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SADRŽAJ

U FINANSIRANJU ČASOPISA UČESTVOVALO MINISTARSTVO PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA REPUBLIKE SRBIJE

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CONTENT

THE FINANCING OF THE JOURNAL PARTICIPATION IN THE MINISTRY OF EDUCATION, SCIENSE AND TEHNOLOGICAL DEVELOPMENT

THERMO-VISION ANALYSIS AS A METHOD OF DETERMINATION THE THERMAL CONDUCTIVITY OF KNITTED FABRICS

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Abstract: *The thermal properties of knitted fabrics as an important element of thermo-physiological comfort are usually measured by methods that belongs to the so-called "plate methods". In this paper a new method of thermo-vision analysis for measuring the thermal conductivity was applied. The results obtained show the possibility for using the method of thermo-vision analysis in determining the thermal properties of interlock knitted fabrics with different raw material compositon in both layers. The thermal insulation is the result of a joint impact of structural characteristics, thickness, and mass per unit area as well as the raw material composition of the knitted fabrics. This research provide a huge area for further investigation.*

Key words: Thermal conductivity, interlock, thermo-vision analysis, thermal resistance.

TERMO-VIZIONA ANALIZA KAO METOD DETERMINACIJE TOPLOTNE PROVODLJIVOSTI PLETENINA

Apstrakt: *Termička svojstva pletenina kao važan element termofiziološkog komfora obično se mere metodama koje pripadaju takozvanim "ploča-metode". U ovom radu primenjen je novi metod merenja toplotne provodljivosti pletenina na bazi termo-vizione analize. Dobijeni rezultati pokazuju mogućnost korišćenja termo-vizione analize prilikom određivanja toplotnih osobina interlok pletenina sa različitim sirovinskim sastavom u oba sloja. Toplotna izolacija je rezultat zajedničkog uticaja strukturnih karakteristika (debljina, površinska masa), i sirovinskog sastava pletenina. Ovaj rad pruža velike mogućnosti za daljna istraživanja u ovoj oblasti.*

Ključne reči: Toplotna provodljivost, interlok, termo-viziona analiza, toplotna otpornost.

1. INTRODUCTION

The last few decades there has been growing interest of the consumers in knitted fabrics because of its characteristics: elasticity, good handle, a snugness of fit to body shape, wide product range and affordable price. In the design and construction of knitted fabrics lately more attention has been paid to the functional properties, especially the comfort. Garment comfort is one of the most important purchasing criterion for consumers. The term comfort is defined as "a neutral state compared to the more active state of pleasure" as well as pleasant situation on the physiological and psychological harmony between man and the environment [1]. Clothing comfort consists of four components: psychological, sensorial, ergonomic and thermo-physiological comfort. Thermo-physiological comfort refers to sensations of hot, cold, dry or dampness in clothes and is usually associated with environmental factors, such as heat, moisture, and air velocity [2].

Thermal properties of fabrics have been of great interest and importance for textile researchers, since they are among the major characteristics that determine thermo-physiological comfort.

Thermal conductivity is an intensive property of material that indicates its ability to conduct heat. According to the formula 1, thermal conductivity is the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area due to a unit temperature gradient. [1] [3]:

$$\lambda = \frac{Q}{A\frac{\Delta t}{h}} \left(\frac{W}{mK}\right) \quad (1)$$

Where is: λ-the thermal conductivity, (W/mK), Q-the heat transmitted, (W), A-the area, (m2), Δt-the temperature gradient, (K) h-the sample thickness, (m).

Thermal resistance is a measure of the material's ability to prevent heat from flowing through it, actually a measure of its insulation. It expresses the difference of the temperature across a unit area of the material of unit thickness when a unit of heat energy flows through it in a unit of time. It is necessary to know the rate of heat transfer through the material in order to be measured its thermal resistance. It is defined by the formula 2 [3]. Thermal resistance is influenced by fabric structure. Increase in fabric thickness will result in increase in thermal insulation, as there will be a decrease in heat losses for the space insulated by the textile. Thermal resistance is a function of the thickness and thermal conductivity of the fabric.

$$R = \frac{h}{\lambda} \left(\frac{m^2 K}{W}\right) \ (2)$$

Where is: R-the thermal resistance of fabrics, $\left(\frac{m^2K}{W}\right)$ [4].

Textile material, air enclosed in it and the air on its surface act as insulators preventing the transfer of heat through conduction and radiation. Since the volume of the enclosed air is much larger than the volume of the fiber, the insulation depends much more on the thickness of the material than on the fiber type [5]. The heat and fluid transmitting properties of textiles, are affected by the mechanical characteristics of the fabrics as well as the fibre properties [6]. The effect of the raw material composition and construction of the textile material on the thermal characteristics of knitted and woven fabrics was studied by various authors [5-11]. Shoshani and Shaltiel noted that heat insulation was increasing by reducing the density of the material [5]. According to the investigation [7] fabric thickness, enclosed air and external air movement are the major factors that influence the heat transfer through fabric. If the amount of fiber increases, the amount of captured air decreases, so the thermal conductivity will be higher for denser and heavier knitted fabrics such as an interlock. Thermal properties of rib knit fabrics investigated by Ucar and Yilmaz showed that the use of 1×1 rib and tight structure would provide better thermal insulation [8]. The thermal resistance of textured fabrics is higher than the fabrics produced with non-textured filaments. Ozcelik, et al. developed a theoretical model to predict the thermal conductivity of knitted structures in relation of porosity, thickness and moisture content. Increasing of porosity leads to decreasing of the thermal conductivity of a dry plain-knitted fabric [6]. Investigation of thermal comfort properties of double layered knitted fabrics with different yarn components showed that the thermal resistance depends more on synthetic thread type than on natural fiber yarns [9]. Investigations for thermal resistance of double- layered knitted fabrics made from cotton or man-made bamboo yarns in the outer (located outer from the skin) layer and PP, PA, PES yarns in the inner (located next to the skin layer) showed that the structure of the knitting fabric highly influences the heat transfer process, more than the raw material composition [10]. The most common problem with investigating and statistical modeling of the thermal characteristics of knitted fabrics are nonlinear connections of various parameters with thermal properties. In addition, the parameters (thickness, mass, porosity) are the result of the characteristics of the yarn and the construction of the material and are closely related to one another. Knitted fabrics with a looser construction, have a larger amount of air, thus decreasing the density drastically decreases the thermal conductivity [11]. In previous mentioned research papers [3, 4, 5, 6] the thermal properties of knitted fabrics were measured with methods that belongs to the so-called "plate methods", more precisely with the Alambeta device which is a computer-controlled instrument for measuring the basic static and dynamic thermal characteristics of textiles. In this paper the possibility of applying the method of thermo-vision analysis in determining the thermal coefficient of conductivity of interlock knitted fabrics was examined.

2. EXPERIMENTAL PART

2.1. Materials and method

For investigating two-layer interlock knitted fabrics with different raw materials in both layers, cotton/polyamide (PA), ie cotton/polyester (PES) were used. The samples were made of yarns of the same fineness: cotton yarn with fineness Tt = 20 tex and polyamide, ie polyester filament with fineness from Tt = 11 tex, knitted on a 20° E interlock circular knitting machine. In order to measure the thermal conductivity of the knitted fabrics λ(W/mK) the method of thermo-vision analysis was applied. The apparatus (figure 1) consists of: FLIR P-45-infrared camera; instrument for measurement of the temperature and online software monitoring: TESTO 635-2 and thermostat for heating and cooling.

Figure 1. Thermo-vision apparatus

The measuring was conducted according to the procedure [12]**:**

- samples of knitted fabrics (250x250mm) are put on the thermostat;
- every 3 minutes in the interval of 15 minutes infrared camera capture image for each sample (5 images for each sample, a total of 20 thermograms);
- while the shooting takes place the online monitoring software generates data for: the exact time of each picture, temperature, and the temperature plate of the thermostat T_w;
- all measurement are conducted with air temperature of $22,0 + 0,3\ ^0C$ and the air relative humidity of 63,4±0,5%;
- obtained data are processed with special software - FLIR;
- T_{sp1} (°C) is the temperature in the center of the sample, T_{sp2} (°C) is the temperature of another dot outside the square area, T_{arp1} (°C) is the average temperature of the fabric
- the temperature change dependence from the time of capture for each sample diagrams are drown T_{sp1}, T_{arp1} and $T_{w.}$ The values of the time in hours-t (3/60), are applied on the x-axis, while the values of natural logarithm Ln(T_{sp1},T_{arp1}, T_w) of the temperature are applied on the y-axis.;
- the temperature change rate coefficient of the knitted fabric m_1 is determined from the linear line equation for average value of the temperature of the knitted fabric T_{arp1}, i.e. y=kx +b, where y = T_{arp1} and k=m_1.

The determining of the thermal conductivity coefficient λ, according to the thermo-vision analysis is based on the theory of the regular temperature regime, i.e. on Kondratievs' second theorem [13] (3) (4) and (5):

$$m_1 = K \cdot a \quad (3) \qquad a = \frac{m_1}{K} \quad (4)$$

$$\text{and} \qquad a = \frac{\lambda}{c \cdot \rho} \quad (5)$$

Where is: m_1-temperature change rate coefficient (heating or cooling of the material (s^{-1}); K-proportionality coefficient; a- thermal diffusion (m^2/s); ρ-fabric density (kg/m^3); c-specific heat capacity (J/kgK).

Coeficient m_1 depends on the physical characteristics, the dimensions and the geometry of the material. Coefficient K depends only on the geometry of the material and for flat plate is calculated according to the formula (6). In this case, knitted fabrics are considered as a flat plate.

$$K = \left(\frac{\pi}{2h}\right)^2 \qquad (6)$$

Where is: h-thickness of the material (mm)

The specific heat capacity of more component fabrics is calculated according to the equation (7).

$$c = \sum_{i=1}^{i=n} c_i \, p_i \qquad (7)$$

Where is: c_i-components'specific heat capacity; p_i-mass percentage of the component

The thermal resistance is determined according to the equation (2).

3. RESULTS AND DISCUSSION

3.1. Structural characteristics of interlock knitted fabrics

The basic structural characteristics of interlock knitted fabric: fabric thickness, h (mm) and mass per unit area m, (g/m^2) are determined according to the standard methods (EN ISO 5084 for thikness and ISO 3081 for mass per unit area). The volume mass or the fabric density ρ is calculated by the equation (8).

$$\rho = \frac{m}{h}\left(\frac{kg}{m^3}\right) \quad (8)$$

Where is: -mass per unit area of the fabric (g/m^2), h-fabric thickness (m).

In Table 1 the basic structural characteristic of interlock knitted fabrics are given.

2.1. Thermal characteristics

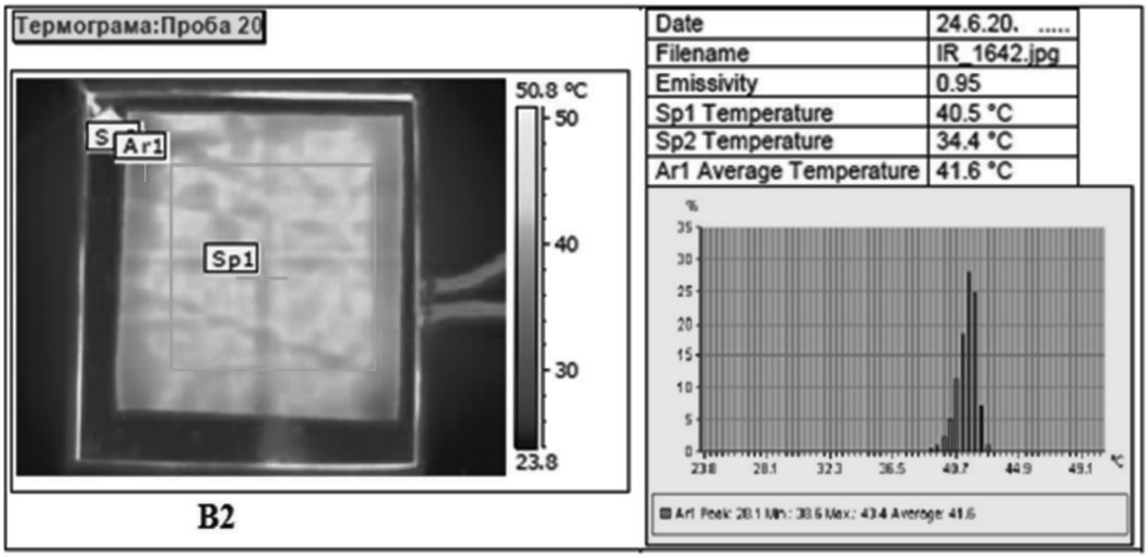
During the measurements, 5 images for each sample (A_1, A_2, B_1, B_2) with the infrared camera were taken. The appearance of the images (thermograms) is shown in Figure 1 (the example of the thermogram for the image 1 for sample B_2 is given). The values of the temperatures T_{sp1} T_{sp2} T_{arp1} of the samples are obtained from the images (thermograms). The online monitoring software generates values of the temperature of the plate (T_w). In the next step their natural logarithms are calculated (Table 3).

In figures 3, 4, 5 and 6 the linear line equation of the samples are given. Based on the thermograms and the linear line equations the coefficient of the temperature change dependence from the time of capture m_1 is determined. After that the coefficient K is calculated. These data are needed to determine the thermal conductivity λ and calculate thermal resistance R (table 4).

Table 1. Basic structural characteristics of interlock knitted fabrics

Sample	Raw material composition (%)		m (g/m^2)	h (mm)	ρ (kg/m^3)
A_1	50/50 cotton / polyamid	$\bar{x}$ Cv(%)	246 (11.32)	0.842 (2.48)	292
A_2	50/50 cotton / polyamid	$\bar{x}$ Cv(%)	255 (3.80)	0.833 (1.89)	306
B_1	50/50 cotton / polyester	$\bar{x}$ Cv(%)	257 (5.74)	0.812 (2.54)	317
B_2	50/50 cotton / polyester	$\bar{x}$ Cv(%)	262 (6.14)	0.955 (3.20)	274

Figure 2. Thermogram (image 1 of sample B_2)



Date	24.6.20. .....
Filename	IR_1642.jpg
Emissivity	0.95
Sp1 Temperature	40.5 °C
Sp2 Temperature	34.4 °C
Ar1 Average Temperature	41.6 °C

Table 3. Data obtained from thermograms and the temperature of the plate (T_w)

Sample	Image number	T_w (°C)	T_{sp1} (°C)	T_{sp2} (°C)	T_{arp1} (°C)	$\ln T_w$	$\ln T_{sp1}$	$\ln T_{arp1}$
A_1	1	48.59	31.0	39.8	36.8	3.883418	3.433987	3.605498
	2	51.11	39.4	41.5	39.5	3.933980	3.673766	3.676301
	3	51.38	41.3	42.6	40.4	3.939249	3.720862	3.698830
	4	50.65	41.0	42.6	40.5	3.924939	3.713572	3.701302
	5	49.29	40.7	41.8	40.6	3.897721	3.706228	3.703768
A_2	1	43.19	37.8	36.6	37.6	3.765609	3.632309	3.627004
	2	41.73	37.5	35.3	37.0	3.73122	3.624341	3.610918
	3	40.53	36.5	35.0	36.2	3.702042	3.597312	3.589059
	4	39.08	35.4	34.0	35.3	3.665611	3.566712	3.563883
	5	38.13	35.4	35.1	35.1	3.641001	3.566712	3.558201
B_1	1	43.42	35.8	36.5	35.9	3.77092	3.577948	3.580737
	2	42.03	35.9	36.2	35.8	3.738384	3.580737	3.577948
	3	40.73	35.0	35.2	34.9	3.706965	3.555348	3.552487
	4	39.41	34.2	34.3	34.2	3.67402	3.532226	3.532226
	5	38.19	34.2	34.0	33.8	3.642574	3.532226	3.520461
B_2	1	51.74	40.5	34.4	41.6	3.946231	3.701302	3.728100
	2	50.7	40.6	35.5	41.6	3.925926	3.703768	3.728100
	3	49.29	39.9	34.5	41.0	3.897721	3.686376	3.713572
	4	47.41	39.6	33.6	40.3	3.858833	3.678829	3.696351
	5	45.65	39	33.4	39.6	3.821004	3.663562	3.678829

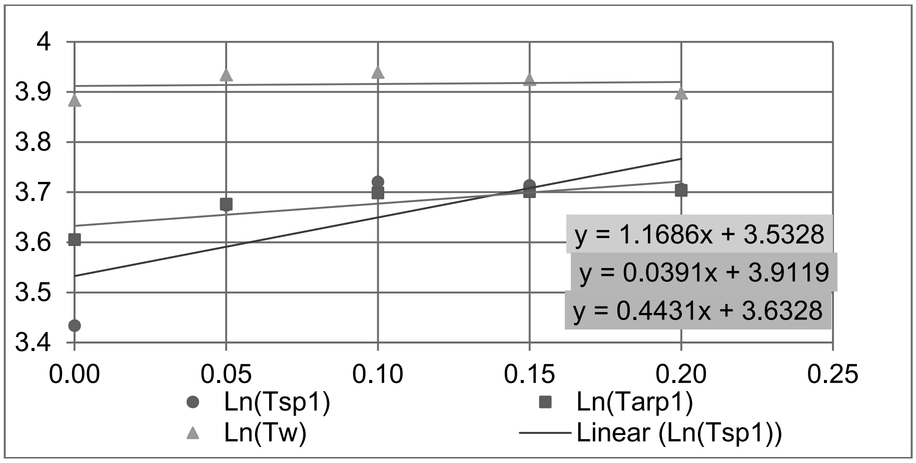


Figure 3. The temperature change dependence from the time of captureT_{sp1}, T_{arp1} and T_w for sample A_1

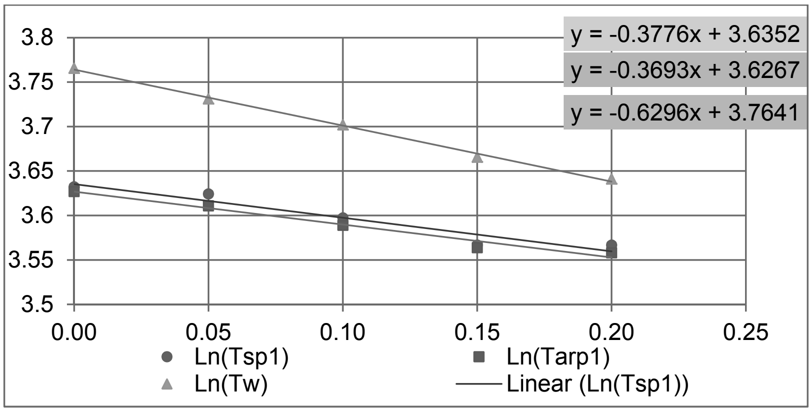


Figure 4. The temperature change dependence from the time of capture T_{sp1}, T_{arp1} and T_w for sample A_2

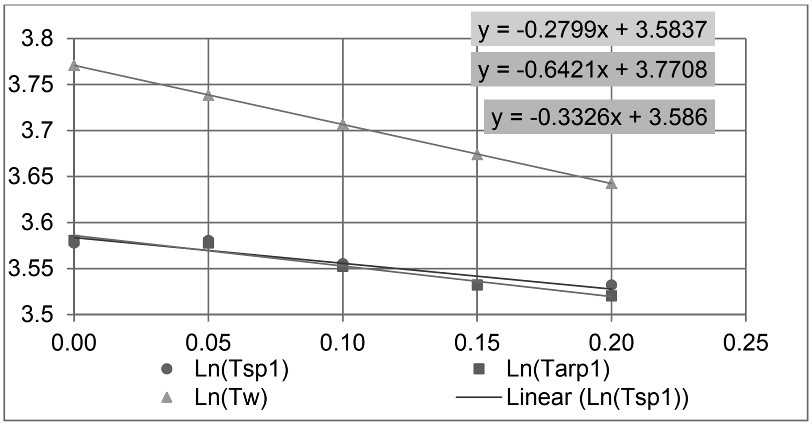


Figure 5. The temperature change dependence from the time of capture T_{sp1}, T_{arp1} and T_w for sample B_1

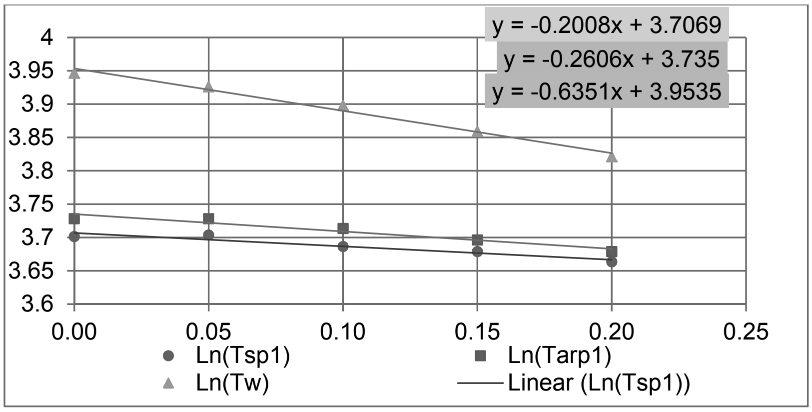


Figure 6. The temperature change dependence from the time of captureT_{sp1}, T_{arp1} and T_w for sample B_2

Table 4. Thermal characteristics of interlock knitted fabrics

Sample	$K=(\pi/2h)^2$	m_1	c (J/kgK)	λ (W/mK)	R (m^2K/W)
A_1	3480241	0.4431	1420	0.0528	0.0159
A_2	3555850	0.3693	1420	0.0451	0.0185
B_1	3742152	0.3326	1220	0.0343	0.0237
B_2	2705370	0.2606	1220	0.0375	0.0254

Specific heat capacity for cotton fibers is 1.34 (kJ/kgK), for polyamide 1.5-1.9, for polyester 1.1 -1.4 (kJ/kgK), [14], [15].

Better thermal insulation showed interlock knitted fabrics of cotton/polyester in relation to those of cotton/polyamide. At the same raw material composition, the thermal insulation is greater in the sample with larger mass per unit area, m. The highest value of thermal insulation is observed in sample B_2, which also has the largest mass per unit area.

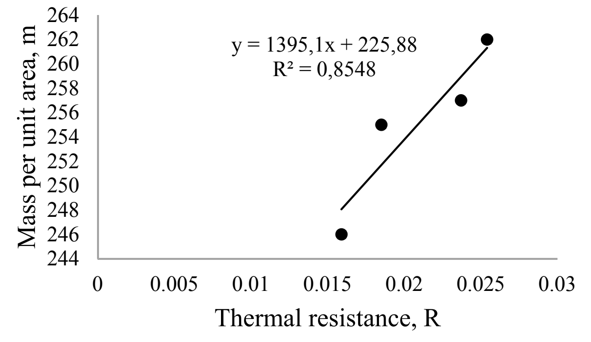


Figure 7. Correlation between thermal resistance and mass per unit area

Dependence of the thermal resistance on the mass per unit area (figure 7), regardless of the raw material composition of the samples, can be observed, but on the other hand, the expected dependence of the thermal resistance on the thickness or density due to the different raw materials of the samples can not be noticed.

The results indicate that the dependence of the thermal insulation can not be considered only depending on the structural characteristics or only from the raw material composition, but these two components together determine the value of the thermal insulation of the knitted materials.

4. CONCLUSION

This research shows the possibility for using the method of thermo-vision analysis in determining the thermal properties of knitted fabrics as an important element of thermo-physiological comfort. The main advantage of the method is the possibility of non contact determination of the temperature change rate coefficient. Due to the small number of samples measured, it is too ambitious assess the relationships between the values of the thermal parameters and the basic structural characteristics of knitted fabrics. However, it can be concluded that thermal insulation is the result of a joint impact of structural characteristics (mass per unit area, fabric density, thickness) as well as the raw material composition. The results obtained provide a huge area for further investigation.

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