(REFEREED RESEARCH)

HEAT, AIR AND WATER VAPOR TRANSFER PROPERTIES OF CIRCULAR KNITTED SPACER FABRICS

YUVARLAK ÖRME SANDVİÇ KUMAŞLARIN ISI, HAVA ve SU BUHARI TRANSFER ÖZELLİKLERİ

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ABSTRACT

Spacer fabrics are 3D textile structures formed of two fabric layers combined by a spacer yarn or layer. The production method of spacer fabrics produced in circular knitting machines is based on the connection of two fabric layers knitted in cylinder and dial with tucks. In this study, thermal comfort properties of fabrics which are produced in three different dial heights and two different spacer yarn on circular knitting machine by using spacer fabric production method were investigated. It is observed that, fabric weight, thermal conductivity, thermal resistivity, air permeability and relative water vapor permeability properties are affected by dial height and the type of spacer yarn significantly.

Key Words: Spacer fabrics, Circular knitting, Dial height, Spacer yarn, Thermal comfort.

ÖZET

Sandviç tekstiller iki kumaş tabakasının bir bağlantı ipliği veya tabakası ile bağlanması sonucu elde edilen üç boyutlu yapılardır. Yuvarlak örme makinelerinde sandviç kumaş üretimi, silindir ve kapak iğneleri tarafından örülen iki kumaş tabakasının, bağlantı ipliklerinin her iki yatakta askı yapması ile birleştirilmesi esasına dayanır. Bu çalışmada yuvarlak örme makinelerinde sandviç kumaş üretim tekniği ile üç farklı kapak yüksekliğinde ve iki farklı bağlantı ipliği ile üretilen sandviç kumaşların fiziksel ve ısıl konfor özellikleri incelenmiştir. Araştırma sonucunda kapak yüksekliği değişiminin ve bağlantı iplik tipinin kumaşların gramaj, ısıl iletkenlik, ısıl direnç, hava geçirgenliği ve bağıl su buharı geçirgenliği özellikleri bakımından farklılık yarattığı tespit edilmiştir.

Anahtar Kelimeler: Sandviç kumaşlar, Yuvarlak örme, Kapak yüksekliği, Bağlantı ipliği, Isıl konfor.

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1. INTRODUCTION

In last decades, increased attention is paid to comfort properties of textiles and garments. As general opinion, personal well-being and high living standards nowadays become certainly important, the significance of comfort is well recognized by the people. Modern and conscious consumers consider comfort as one of the most important garment properties. This fact should not be surprising since it is well known the strong relation between the comfort properties of garment and human sensations.

Comfort is defined as “the absence of displeasure or discomfort” or “a neutral state compared to the more active state of pleasure” (1).

There is general agreement that the transfer of heat, moisture and air through the fabric are the major factors for thermal comfort. Many authors have pointed out that the major factors influencing heat transfer through a fabric are the thickness and enclosed air. A decrease in thickness of fabric, together with a corresponding decrease of fabric volume, is generally followed by decrease of air entrapped in fabric structure changing the thermal properties of the fabric (2, 3). Milenkovic et al. (1) proved that fabric thickness, enclosed still air and external air movement are the major factors that affect the transfer through fabric. Also Greyson (4) and Havenith (5) mentioned that the heat and water vapor resistances increase with the increase of material thickness and air entrapped in the fabric. Shoshani and Shaltiel (6) noted that the thermal insulation increases while the density of fabric decreases. Pac et al. (7) investigated the influence of fiber morphology, yarn and fabric structures on transient thermal properties and friction behaviour. They found that, the contact interfacial area between skin and fabric is small for rough fabrics and more air is entrapped on a hairier fabric surface so these fabrics give warmer feeling. They also stated that structural roughness and warm–cool feeling of the fabrics change according to fiber type, yarn and fabric structure. Anand (8) reported that the open construction 3D eyelet has better water vapor permeability than micromesh, pique and mock rib structures. Hes et al. (9) developed a new functional knitted fabric possessing double layers by using different yarn components (like polypropylene and cotton) in order to maximize the suction and transport moisture properties. Uçar and Yılmaz (10) studied the thermal properties of rib knitted fabrics and noted that a decrease in rib number leads to a decrease in heat loss; the use of 1×1 rib and tight structure would provide better thermal insulation. Despite all the research regarding thermal comfort, there is very little research regarding thermal comfort properties of circular knitted spacer fabrics.

Spacer fabrics are 3D textile structures formed of two fabric layers combined by a spacer yarn or layer. Due to their three dimensional construction, spacer fabrics have specific properties which cannot be met by conventional textiles. There are lots of application areas of spacer fabrics such as medical textiles, automotive textiles, geotextiles, protective textiles, sportswear and composites, because of the possibility of using a variety of different materials, good performance characteristics and the three dimensional construction. It is possible to produce these fabrics by weaving or nonwoven techniques besides warp and weft knitting processes. Knitting technology especially warp knitting technique is the most commonly known and applied technology for the production of spacer fabrics.

To produce spacer fabrics using circular knitting machine requires the use of at least three different yarns for each course of fabric. These are; a) yarn for the cylinder needles; b) yarn for the dial needles and c) a spacer yarn, generally monofilament yarn connecting the two layers by tucks (11). The distance between the two fabric layers can be set by the dial height adjustment. There are two techniques of producing spacer fabrics: tucking on dial and cylinder needles at the same feeder and knitting/plating on the dial needles and knitting on cylinder needles (12).

Spacer fabrics are lightweight and breathable structures. They have good physiological and thermal comfort. They transport moisture easily; their air permeability and water vapour permeability values are high. Their compression characteristic is also higher than conventional textile surfaces.

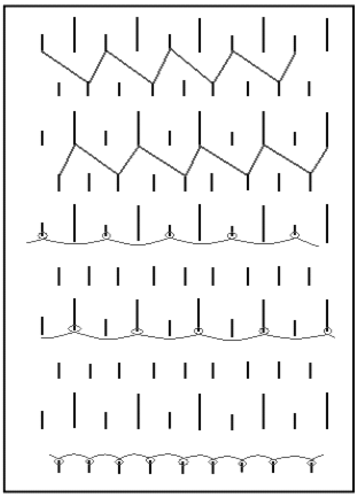
Spacer warp knitted fabrics have been studied globally for many years (13, 14, 15, 16), but the number of researches about the properties of spacer fabrics produced on circular knitting machines are relatively few. Anand (12) compared the dimensional, comfort and elastic properties of fabrics produced with warp and weft knitting methods. He found that both spacer fabrics had more or less identical tenacity, breaking extension and initial modulus properties. The comfort properties of weft knitted spacer fabrics are better than warp knitted spacer fabrics. Wei and Hairu (17) investigated the compression behavior of different circular knitted spacer fabrics. The results indicate that under the stated conditions the increase of spacer yarn fineness, fabric density and the distance between dial and cylinder is favorable for reducing compressive deformation and improving recoverability. Yip et.al. (18) compared the characteristics of different spacer fabrics including low-stress mechanical properties, air permeability and thermal conductivity. They found that all tensile, bending and compression properties of spacer fabrics are greatly depending on the structure and the stitch density of spacer fabric, the type and the yarn count of the spacer yarn beside the spacer yarn configuration. Air permeability and thermal conductivity properties of spacer fabrics are closely related to the fabric density.

The increased demand of 3D knitted fabrics and lack of comprehensive studies on the characteristics especially thermal comfort properties of weft knitted spacer fabrics are sound basis for this research. In this study, the effect of dial height arrangement and the type of spacer yarn on thermal comfort properties of circular knitted spacer fabrics were investigated rigorously.

2. MATERIAL AND METHOD

2.1. Material

As a spacer yarn, two different type of 100 denier poliester yarns (monofilament and multifilament) were used and 150 denier multifilament polyester yarns were also used for the back and face side of the spacer fabrics. The non-porous structures were selected for both side of fabrics (Fig.1).



1st feeder spacer yarn

2nd feeder spacer yarn

3rd feeder yarns for face side of the fabric

4th feeder yarns for face side of the fabric

5 th feeder yarns for back side of the fabric

Figure 1. Needle diagram of spacer fabrics

Fabrics were produced in three different thicknesses by means of adjustment of the dial height (3, 3.5, 4 mm) using both monofilament and multifilament spacer yarns. As it is known, the distance between the two sides of spacer fabrics can be arranged by the dial height. Theoretically, this distance can be maximum 10 mm; but pratically it can be used max. 5mm for monofilament spacer yarn. Limitation of the distance caused by multifilament spacer yarn, these values (3, 3.5, 4 mm) were chosen for experiments.

The knitting process was performed on a 20 gauge and 38"diameter Mayer & Cie, OVJA 1.6 E 3 WT circular knitting machine with constant machine settings. The fabric samples were kept under the standard atmospheric conditions for the relaxation.

2.2. Method

Alambeta and Permetest instruments (Sensora instruments, Czech Republic) were used for measurements (19). The Alambeta basically simulates the dry human skin and its principle depends in mathematical processing of time course of heat flow passing through the tested fabric due to different temperatures of bottom measuring plate (22^0C) and measuring head (32^0C) (20). Whole measurements were repeated five times

Air permeability values were obtained by using Textest FX 3300 instrument according to TS 391 EN ISO 9237. Its principle depends in the measurement of air flow passing through the fabric at certain pressure gradient Δp. The results of the measurements, reported in Fig. 4 are averages from the values of 10 readings. All the measurements were done in controlled laboratory conditions.

Relative water vapor permeability was measured on Permetest instrument working on similar skin model principle as given by the ISO 11092 (21). The results illustrated in Fig. 5 are averages from the values of 3 readings.

Evaluation of the test results was made using statistical software. To determine the statistical importance of the variations, ANOVA tests were applied. To deduce whether the parameters were significant or not, p values were examined. Ergun emphasized that if "p" value of a parameter is greater than 0.05 ($p>0.05$), the parameter will not be important and should be ignored (22).

3. RESULTS AND DISCUSSION

The thermal comfort values and statistical differences of the fabrics with monofilament and multifilament spacer yarns are given in Table 1 and Table 2, respectively. In these tables, the mean values are marked with the letters 'a', 'b' and 'c'. Any levels marked by the same letter showed that they were not significantly different ('a' shows the lowest value and 'c' shows the highest value). For instance the fabric weight values of the fabrics with multifilament spacer yarns were significantly different and Multi 4 marked with "c" is heavier than Multi 3 marked with "a".

3.1. Thermal Conductivity

Thermal conductivity coefficient λ presents the amount of heat, which passes from $1m^2$ area of material through the distance 1m within 1s and create the temperature difference 1K (20). 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 compared to all fibers ($\lambda_{air} = 0.026$).

According to statistical evaluation, there is not a significant difference between thermal conductivity values of the fabrics with monofilament spacer yarn (Table 1). For the fabrics with multifilament spacer yarn, Multi 4 has the highest thermal conductivity value. The difference between Multi 3 and Multi 3,5 is not significant statistically (Table 2).

The fabrics knitted using monofilament spacer yarn have higher thermal conductivity values than the fabrics produced with multifilament spacer yarn (Fig.2).

Whole differences are attributed to the differences in fabric thickness and the amount of entrapped air in the fabric structure. While the fabric thickness increases, the fabric volume and the fabric weight increase also. With the increasing of the fabric weight the amount of fiber in the unit area increases as well and the amount of air layer decreases. Therefore heavier fabrics that contain less still air have higher thermal conductivity values, because of higher thermal conductivity values of textile fibers than of entrapped air (23).

Table 1. Thermal comfort properties of the fabrics with monofilament spacer yarn

Fabric code	Dial height (mm)	Fabric weight (g/m^2)	Thickness (mm)	Thermal conductivity (W/mK)	Thermal resistance (m^2K/W)	Relative water vapor permeability (%)	Air permeability (lt/m^2s)
Mono 3	3	380 a	3.227 a	0.0525 a	0.0600 a	20.90 a	2133 b
Mono 3,5	3,5	388 a,b	3.523 b	0.0522 a	0.0675 b	21.57 a	2010 a
Mono 4	4	393.6 b	3.425 b	0.0538 a	0.0695 b	24.23 a	2006 a

Table 2. Thermal comfort properties of the fabrics with multifilament spacer yarn

Fabric code	Dial height (mm)	Fabric weight (g/m^2)	Thickness (mm)	Thermal conductivity (W/mK)	Thermal resistance (m^2K/W)	Relative water vapor permeability (%)	Air permeability (lt/m^2s)
Multi 3	3	315.8 a	2.265 a	0.0437 a	0.0518 a	39.27 a	925.9 b
Multi 3,5	3,5	324.4 b	2.313 a	0.0429 a	0.0538 a	40.63 a	899.2 a
Multi 4	4	339.0 c	3.134 b	0.0450 b	0.0565 b	38.80 a	898.6 a

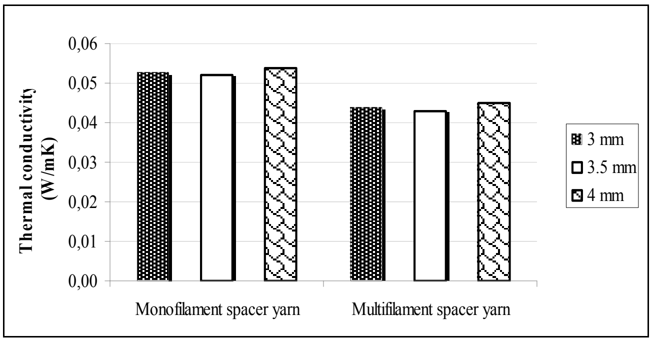


Figure 2. Thermal conductivity values of spacer fabrics

3.2. Thermal Resistance

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 small, 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 Equation 1:

$$Rct = \frac{h}{\lambda}(m^2 K / W) \quad (1)$$

As it is seen from Fig.3, for the both spacer yarns, the thermal resistance increases as the dial height and fabric weight increase as mentioned in a previous research (24).

For the comparison of spacer yarn type, the fabrics with monofilament spacer yarn have better insulation than the fabric with multifilament spacer yarn, because of higher still air between monofilament yarns.

Although the general expectation was to register an inverse relationship between thermal resistance and thermal conductivity, the graphs for these parameters in Fig. 2 and 3 have the same inclination. This contradiction might be explained by fabric thickness. If the amount of increase in fabric thickness is more than the amount of increase in thermal conductivity, thermal resistance will also increase and a significant increase is seen in the fabric thickness value (Table 1 and Table 2).

3.3. Air Permeability

Air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. As illustrated in Figure 4, the highest air permeability value belongs to the samples knitted with the dial height 3 mm for both spacer yarn types. Because the fabrics get finer, the amount of air passed through the fabric increases.

Statistical analysis show that spacer fabrics with monofilament spacer yarn have higher air permeability values than fabrics with multifilament spacer yarn (Table 1 and 2). In fact, an opposite result is expected because of the higher thickness of fabrics from monofilament yarns. This result can be explained by the cross sectional view of the fabrics. The fabrics with monofilament spacer yarns have more open structure inside the fabric, so the air pass easily through the fabric.

3.4. Relative Water Vapor Permeability

Water vapor permeability is the ability to transmit vapor from the body. Relative water vapor permeability is given by the relationship:

$$q[\%] = 100 \times \frac{q_s}{q_0} \quad (2)$$

where q_s is the heat flow value with a sample (W/m^2) and q_o is the heat flow value without sample (W/m^2).

Statistical evaluations show that the effect of dial height on relative water vapor permeability values is insignificant (Table 1 and 2). However the spacer yarn type has a significant effect on this property. The water vapor permeability values are higher for the fabrics with multifilament spacer yarns because of capillarity between filaments in multifilament yarn.

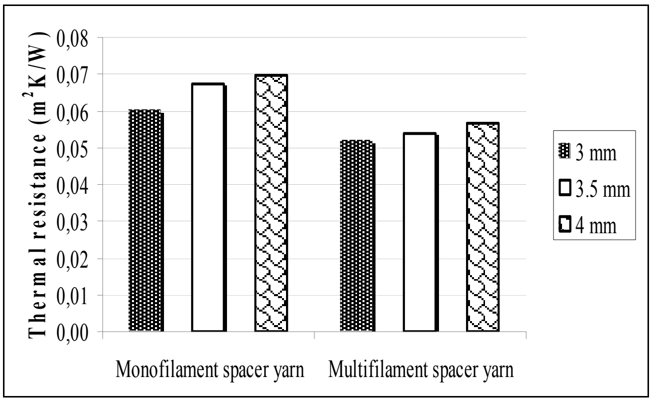


Figure 3. Thermal resistance values of spacer fabrics

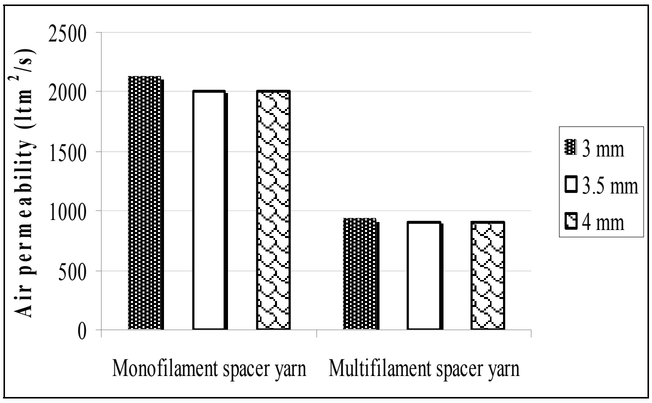


Figure 4. Air permeability values of spacer fabrics

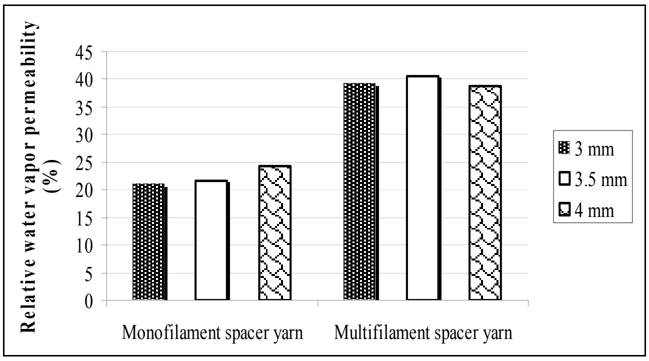


Figure 5. Relative water vapor permeability values of spacer fabrics

4. CONCLUSION

This study performs a quantitative investigation of various fabric characteristics, such as fabric weight, air permeability, thermal conductivity, thermal resistance and relative water vapor permeability properties of spacer fabrics.

The results indicate that for monofilament spacer yarn as the dial height increases; the parameters such as weight, thickness, and thermal resistance increase and air permeability decreases. For multifilament spacer yarn by the increasing of the dial height weight, thickness, thermal conductivity and thermal resistivity values increase and air permeability value decreases as well.

The fabrics with monofilament spacer yarn have higher weight, thickness, thermal conductivity, thermal resistivity, air permeability values and lower relative water vapor permeability values than the fabrics with multifilament spacer yarn.

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