Study on the Physical Properties of Three-dimensional Spacer Fabrics

Joanne Yip[a], Li Sze Chung[a]

[a] *ACE Style Institute of Intimate Apparel, Institute of Textiles & Clothing*
The Hong Kong Polytechnic University, Hong Kong

Abstract

Spacer is a three-dimensional knitted fabric which consists of two outer textile substrates which are joined together and kept apart by spacer yarns. Spacer fabrics are used for environmental reasons, which can be used in different product groups such as mobile textiles (car seat covers, dashboard cover), industrial textiles (composites), medical textiles (anti-decubitus blankets), sports textiles and foundation garments (bra cups, pads for swimwear). In this study, fabric properties included low-stress mechanical properties, air permeability and thermal property of five different spacer fabrics were investigated. Low-stress mechanical properties obtained by KES-fabric evaluation system revealed that tensile, bending and compression properties of spacer fabric are greatly depending on the type of spacer fabric (warp knit or weft knit), the type of spacer yarn used (mono-filament or multi-filament), the yarn count of the spacer yarn, the stitch density and the spacer yarn configuration. Air permeability and thermal property of spacer fabric is closely related to the fabric density. This experiment work suggests that a careful selection of spacer fabric for its application is of primary importance.

Keywords: Spacer fabrics, physical properties

1. Introduction

Spacer fabrics are used widely in different products such as mobile textiles (car seat covers, dashboard cover), industrial textiles (composites), medical textiles (anti-decubitus blankets), sports textiles and foundation garments (bra cups, pads for swimwear). It is regarded as an environmentally friendly textile materials when compared with polyurethane foam since they can be recycled, emission controlled and resources used are conservation [1].

Spacer fabric is a three dimensional knitted fabric which consists of two separate knitted substrates and joined together or kept apart by spacer yarns[1-3]. There are two types of spacer fabric which are warp knitted spacer fabric and weft knitted spacer fabric. Warp knitted spacer fabric is knitted on rib raschel machine having two needle bars while weft knitted spacer fabric is knitted on a double jersey circular machine having a rotatable needle cylinder and needle dial [1, 4, 5].

Spacer fabrics have been studied globally for many years. However, very little attention has focused on the effect of fabric characteristics on its physical properties including the mechanical properties, thermal property and air permeability of spacer fabrics. This paper is concerned mainly with the assessment of the fabric structures on the physical properties of spacer fabric.

2. Experimental

2.1 Materials

The fabric characteristics of five different spacer samples are shown in table 1. The fabric structure, front view, back view and side views (both warpwise and weftwise) of the samples are shown in table 2.

Table 1 Fabric characteristics of different spacer fabrics

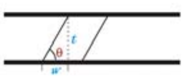
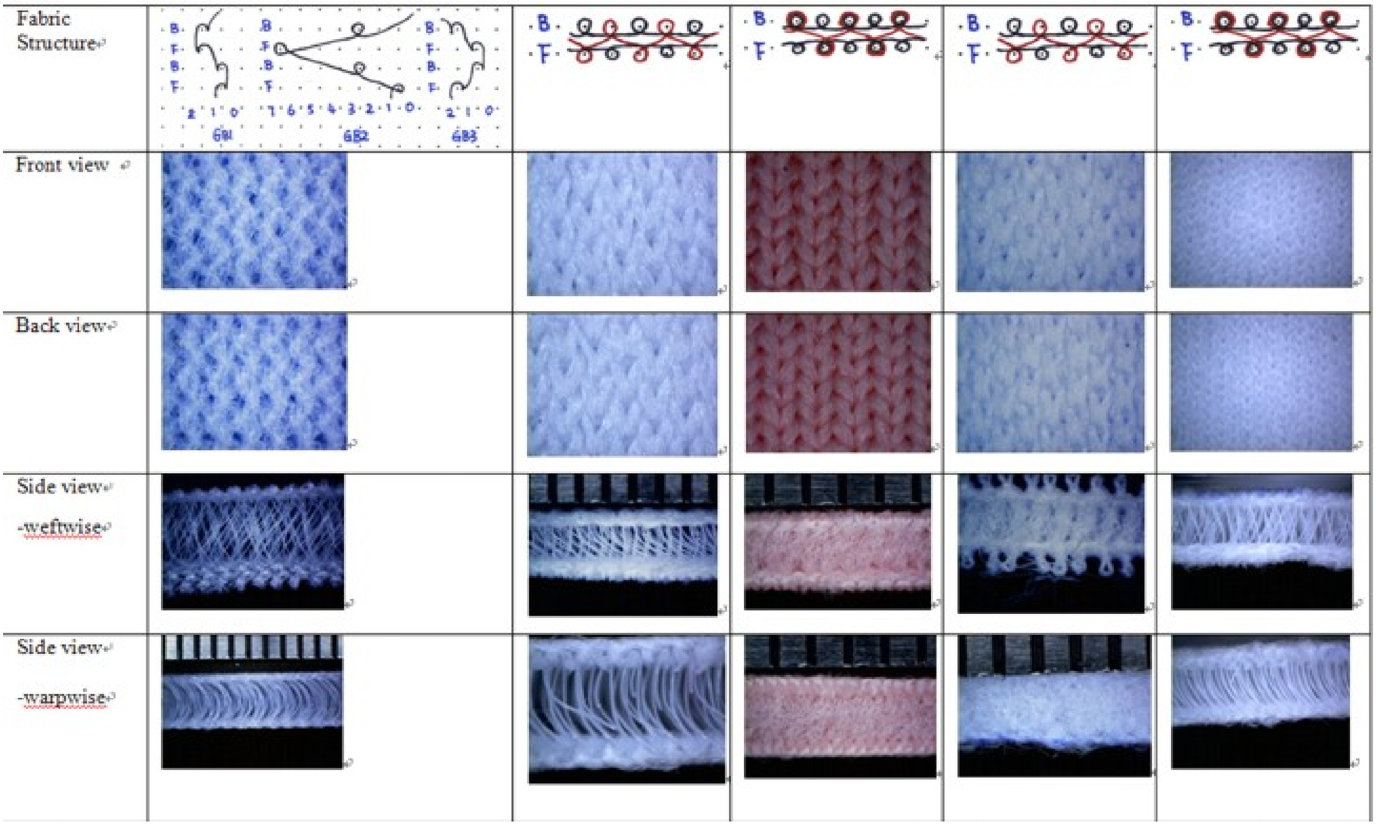
	Sample 1 (WA-MO)	Sample 2 (WE-MO-1)	Sample 3 (WE-MU-1)	Sample 4 (WE-MU-2)	Sample 5 (WE-MO-2)
Fabric Type	Warp knitted	Weft Knitted	Weft Knitted	Weft Knitted	Weft Knitted
Density (kg/m^3)	54.866	117.858	204.269	146.289	125.387
Spacer yarn type	Monofilament	Monofilament	Multifilament	Multifilament	Monofilament
Thickness (mm)	4	3.3	2.866	2.91	3.54
Spacer yarn arrangement (θ) 	$\theta = \tan^{-1} t/w$ $\theta = 52.33^{\circ}$	$\theta = \tan^{-1} t/w$ $\theta = 79.49^{\circ}$	$\theta = \tan^{-1} t/w$ $\theta = 78.07^{\circ}$	$\theta = \tan^{-1} t/w$ $\theta = 63.43^{\circ}$	$\theta = \tan^{-1} t/w$ $\theta = 61.08^{\circ}$

Table 2 Fabric structure and microscopic view of different spacer fabrics



2.2 Air permeability
The air permeability of the samples was studied by KES-F8-AP1 air permeability tester. The air resistance (R) was recorded in terms of kpa.s/m. The results were averages from the values of ten readings.

2.3 Thermal property
The thermal property was studied by KES-F Thermo Labo II. This test is used to measure the power loss from BT-Box (Watt) to the Water Box through the spacer samples. The sample was put on the Water Box which is in the room temperature (20^{o}C). The temperature of BT-Box and Guard were set to the temperature 30^{o}C. The amount of heat passing through the sample in watts per square meter was measured from the power consumption of the test plate heater. The thermal conductivity value (W/mK) of different spacer fabrics can be calculated:
Thermal conductivity (k) =
Heat flow rate × distance / (area × temperature difference)

$$k = \frac{Q}{t} \times \frac{L}{A \times \Delta T}$$

2.4 Low stress mechanical properties
The KES-F (Kawabata Evaluation System) was used for measuring the low stress mechanical properties of the spacer samples including bending and compression properties. The parameters obtained from these hystersis curves are defined and shown in table 3.

Table 3 The low stress mechanical properties obtained from the hysteresis curves.

Properties		**Symbol**	**Definition**	**Unit**
Bending properties	Bending Rigidity	B	Average slope of the linear regions of the bending hysteresis curve to 1.5cm^{-1}	gf.cm^2/cm
	Bending Moment	2HB	Average width of the bending hysteresis loop at 0.5cm^{-1} curvature	Gf.cm/cm
	Coefficient of Friction	MIU	Coefficient of friction between the fabric surface and a standard contactor	-----
Compression properties	Linearity	LC	Linearity of compression/thickness curve	-----
	Compressional Energy	WC	Energy in compressing fabric under 50 gf/cm²	gf.cm/cm²
	Compressional Resilience	RC	Percentage energy recovery from lateral compression deformation	%
	Fabric Thickness at 0.5gf/cm^2 pressure	T_0	Fabric thickness at 0.5gf/cm² pressure	mm
	Fabric Thickness at 50gf/cm^2 pressure	T_m	Fabric thickness at 50gf/cm² pressure	mm

2.5 Stretch and Recovery

The stretch and recovery properties of spacer samples were studied by INSTRON 4411 according to the British standard 4294. By using this method, the specimen of standard dimensions is stretched under a specified load. The INSTRON 4411 machine consists of two clamps which is 7.5cm width. The length of the specimen should be sufficient to allow a distance of 7.5cm (L1) between the inner edges of the clamps to hold the specimen. The load was gradually increased on the specimen to 6kg ± 5kg within 7.5s ± 2.5s. The load was maintained for 10s ±2s and then reduced the load gradually until the clamps were returned to their original position. The load was reapplied immediately to the specimen and the length of the specimen (L2) after 1 minute was measured. The specimen was removed form the clamps to a flat and smooth surface. The distance between the marks after 1 minute (L3) was measured. After 30 minutes the distance between the marks (L4) was measured. The same procedures were done on both warp and weft directions. The values of elongation (E), recovery after 1 minute (R1) and 30 minutes (R30) of different spacer fabrics were calculated as below:

$$E = 100(L2-L1)/L1$$

$$R_1 = 100(L3-L1)/L1$$

$$R_{30} = 100(L4-L1)/L1$$

3. Results and discussion

3.1. Air permeability and Thermal Properties

In this study, the air resistance (R) of different spacer fabrics in terms of kPa.s/m was recorded. A higher number of kPa.s/m indicates a higher air resistance of the fabric [6]. Figure 1 shows the air resistance of different spacer fabrics. The thermal conductivity of different spacer fabrics in terms of W/mK was also recorded. A higher value of thermal conductivity indicates more rapid movement of heat from the skin to the fabric surface, which will provide a cooler feeling [6]. Figure 2 shows the thermal conductivity of different spacer fabrics.

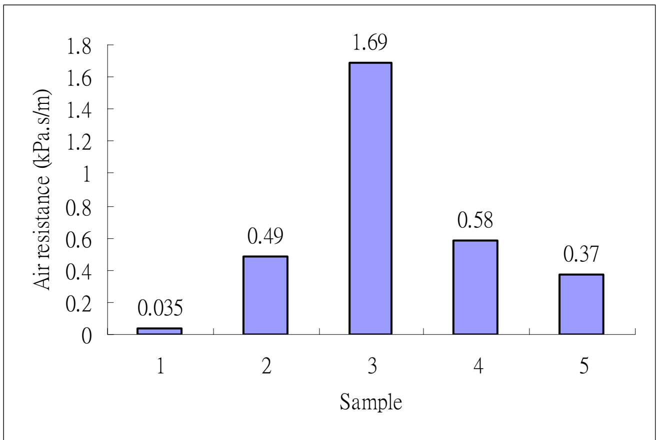


Fig. 1. Air resistance of different spacer fabrics

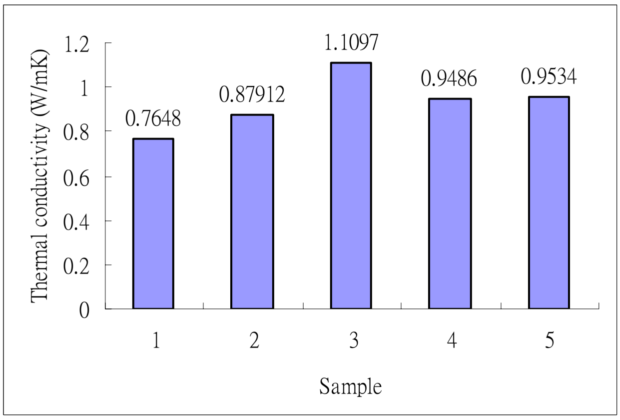


Fig. 2. Thermal conductivity values of different spacer fabrics

Figure 1 indicates that sample 1 (WA-MO) has the lowest air resistance while sample 3 (WE-MU-1) has the highest air resistance. Figure 2 indicates that sample 1 (WA-MO) have a lower thermal conductivity while sample 3 (WE-MU-1) has a higher thermal conductivity.

The air permeability of a fabric is closely related to the construction characteristics of the yarns and fabrics in which large volumes are occupied by air. There are some factors that affect the air permeability of the fabric, e.g. fabric structure, thickness, surface characteristics, etc [7, 8]. In this study, it is suggested that density shows the most significant effect on the air permeability and thermal property of the spacer fabric. A higher fabric density will hinder the air flows through the fabric, thus resulted in poor air permeability of the fabrics. However, a higher fabric density will have a better thermal conductivity as less space to trap the air inside. Therefore, it has better thermal ventilation.

3.2. Compression properties

The compression resistance of different spacer fabrics in terms of the percentage change of thickness compressed under 50 gf/cm² loading was recorded (shown in figure 3). A higher percentage of thickness compressed indicates a lower compression resistance. It is interesting to find that sample 3(WE-MU-1) & 4 (WE-MU-2) have lower compression resistance than sample 1(WA-MO), 2(WE-MO-1) and 5(WE-MO-2). It is suggested that fabric using monofilament as spacer yarn generally has better compression resistant than using multifilament yarn. When the results of spacer fabrics using same type of spacer yarn were compared, it is found that the compression resistance of the sample is closely related to the spacer yarn arrangement. The resistance force of the spacer yarn is F sin θ. Therefore, the sample which has a greater degree will have a higher compression resistance [9, 10].

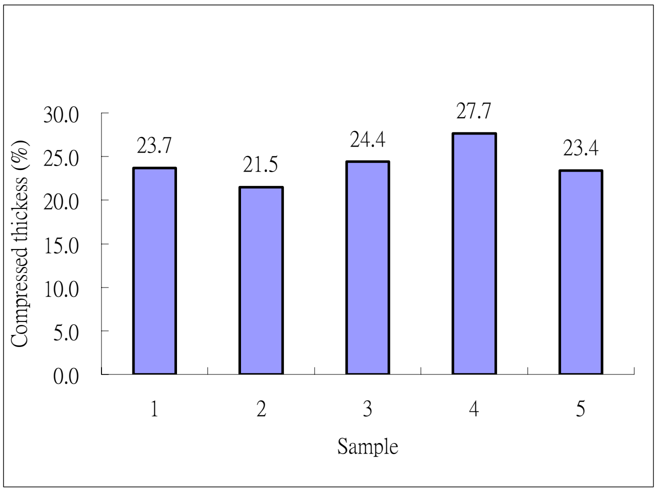


Fig. 3. Compressed thickness of spacer samples

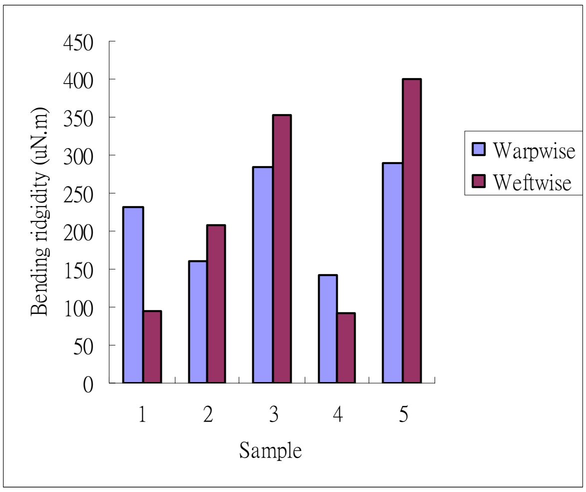


Fig. 4. Bending rigidity of spacer samples

Table 4 shows the compressional resilience of different spacer fabrics which is the percentage energy recovery from lateral compression deformation. A higher percentage indicates a better recovery property. The result indicates that sample 1, 2 and 5 have better recovery property than sample 3 and 4. It is observed that the recovery properties after compression is greatly depended on the spacer yarn type. Spacer samples using monofilament as their spacer yarns have a better recovery properties than that of using multifilament spacer yarns.

Table 4 Compressional resilience of different kind of spacer fabrics

Sample	1	2	3	4	5
RC(%)	75.417	52.247	37.02	35.15	51.317

3.3 Bending Properties

In this study, the bending rigidity of different spacer fabrics in terms of uN.m was recorded. A higher number of uN.m indicates a higher bending rigidity of the fabric. Figure 4 indicates the bending rigidity of both warp-wise and weft-wise of spacer fabrics.

From figure 4, the bending rigidity of spacer fabric is greatly related to the fabric type. Bending rigidity of weft knitted spacer fabric has a higher bending rigidity in weft-wise direction while warp knitted spacer fabric has a higher bending rigidity in warp-wise direction. It is mainly due to the direction of yarn incorporated [11-13]. When the samples are in the same fabric type (weft knitted spacer fabric), the bending rigidity is closely related to the fabric density, spacer structure and spacer type [14, 15]. Weft knitted spacer fabric using interlock structure, monofilament spacer yarn and a higher fabric density will have a higher bending rigidity.

3.4 Stretch and recovery

The stretch and recovery properties of different spacer fabrics in terms of percentage (%) were recorded. A higher percentage indicates a better stretch and recovery properties. The results from table 5 and 6 indicate that sample 1 (WA-MO) has the best stretchabilty in weft-wise while has the poorest stretchabilty in warp-wise. Sample 3 (WE-MU-1) has the best recovery property in both the warp-wise and weft-wise fabric while sample 1 (WA-MO) has the poorest recovery property in both directions.

Table 5 Elongation and recovery of the warp-wise spacer fabrics

Sample	Elongation, E	Recovery after 1min, R1	Recovery after 30min, R30
1	49.17%	86.90%	96.83%
2	67.96%	95.74%	98.69%
3	93.28%	97.38%	99.53%
4	47.32%	94.36%	98.59%
5	114.03%	91.61%	96.88%

Table 6 Elongation and recovery of the weft-wise spacer fabrics

Sample	Elongation, E	Recovery after 1min, R1	Recovery after 30min, R30
1	159.68%	78.01%	94.30%
2	101.77%	90.83%	96.73%
3	129.80%	94.86%	97.09%
4	119.51%	85.31%	94.79%
5	86.73%	89.31%	96.16%

It is suggested that stretchability of the spacer fabrics is closely related to their fabric type. The results shown in figure 5 reveled that the stretchability of warp knitted spacer fabric only has a high stretchability in weft-wise direction while the stretchability of warp-wise direction is very low (below 50%). On the other hand, weft knitted spacer fabrics have similar and high percentage of stretchability in both weft-wise and warp-wise directions. As the spacer fabric is composed of two separate surface fabrics and linked together by a spacer yarn, therefore, it can be concluded that spacer fabrics carry the same fabric stretchability as their fabric types (i.e. warp knitted or weft knitted).

When the results of the weft knitted spacer samples are compared, the stretchability of weft-wise direction of sample 3 and 4 are higher than that of sample 2 and 5. It is due to sample 3 and 4 are using multifilament spacer yarns which has higher stretchability than those samples using monofilament spacer yarns [16].

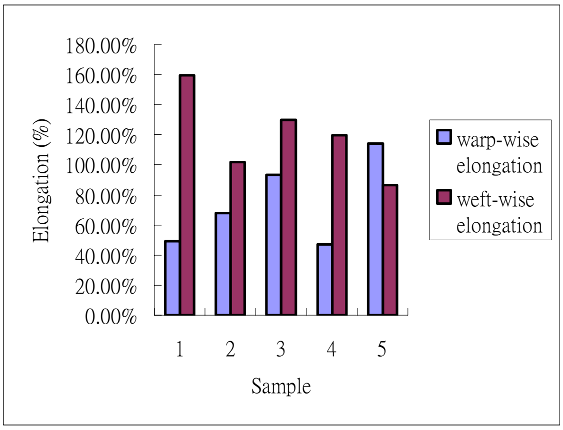


Fig. 5. Elongation of different spacer samples

4. Conclusion

The air permeability, thermal property and low-stress mechanical properties of spacer fabric have been studied quantitatively. It is found that both air permeability and thermal properties are closely related to the fabric density. The compression properties depend very much on the spacer yarn type and the spacer yarn arrangement. Bending properties are closely related to the fabric type, structure, spacer yarn type and density while stretch and recovery properties depend very much on fabric type and spacer yarn type. It is believed that the fabric characteristics of spacer fabric show a very significant effect on the air permeability, thermal property and low-stress mechanical properties of spacer fabric. Therefore, a careful selection of spacer fabric for its application is of primary importance.

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