(REFEREED RESEARCH)

INVESTIGATION OF THE PHYSICAL AND THERMAL COMFORT CHARACTERISTICS OF KNITTED FABRICS USED FOR SHOE LININGS

AYAKKABI ASTARLARINDA KULLANILAN ÖRME KUMAŞLARIN FİZİKSEL VE ISIL KONFOR ÖZELLİKLERİNİN İNCELENMESİ

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ABSTRACT

The versatility of spacer fabrics includes the ability to knit two entirely different fabrics having different properties and connect them to form a unique structure. Their characteristics like excellent compression elasticity and cushioning, high breathability and air permeability, high thermal insulation and temperature regulation, surface resistance make them concept of study for footwear area. This paper aims to investigate the physical and thermal comfort attributes of flat knitted spacer and interlock fabrics designed for shoe linings. Cotton, Cotton/Bamboo, Cotton/Type A blended yarn and Cotton/Type B blended yarn (20/1 Nm) were used for the production of interlock and flat knitted spacer fabrics. In the production of spacer fabrics, polyamide (20/1 Nm) yarn was used as spacer yarn. Characteristics like fabric extensibility, friction coefficient, water vapour permeability, air permeability and thermal comfort properties of the fabrics were investigated, in order to select the most suitable materials and fabric structures for footwear linings.

Keywords: Shoe linings, flat knitted spacer fabrics, interlock fabrics, electronic flat knitting machine, physical and thermal comfort properties.

ÖZET

Farklı özelliklere sahip iki farklı kumaşın birlikte örülmesi ve ayrı bir yapı ile birleştirilmesi ile sandviç kumaşlar çeşitli kullanım alanlarına hitap etmektedir. Yüksek sıkıştırılabilirlik dayanımı ve sönümleme yeteneği, yüksek hava geçirgenliği ve nefes alabilirlik, yüksek izolasyon, ısı dengeleme yeteneği ve iyi yüzey dayanımı, bu kumaşların ayakkabı üretiminde kullanımını mümkün kılmaktadır. Bu çalışmada ayakkabı astarı olarak tasarlanmış düz örme sandviç kumaşların ve interlok kumaşların fiziksel ve ısıl konfor özellikleri incelenmiştir. Pamuk, Pamuk/Bambu, Pamuk/A tipi karışımlı iplik, Pamuk/B tipi karışımlı iplik (Nm 20/1) interlok ve düz örme sandviç kumaşların üretiminde kullanılmıştır. Sandviç kumaşların üretiminde bağlantı ipliği olarak poliamid (Nm 20/1) ipliği kullanılmıştır. Ayakkabı astarı için en uygun materyal ve kumaş yapılarını belirlemek için kumaşların uzama yeteneği, sürtünme katsayısı, su buharı geçirgenliği, hava geçirgenliği ve ısıl konfor özellikleri incelenmiştir.

Anahtar Kelimeler: Ayakkabı astarı, düz örme sandviç kumaşlar, interlok kumaşlar, elektronik düz örme makinesi, fiziksel ve ısıl konfor özellikleri.

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1. INTRODUCTION

The versatility of spacer fabrics includes the ability to knit two entirely different fabrics having different properties and connect them to form a unique structure. Spacer fabrics can be produced by using weaving, nonwoven, warp and weft knitting techniques. Weft knitting is recently developed technique while warp knitting is the most commonly used technology for the production of spacer fabrics. The production of weft knitted spacer fabrics can be done on the double jersey circular knitting machine or electronic V-bed flat knitting machine. These fabrics are characterised by excellent compression elasticity and cushioning, high breathability and air permeability, high thermal insulation and temperature regulation, surface resistance, being thus capable of meeting the requirements of various applications, from protective clothing to mattresses and composites.

Footwear uppers are partly or completely lined. Considering that the interaction between foot and footwear is made by linings, it is important to select suitable materials and structures for both linings and uppers, in order to ensure the required comfort characteristics. The main functions of footwear linings are to improve its appearance, to increase the comfort and durability of the footwear, softness or protection where is needed (1). During wearing, linings must protect the foot skin against the direct contact of the foot with the semi-rigid footwear components such as a stiffener and a toe cap. A lining must prevent an upper from distortion and ensure the stability of the spatial form and, hence, maintain the product aesthetical look over time. To assure feet comfort, the lining material should have basic characteristics such as: good hygienic properties (good absorption capacity, good air and water vapour permeability, capacity to remove static electricity, etc.), good resistance to wet and dry friction, good resistance to stress and strain, good resistance to perspiration, high thermal resistance as regards footwear designed for the cold season (2). Special attention has been paid to the orthopaedic footwear for diabetic patients, which should be selected correctly both in terms of shape and materials used for the uppers (3). These materials should be soft and flexible, as well as adaptable to any surface irregularities in such a way as to guarantee perfect fitting and to avoid the threat of friction (4).

Despite many researches about the thermal comfort behaviour of knitted fabrics and the use of flat knitted spacer fabrics as composite structures or other applications, there are relatively few studies regarding mechanical and thermal comfort characteristic of flat knitted spacer fabrics for shoe linings. Marmaralı et al. (5) investigated the thermal comfort properties of knitted fabrics made from three different engineered yarns (tetra-channeled polyester, high functional polyester and a patented yarn blended of natural and synthetic fibres) in three tightness values. Onofrei et al. (6) studied the influence of fabric’s structure on the thermal and moisture management properties of knitted fabrics made of Coolmax® and Outlast® yarns. Liu and Hu (2011) investigated the compression and air permeability properties of flat knitted spacer fabrics with different weft knit patterns, spacer yarns, and loop lengths (stitch cam settings) (7). Crina et. al. (2013) studied the effect of structural parameters on the comfort properties of flat knitted spacer fabrics with various yarn (face-soybean protein yarn, back-polyester, polyamide and polypropylene yarns) and structure combinations (8). Blaga et.al. examined the effect of yarn type, fabric tightness and finishing on the behaviour of the knitted fabrics for footwear linings, throughout the properties: fabric extensibility, pilling, friction properties, initial elastic modulus (2).

This research is focused on the investigation of the physical and thermal comfort attributes of flat knitted spacer and interlock fabrics produced by using different high performance yarns (Bamboo, Type A, Type B), especially designed for shoe linings. Bamboo, which is one of a new generation of natural and organic fibres, is known for high strength and durability while providing exceptional softness and breathability. This eco-friendly and sustainable fibre is a derivative of the Bamboo pulp, which is processed into a natural fibre without petrochemical additives (9). Type A yarn is the purest cellulose fibre from renewable resource. The fibres retain the wood's natural properties. The main differences in this yarn compared to other cellulose fibres is its softness, absorption capacity, ability to release dampness (as a yarn or fabric), deodorant properties, and adsorption characteristics (due to its morphology). When mixed with other fibres, Type A yarn is in "mechanical synergy" with them (10). Type B yarn is a cellulose fibre which is produced by the so-called Lyocell process using cellulose and seaweed. The Lyocell process has established itself as an environmentally-friendly, economically viable, product-enhancing and highly flexible alternative for the manufacture of man-made cellulose fibres (11). Type B yarn is produced in two versions: pure stands for the pure effect of the seaweed and active holds an additional antimicrobial effect that occurs by adding silver (12).

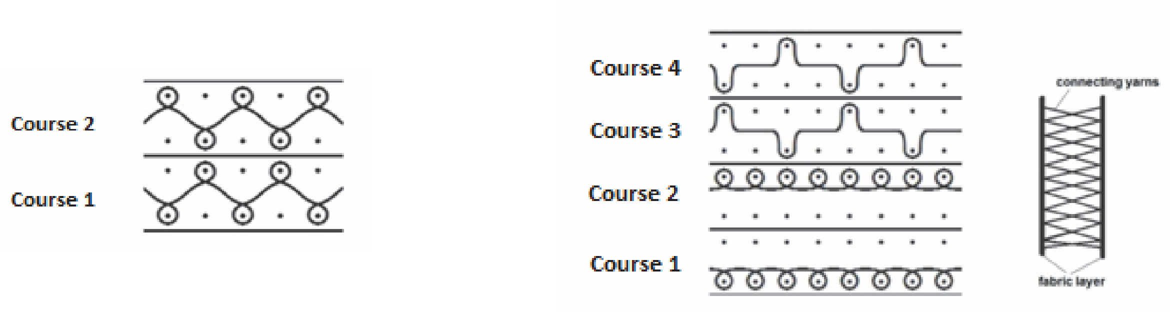
2. MATERIALS AND METHODS

This paper reports an investigation of the behaviour of flat knitted fabrics designed for shoe linings. Cotton, bamboo and two high performance yarns (Type A, Type B) were used in the yarn production and the cotton yarns and their blends were produced at a yarn count of 20/1 Nm. For the production of spacer fabric, polyamide with a count of 20/1 Nm was also used as a spacer yarn. The characteristics of the yarns were measured by using Uster Tester 5 and the results are given in Table 1.

Interlock and spacer fabric structures were knitted on an electronic flat knitting machine CMS 530 E 6.2. The needle diagram of the fabric structures was given in Fig. 1. 10 different fabrics (Table 2) were produced by using the yarns listed in Table 1. After knitting process, the fabric samples were kept under the standard atmospheric conditions for the relaxation.

Table 1. Yarn characteristics

Yarn property	100 % Cotton (Ring)	100% Cotton (Open- End)	50/50 % Cotton/Bamboo	40/ 60 % Cotton/Type A yarn	80/20 % Cotton/Type B yarn
U%	9.39	8.23	14.38	10.41	14.20
CV of yarn count, %	11.87	10.38	19.30	13.09	18.73
Thin places (-40%) per km	7.5	2.5	837.5	52.5	1025
Thin places (-50%) per km	0	0	60	2.5	202.5
Thick places (+35%) per km	347.5	37.5	1313	402.5	1798
Thick places (+50%) per km	25	0	455	17.5	732.5
Neps (+200%) per km	45	0	507.5	15	1100
Hairness index	8.15	5.35	7.70	7.96	6.61



Interlock structure **Spacer fabric structure**

Figure 1. Cross sectional view of the knitted fabrics

Table 2. The fabrics used in this study

Fabric structure	Fabric codes	Type of yarn
Interlock fabric	**Co (RG)**	100 % Cotton (Ring)
	Co (OE)	100% Cotton (Open- End)
	Co (BA)	50/50 % Cotton/Bamboo
	Co (Type A)	40/ 60 % Cotton/Type A
	Co (Type B)	80/20 % Cotton/Type B
Spacer fabric	**Co (RG)**	100 % Cotton (Ring)
	Co (OE)	100% Cotton (Open- End)
	Co (BA)	50/50 % Cotton/Bamboo
	Co (Type A)	40/ 60 % Cotton/Type A
	Co (Type B)	80/20 % Cotton/Type B

The physical characteristics of the fabrics include courses/cm, wales/cm, loop length, fabric density, mass per unit area, thickness, extensibility, friction coefficient and porosity were determined. Fabric density values were calculated by using Eq.1. Mass per unit area values were measured according to the TS 251 standard. Fabric thickness was measured using Alambeta device. The extensibility of the fabrics was tested in both wale and course direction, using a Fryma Fabric Extensometer, SDL Atlas according to BS 4294 standard, under a 30 N tensile force, which is considered to be in the range of the regular strain. Additionally the friction coefficient of the fabrics, which is one of the most important parameter for the production of linings, was tested using the inclined plane method, applied with the Shirley Fabric Friction Tester M264, developed to comply with British Standard test method BS 3424. The porosity of the fabrics was calculated using the following Eq. 2.

$$\rho_r = \frac{M}{t} \qquad (1)$$

Where: ρ_r – fabric density, [kg/m^3];

M – mass per unit area of the fabrics [kg/m^2];

t – fabric thickness [m].

$$\varepsilon = \frac{\rho_r - \rho_a}{\rho_r} \cdot 100 \qquad (2)$$

Where:

Ɛ – fabric porosity, [%];

ρ_r – fabric density, [kg/m^3];

ρ_a –fibre density, [kg/m^3].

An important aspect of the textiles designed for footwear is to ensure a proper microclimate for the foot. For this reason the thermal comfort characteristics (thermal conductivity, thermal resistance, thermal absorptivity, air permeability and water vapour permeability) were investigated. Air permeability values were obtained by using Textest FX 3300 instrument according to TS 391 EN ISO 9237 at a pressure of 100 Pa. Relative water vapour permeability was measured on Permetest instrument working on a similar skin model principle as given by the ISO 11092. Alambeta Instrument was used for the determination of the thermal conductivity, thermal resistance and thermal absorptivity values of the fabrics.

As statistical evaluation ANOVA tests (p, 0.05) were applied to the results of the air permeability, water vapour permeability and thermal comfort properties.

3. RESULTS AND DISCUSSION

3.1. Physical characteristics of the fabrics

The dimensional characteristics of the fabrics such as courses/cm (cpc), wales/cm (wpc), loop length, thickness, mass per unit area and fabric density were presented in Table 3. The results revealed that the thickness of the samples varied from 1.84 mm to 3.17 mm. 100% cotton yarn produced by open end technique have the highest thickness values for both knitted structures. When construction types are compared, the smallest thickness values were obtained from the interlock fabrics. For spacer fabrics, spacer yarn form the fabrics and forces the layers to be distanced, making thus their thickness values higher than for interlock ones. The smallest mass per unit area value was obtained from Cotton/Type A fabrics for both interlock and spacer fabrics. This can be explained by the fibre cross section containing channels, and consequently a reduced mass. Due to the addition of spacer yarn into the structure, spacer fabrics have higher mass per unit area values than interlock fabrics.

Fabric extensibility is defined as the capacity to reach the maximum value of elongation when subjected to forces below breaking point. In the case of footwear linings, this property is required for upper part formability and 3D shaping. These materials also demand characteristics like soft-feel in wearing and flexibility to keep the possibility of friction at the lowest point (2). It was confirmed that the testing direction (course-wise vs wale-wise) had a higher influence compared to the knitted structure and the type of yarn (Fig.2). The results indicated that due to the direction of loop forming in weft knitting technique, the extensibility in course-wise has higher than in wale-wise. When stretching the fabric in course-wise, the yarn is redistributed and the loop shape is reducing its wale spacing and increasing its course spacing. In contrary, when applying the force in wale-wise, the redistribution of the yarn is considerably smaller.

For both fabric structures, Cotton/Type A fabrics were found the most extensible fabrics in both course and wale direction with respect to the other samples (Fig.2). A possible explanation for this might be due to the fabric density. As the fabric density decreases, the amount of the yarn to be redistributed increases and consequently its extensibility becomes higher. It was also observed that spacer fabrics are the most balanced fabric structures with closest extensibility values in both directions. It seems possible that these results are due to the spacer yarn. The polyamide yarn provides dimensional stability to the fabric, forcing it to expand, almost with the same value in both directions.

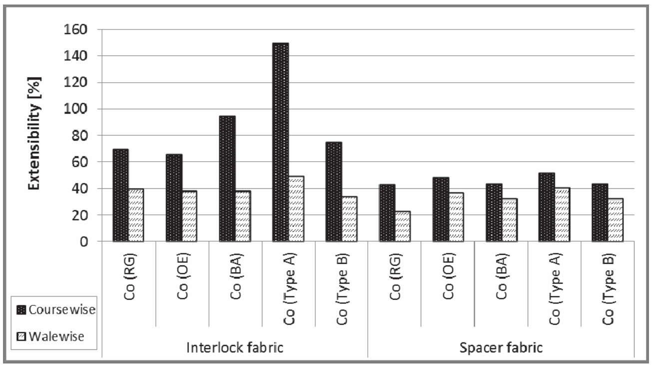


Figure 2. The extensibility (course- and wale-wise) values of the samples

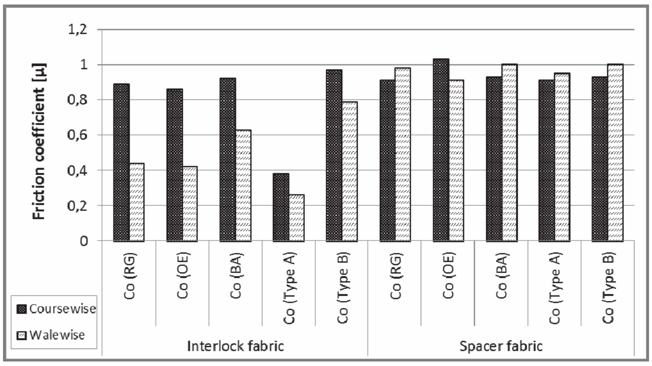


Figure 3. The friction coefficient values (course- and wale-wise) values of the samples

Table 3. Dimensional characteristics of the fabrics

Fabric structure	Type of yarn	cpc	wpc	Loop length [mm]	Thickness [mm]	Mass [g/m^2]	Fabric density [kg/m^3]
Interlock fabric	Co (RG)	7	10	5.35	2.094	407.00	194.36
	Co (OE)	7	9	5.31	1.844	348.00	188.72
	Co (BA)	7	9	5.08	1.881	368.75	196.04
	Co (Type A)	8	8	5.13	1.904	226.00	118.70
	Co (Type B)	9	9	4.97	1.902	368.56	193.77
Spacer fabric	Co (RG)	6	10	5.09	3.167	557.37	175.99
	Co (OE)	6	10	5.15	2.812	500.27	177.91
	Co (BA)	6	10	5.11	3.036	536.34	176.66
	Co (Type A)	5	10	5.12	3.140	397.13	126.47
	Co (Type B)	6	10	4.93	2.805	532.36	189.79

The frictional behaviour of textile structures is of considerable importance especially in footwear components. The friction coefficient of linings refers to sliding resistance between leather and lining. In the upper part of the footwear, lining and leather are attached together. If the friction between leather and lining is too low, the linings begin to slide and wrinkles will occur on the surface of the linings and this will cause an uncomfortable feeling for the wearer. According to "ISO/TR 20882:2007, Footwear - Performance requirements for components for footwear – Lining and insocks", the friction coefficient of the materials designed for shoe linings should be equal or higher than 0.7 (13). The results indicated that, the spacer fabrics are more appropriate structure for shoe linings as compared with interlock fabrics. Spacer fabrics produced with Cotton/Type A, Cotton/Type B and Cotton/Bamboo blended yarns report slight differences of the coefficient in both direction compared with the others, where the differences are quite visible (Fig.3). This particular behaviour makes them suitable to be used in any direction, according to the shoe part where they find place.

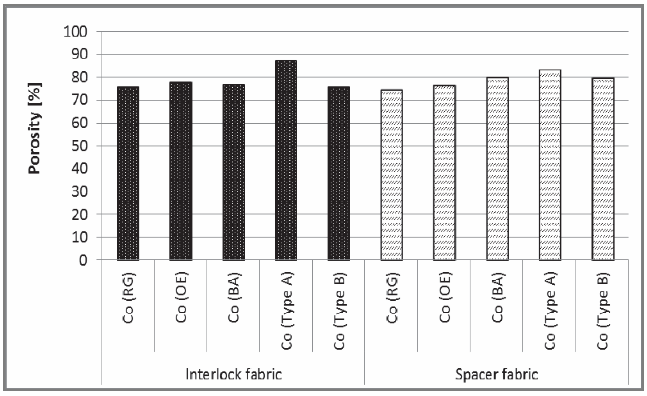


Figure 4. The porosity values of the samples

It can be seen from the Fig. 4, all fabric samples have porosity values higher than 70% and Cotton/Type A fabrics have higher porosity values for interlock and spacer fabrics. Additionally, the spinning technique used to produce the cotton yarn, influences theses fabrics in terms of porosity. The yarns produced by ring spinning technique exhibits the lowest porosity as compared to open end yarn production technique.

3.2. Thermal comfort characteristics of the fabrics

In general, linings must be light, flexible enough to take over the desired form, durable in wearing, and must present cushioning effect. Besides all these characteristics, comfort is the most important aspect of the footwear. Textiles used for footwear linings must provide an adequate microclimate to normal physiology of the foot, such as: temperature T=21-33^oC, relative humidity φ=60-80%, content of CO_2=0.8%. Thus, in order to be compatible to the body, the fabrics must have a good capacity of water absorption and desorption, high permeability to air and water vapour and good thermal properties (14).

The statistical evaluation of the thermal comfort results are given in Table 4.

Table 4. p values of the thermal comfort properties of the fabrics

	Interlock fabrics	Spacer fabrics
Air permeability	.000	.000
Relative water vapour permeability	.000	.000
Thermal conductivity	.000	.000
Thermal resistance	.000	.000
Thermal absorptivity	.000	.000
Thickness	.000	.000

Air and water vapour permeability

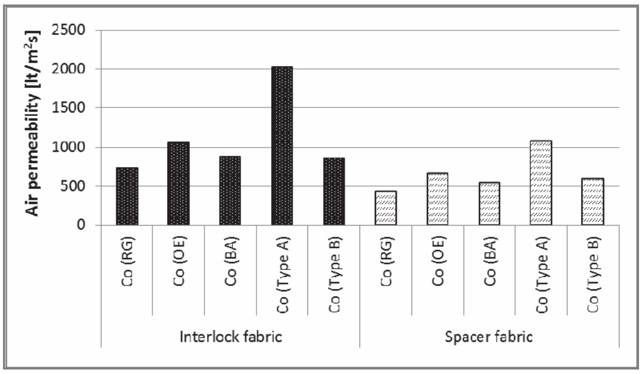


Figure 5. Air permeability values of the samples

Air permeability indicates how well the air passes through the fabric. The main factors that influence the air to flow through the fabrics are the porosity, thickness, mass per unit area, density, the structure of the fabric and yarn characteristics (15-18). It is noticeable from Fig.5 that, Cotton/Type A fabrics have the highest air permeability values for both interlock and spacer fabric structures. This situation might be explained by the fabric density and porosity. Fabric density is one of the most effective factors for air permeability. As the fabric gets denser, the surface will be more compact, resulting poor air permeability. The spaces created between yarns by the loop geometry, specific to the knitted fabrics, will be reduced and the fabric is acting like a barrier that hampers the passage of the air through it. As mentioned before, air permeability is closely related with porosity. With increasing of the porosity, the structure will be more open, facilitating in this way the transport of vapours through fabric from skin to the surface (15, 16). In this study, this aspect is confirmed by the Cotton/Type A fabrics for both interlock and spacer fabric structures which present the lowest fabric density, the highest porosity and air permeability values (Table 3, Fig. 4). When the construction types are compared, spacer fabrics contribute lower air permeability characteristics than interlock fabrics. A possible explanation for this might be due to the higher weight and thickness values of these fabrics. As the fabrics get heavier and thicker, the amount of air passed through the fabric decreases (Table 3).

Water vapour permeability of a fabric indicates the capacity of the fabric to transmit water vapour from skin to the surface of the fabric. Water vapour transmission takes place along the fibres and through the air spaces between the yarns created by their arrangement within the structure (19). As illustrated in Fig.6, the highest water vapour permeability values were obtained from Cotton/Bamboo and Cotton/Type A fabrics for interlock and spacer fabric structures, respectively. It is clear that for these blends, fabrics containing bamboo or Type A yarn will possess a higher water vapour permeability, as it has been mentioned that the water vapour permeability of a fabric depends on the moisture regain/hygroscopic property of the constituent fibres. The relative water vapour permeability characteristic is generally increased with an increase of hygroscopic fibres (20-22).

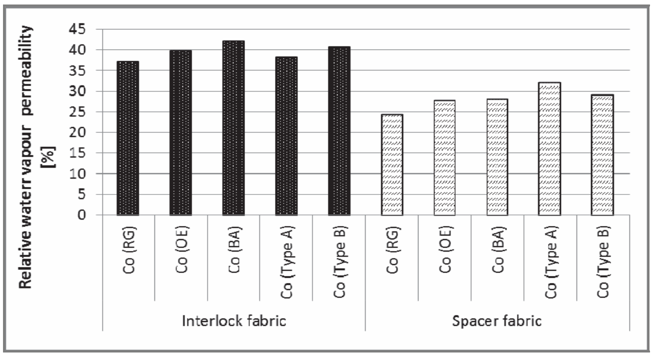


Figure 6. Relative water vapour permeability values of the samples

Thermal conductivity, thermal resistance and thermal absorptivity

Besides air and water vapour permeability, thermal comfort characteristics of fabrics can be evaluated through three properties: thermal conductivity, thermal resistance and thermal absorptivity.

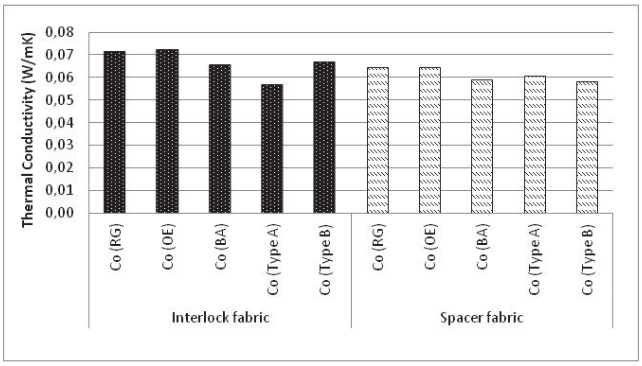


Figure 7. Thermal conductivity values of the samples

The thermal conductivity (λ) represents the amount of heat, which passes from 1m^2 area of material through the distance 1m within 1s and creates the temperature difference of 1K (23). For textile materials, still air in the fabric structure is the most important factor for conductivity value, as still air has the lowest thermal conductivity value as compared to all fibres (λ_{air} = 0.026). According to the results (Fig.7) and statistical evaluations (Table 4), for both fabric structures, 100% cotton yarns produced by ring and open end technique have the highest thermal conductivity values. This situation is attributed to the differences in the amount of entrapped air in the fabric structure. While the fabric mass per unit area decreases, the amount of fibres in the unit area decrease as well and the amount of air layer increases. Therefore, lighter fabrics that contain more still air have lower thermal conductivity values, because of lower thermal conductivity values of textile fibres than the entrapped air.

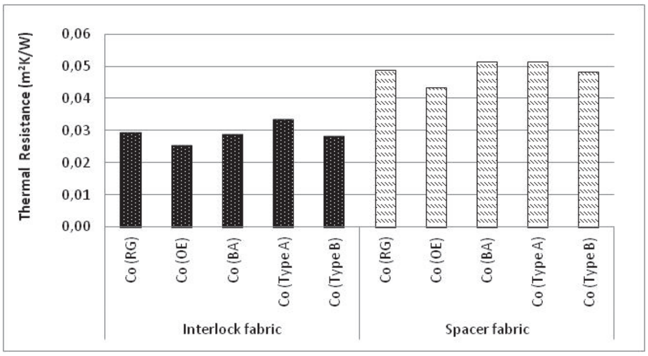


Figure 8. Thermal resistance values of the fabrics

The thermal resistance is a measure of the body's ability to prevent heat from flowing through it. Under a certain condition of climate, if the thermal resistance of clothing is low, the heat energy will gradually reduce with a sense of coolness. Thermal resistance Rct depends on fabric thickness (h) and thermal conductivity (λ) as illustrated in Eq. 3:

$$Rct = \frac{h}{\lambda}(m^2 K / W) \quad (3)$$

As it is seen from Fig.8, the spacer fabric samples with higher thickness have higher thermal resistance values than interlock samples. The spacer yarn keeps the two constituent layers at a certain distance from one another, which facilitates a quantity of air to be trapped inside. This acts as an insulating layer that slows down the conduction of heat to outside. When comparing the yarn types, Cotton/Type A fabric has the highest and 100% cotton yarn produced by open end technique has the lowest thermal resistance properties. This situation can be explained by the inverse relationship between thermal resistance and thermal conductivity as indicated in Eq.2. If the fabric is thin and has higher thermal conductivity values, its thermal resistance will be low.

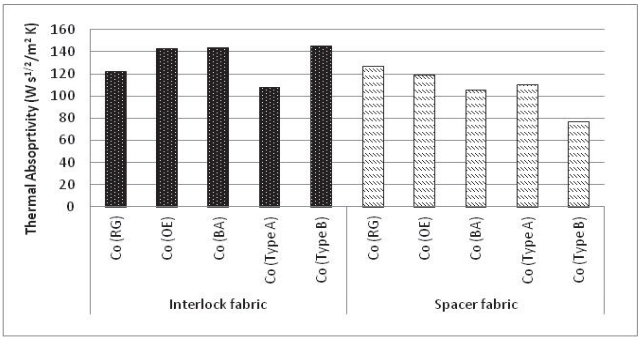


Figure 9. Thermal absorptivity of the fabrics

The thermal absorptivity reveals the warm-cool sensation of the fabric at initial touch. If the thermal absorptivity of clothing is high, it gives a cooler feeling at the first contact. The fabric sensation is given by the surface roughness. A smoother surface will provide a cooler feeling (24). Studies have revealed that compact fabrics, which mean increased knit density, present smoother fabric surfaces (25). As illustrated in Fig. 9, the lowest thermal absorptivity values belong to Cotton/Type A fabric for interlock structure and

Cotton/Type B fabric for spacer fabric structures meaning that these fabrics present the warmest feeling at the initial touch.

CONCLUSIONS

- ✓ The results indicate that from all structural parameters, stitch density has the most significant effect on the fabric extensibility. By increasing the fabric compactness, the yarn amount to be redistributed in this way decreases, so its extensibility becomes lower, this hypothesis was confirmed by the comparative sample analysis. Spacer fabrics are the most balanced fabric structures with closest extensibility values in both directions. The extensibility property is also influenced by the characteristics of the yarn used for knitting. The Cotton/Type A spacer fabrics exhibit the most balanced behaviour in both directions, so they can be recommended to be used in the direction convenient for the subsequently 3D shaping with leather part.

- ✓ The frictional properties of the fabrics are of considerable importance in case of footwear linings, especially the friction coefficient, which must have a minimum value of 0.7. Also it has been demonstrated from the results that *spacer fabrics are more appropriate structure for shoe linings as compared to interlock fabrics*. *Spacer fabrics produced with Cotton/Type A, Cotton/Type B and Cotton/Bamboo blended yarns have shown slight differences in the friction coefficient in both directions as compared to the others.*

- ✓ Within the complex analysis of knitted fabrics for footwear linings, the primary selection should be made in accordance with their extensibility and friction coefficient, as eligible conditions for the subsequent footwear production stages and wear requirements. *According to the extensibility and friction coefficient values of the samples, all spacer fabrics and interlock fabrics produced with Cotton/Type A and Cotton/Bamboo blended yarn are appropriate fabrics for shoe linings.*

- ✓ Interlock fabrics produced with Cotton/Type B and Cotton/Bamboo blended yarn are recommended for use in hot climates with high water vapour permeability, thermal conductivity and cooler feeling at the initial contact.

- ✓ The spacer fabric produced with Cotton/Type A blended yarn is suitable for cold climate conditions with high thermal resistance, air and water vapour permeability and give warmer feeling with low thermal absorptivity values.

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