermal resistance, R_{ctn}, in the sequence R1:1<R3:1<R7:1, regardless of the raw material composition. The values of porosity and sock thickness decrease in the series of marks R3:1>R7:1, which is opposite to the changes in R_{ctn}.

The values of R_{ctn} in socks of different pattern construction and raw material composition in the stretched state reflect the deformation of the loop in the rib knitted fabrics due to stress, when the whole structure is deformed, thus changing the thermal behavior. On the other hand, when measuring the thermal resistance in the relaxed state, R_{ct}, effects of the original structure and construction of the knit, density, loop size, thickness, porosity, *etc.* are more pronounced.

Table 3. Thermal properties of rib knitted socks determined by the Thermo Labo and Thermal Mannequin tests

Sock tags	Photographs showing the sock surface	Thermo Labo method				Thermal Mannequin method
		q_{max} / W·cm^{-2}	λ / W·m^{-1} K^{-1}	α / %	R_{ct} / 10^3 m^2 K·W^{-1}	R_{ctn} / 10^3 m^2 K·W^{-1}
BB-R1:1		0.100	0.050	18.64	32.31 ± 0.001	16.93 ± 0.0005
CO-R1:1		0.094	0.053	22.03	32.85 ± 0.001	16.97 ± 0.0005
CO/PES-R1:1		0.086	0.052	22.46	34.97 ± 0.0007	17.20 ± 0.0007
BB-R3:1		0.072	0.048	18.22	35.29 ± 0.0009	17.97 ± 0.001
CO-R3:1		0.066	0.052	22.88	37.04 ± 0.001	18.35 ± 0.001
CO/PES-R3:1		0.060	0.048	24.58	37.44 ± 0.001	18.39 ± 0.001
BB-R7:1		0.057	0.041	22.03	40.54 ± 0.001	19.57 ± 0.001
CO-R7:1		0.045	0.037	27.97	46.18 ± 0.002	19.98 ± 0.0009
CO/PES-R7:1		0.044	0.033	31.78	48.19±0.0009	19.99±0.0008

3. 1. Correlation and regression analysis of measurements

Figure 1 shows the correlation of the thermal resistance results determined by the Thermo Labo (R_{ct}) and Thermal Mannequin (R_{ctn}) methods for all socks investigated in the present study. The value of the obtained Pearson's correlation parameter (r = 0.949) indicated statistically proven linear correlation between the results measured by two different measuring devices. In other words, the correlation analysis of the thermal resistance results of the socks in the relaxed state measured by the thermal plate and the corresponding values for the socks in the stressed state determined by the Thermal Mannequin showed that there is a statistically significant correlation between the measurements (Fig. 1).

Next, multiple linear regression analysis is performed, which studies the relationship between several regression (independent) variables and criterion (dependent) variables and/or serves for prediction of the value of the dependent variable based on one or more regression variables. It is an extension of a simple linear regression in which there are now several independent variables (x_1, x_2, x_3...) used to study the effects on the dependent variable *(y)* [14,15].

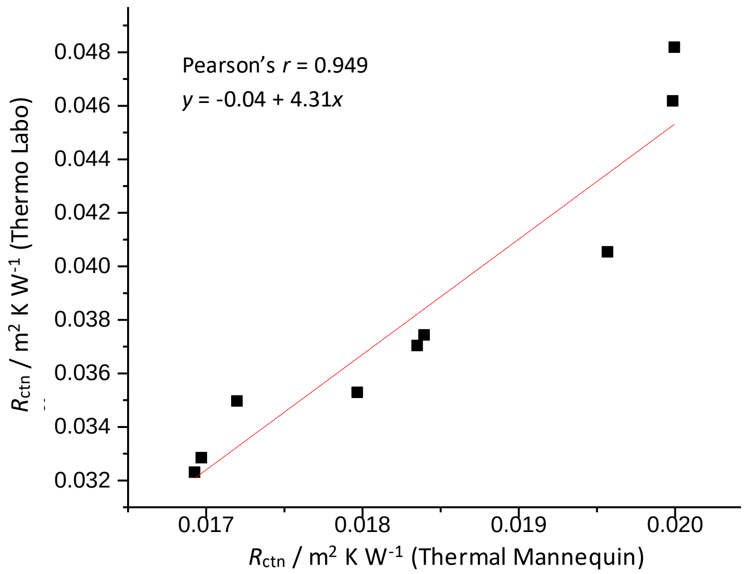

Figure 1. Correlation between thermal resistances determined for all sock types investigated in the present study by using Thermo Labo and Thermal Mannequin measuring systems

In the selected case, the dependent variable is the thermal resistance R_{ct} (determined by the Thermo Labo method) of bamboo socks in all knitting patterns. These sock samples were selected based on the lowest results for R_{ct}, regardless of the pattern construction. Thickness (*T*), loop length (*L*), mass per unit area (*M*), and porosity (*P*) were taken as independent variables, in order to explain the variability of the dependent variable, R_{ct}.

Tables 4 and 5 show the data of this type of analysis, starting from the applied parameters and their coefficients, through the basic statistical data on the success of the dependence description to the Anova analysis, *i.e.* analysis of variance.

According to Table 4, the regression equation-model, can be represented as in equation (8):

$$R_{ct} = 0.044 + 0.0064T - 0.0064L + 1.14\times10^{-4}M - 2.34\times10^{-4}P \tag{8}$$

Table 4. Values of the coefficients of the regression model for prediction of R_{ct} of bamboo socks

	Value	Standard error	*t*-value	Prob >|*t*|
Intercept, m^2 K·W^{-1}	0.044	0.056	0.78	0.48
T / mm	0.0064	0.022	0.28	0.79
L / mm	-0.0064	0.001	-5.97	0.0039
M / g·m^{-2}	1.14×10^{-4}	2.78×10^{-5}	4.10	0.0148
P / %	-2.34×10^{-4}	9.75×10^{-4}	-0.24	0.82

Given the very high value of the coefficient of determination (R^2 = 0.988), it is concluded that 98.8 % of the variability of the dependent variable can be explained by using the analyzed independent variables.

According to Table 4, the independent variables loop length and mass per unit area significantly contribute to the model (Prob > |*t*| = 0.0039 and 0.0148 < 0.05, respectively). The other variables, thickness and porosity have values for Prob > |*t*| > 0.05, so their contribution to the model is lower (Prob > |*t*| = 0.79 and 0.82, respectively), since these values exceed the standard level of significance (p = 0.05).

Analysis of variances for multiple regression, Table 5, tests the significance of the regression relationship, *i.e.*, checks whether the independent variables are relevant for describing the behavior of the dependent variable. This table highlights a statistically significant F-value (Prob> F = 4.47×10^{-4} < 0.05), so the use of this model is justified, *i.e.* the thickness, loop length, mass per unit area and porosity regressors cause at least 95 % variance of the R_{ct} variable. Thus, there is a statistically significant association between the key variable and its regression variables. In other words, the used regression model is practically usable because with the help of selected properties of socks, the thermal resistance of socks can be predicted with great reliability. In addition, the model could be tested for prediction of the values of thermal resistance for other socks produced from a similar raw material composition and different rib knitting patterns when the construction parameters, thickness, loop length, mass per unit area and porosity are known.

Table 5. Parameters of the Anova analysis for multiple regression of R_{ct} of bamboo socks

	Degrees of freedom	Sum of squares	Mean square	*F* value	Prob > *F*
Model	4	1.02×10^{-4}	2.55×10^{-5}	80.58	4.47×10^{-4}
Error	4	1.26×10^{-6}	3.16×10^{-7}		
Total	8	1.03×10^{-4}			

Normality and linearity of the distribution, as well as the existence of atypical points are analyzed in graphs presented in Figure 2. The upper diagram shows that the values of the dependent variable, experimentally determined and predicted by the model, are highly overlapping, implying that that the criterion of acceptability and significance of the regression model is met.

The lower diagram (Fig. 2) confirms that atypical points and large variations of residuals are absent *i.e.* deviations are fairly evenly distributed and most results are accumulated around a straight line, *i.e.* around point 0. The horizontal band pattern suggests that the residual variance is constant.

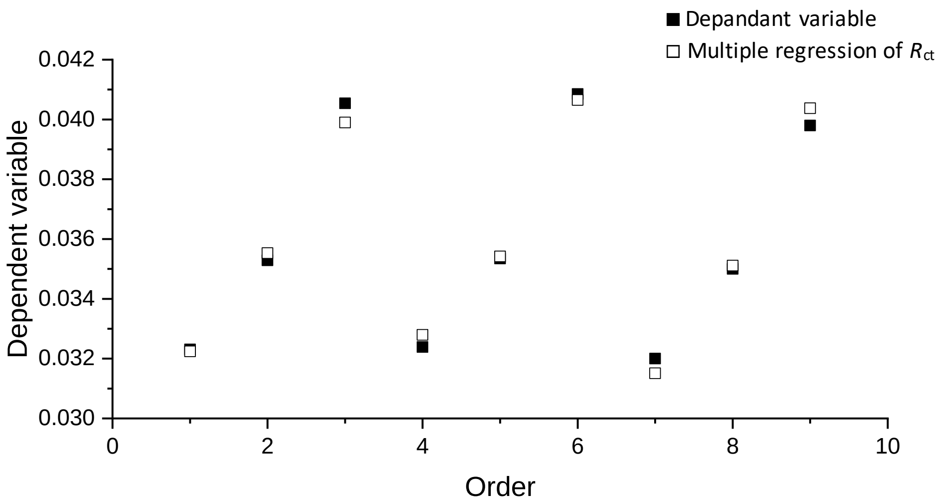

Figure 2. Diagrams of model validity and regularity of residuals

4. CONCLUSION

Thermophysiological comfort of knitted socks depends on many parameters. A comprehensive approach to measuring and calculating a number of parameters in the technological process including yarn characteristics, production variables and the final sock characteristics can provide reliable indicators for quality characterization of the properties of finished socks.

The results obtained in this research emphasize the fact that thermal properties of socks largely depend on the rib knitting pattern, type of the basic yarn in the blend and finally on the type of fiber out of which this basic yarn is made.

The results obtained in the present study for the parameter warm-cold feeling, thermal conductivity and heat retention coefficient varied depending on the construction pattern, mass per unit area, loop length, thickness and raw material composition. Socks of basic bamboo yarn are recommended for use on warmer days, *i.e.* in spring and summer. Socks marked CO/PES-R7:1 and CO-R7:1 proved to be warmer, so they are recommended for use on colder days, *i.e.* in autumn and winter.

Thermal resistance of the socks determined by using two methods (Thermo Labo and Thermal Mannequin) varied according to the construction pattern, raw material composition and individual tested properties. The R7:1 rib knitted sock is the greatest thermal insulator, while the R1:1 sock is the greatest thermal conductor in the present study, which is due to the fact that the R7:1 rib knitted sock has the most compact and even structure compared to the other knits, owing to the very construction and arrangement of loops. Also, thermal resistance values determined by the two methods for socks in the relaxed state and in the stressed state were shown to be linearly correlated with the statistical significance.

Multiple linear regression showed that the independent variables loop length and mass per unit area significantly affect the dependent variable - thermal resistance of socks (determined by the Thermo Labo method).

Based on the above, it can be concluded that bamboo (regenerated cellulose) socks, regardless of the knitting pattern, are more suitable for wearing during higher temperatures or in summer, while for lower temperatures, socks made of the CO/PES blend or pure cotton are better solution.

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Uticaj strukturnih i konstrukcijskih parametara pletenina na termička svojstva muške čarape

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Izvod

Istraživanje je fokusirano na utvrđivanje uticaja strukturnih i konstrukcijskih parametara rebrastih pletenina na termička svojstva muških čarapa. Muške čarape izrađene su u tri različita prepletaja (1:1, 3:1, 7:1) od tri vrste osnovnih pređa: bambus, pamuk i mešavine pamuk/poliester sa dodatnom filamentnom poliamidnom pređom obmotanom gumenom niti za tzv. render čarape. Za sve analizirane uzorke čarapa u desno-desnom prepletaju, određeni su strukturni parametri pređa i konstrukcijski parametri pletenina. Uticaj pojedinih parametara na toplotna svojstva čarapa proveren je na temelju istrazivanja toplo-hladnog osećaja (toplota opipa), koeficijenta toplotne provodljivosti, koeficijenta sposobnosti zadržavanja toplote i toplotne otpornosti, određene pomoću mernih uređaja "Thermo Labo" i "Thermal Mannequin". Utvrđeno je da strukturni i konstrukcijski parametri pletenina utiču na toplotna svojstva čarapa, čineći ih manje ili više izolatorima, odnosno provodnicima toplote. Vrednosti parametra toplota opipa, kao i toplotna provodljivost variraju zavisno od prepletaja, pokazujući pad u nizu, R1:1 > R3:1 > R7:1. Sposobnost zadržavanja toplote opada u nizu, R7:1 > R3:1 > R1:1. Najveće vrednosti toplotne otpornosti određene pomoću oba primenjena metoda registrovane su kod čarapa rebrastog prepletaja oznake R7:1. Primenjena je regresiona analiza pri čemu su kao nezavisne promenljive izabrane debljina, dužina petlje, površinska masa i poroznost, dok je zavisna promenljiva toplotna otpornost određena primenom "Thermo Labo" uređaja. Pokazano je da nezavisne promenljive, dužina petlje i površinska masa značajno doprinose modelu.

Ključne reči: pređa; rebrasta pletenina; toplotna izolacija