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Effect of Yarn Linear Density and Thread Density on the Air Permeability of Light- to Medium-Weight Plain Woven Fabric Derivatives Used as Summer Shirting Fabrics

Vpliv dolžinske mase preje in gostote niti na zračno prepustnost lahkih do srednje težkih tkanin, izpeljank iz vezave platna, ki se uporabljajo za poletne srajce

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Abstract
This article presents the results of an analysis of the air permeability behaviour of shirting fabrics. Woven fabrics comprising derivatives of plain fabric, such as voile, poplin and canvas, were selected. The fabrics were made from 100% cotton, and blends of 50% polyester and 50% cotton. Light-weight fabrics, such as voile, had the highest air permeability and are suitable for summer shirting fabrics, while canvas fabrics had the lowest air permeability and are suitable for winter shirting fabrics. Finally, 100% cotton poplin fabrics are more comfortable than polyester/cotton poplin for summer shirting fabrics.
Keywords: shirting fabrics, plain weave, air permeability

Izvleček
V raziskavi je bila izvedena analiza zračne prepustnosti tkanin za srajce. Uporabljene so bile tkanine, ki so izpeljanke iz platna, kot so voál, poplin in kanvas. Tkanine so bile izdelane iz 100-odstotnega bombaža in mešanice 50 odstotkov poliestra in 50 odstotkov bombaža. Lahke tkanine, kot je voál, so imele najvišjo zračno prepustnost, zaradi česar so primerne za poletne srajce. Na drugi strani pa so tkanine iz kanvasa imele najnižjo zračno prepustnost in so zato primerne za zimske srajce. Tkanine iz 100-odstotnega bombažnega poplina so udobnejše od tkanin iz mešanice poliester/bombaž in so zato primerne za poletne srajce.
Ključne besede: srajčevina, vezava platno, voál, poplin, kanvas

1 Introduction

Robertson [1] presented a model to analyse fabric air permeability. He used a wire mesh as a simplified fabric model, and every pore space between the cross-over of the warp and weft acted as a nozzle with an equal discharge coefficient. His work was continued by Hoerner [2], who also used wire mesh for his model, assuming that the wire mesh and a screen fabric behave similarly under the same conditions and assuming that a drop in pressure is the result of friction between the air and contact surface of the medium, and the speed of flow. In fact, he believed that airflow through a fabric is similar to airflow through a tube, but with the effect of a greater aspect ratio. His model was thus simple but not sufficiently accurate. Saidenov [3] proposed a two-term equation to predict the air permeability of

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fabric exposed to a drop in pressure, in which the viscosity of the air, the density of the fabric, the void geometry and air velocity were the main model parameters. However, his model was only perfect for predicting the air permeability of plain weave filament garments. In fact, his model can be used for filament cloths with a plain construction [4]. Olšauskienė et al. [5–7] studied the dependency of air permeability on differing integrated fabric firmness, such as fabric density, yarn counts, etc.

Today's consumers are not only attracted by the appearance of garments, but also by the need for great comfort. Studies have shown the importance of clothing comfort in decisions that lead to customer satisfaction [8]. The term comfort derives from the integrated visual, thermal and tactile sensations felt by the wearer, psychological conditions, body-clothing interactions and ambient environments [9]. Of all the shirting fabrics that are used in the world, cotton is the most important. Cotton is commonly used because of its unique properties, such as breathability, texture, absorbency and durability. Breathability makes it cooler in the summer and warmer in the winter. It is soft and feels good against the body [10]. The plain weave is the most common and simple of all weaves. It comprises the interlacement of warp and weft yarns in alternating order. Woven fabrics are the mostly frequently used fabric type in our daily life. Their application varies from aesthetical to technical use [11]. Weaves and different thread positions in the fabric are important for the final design and for final fabric properties. Fabric thickness depends on the yarn diameter, compression in interlacing and on the float element in weave repeats [12]. Woven fabric is an integration of warp and weft yarns through intersection, the extent of which depends primarily on the friction between fibres and yarns, together with fibre entanglement. The distance between two parallel yarns determines the air gap of a fabric structure. Porosity represents the passage of air flow, and thus gives a fabric its air permeability property [13]. Air permeability is defined as "the rate of air flow through a material under a differential pressure between two fabric surfaces" [14, 15]. Air permeability is a hygienic and important garment property, which affects the flow of gas from the human body to the environment, and the flow of fresh air to the human body. Air permeability depends on fabric porosity, which means the rate of passage through a textile fabric, its cross-section and shape. Fabrics made of 100% cotton yarns of canvas weave have the highest air permeability value, while fabrics of plain weaves have the lowest value [16].

2 Materials and methods

2.1 Fabrics

We conditioned 100% cotton woven fabrics and 50% polyester and 50% cotton fabrics samples in accordance with the ASTM D1776 standard. A relative air humidity of 65 ± 2% and a temperature of 21 ± 1 °C were maintained during measurements. Technical data regarding samples are presented in a Table 1.

2.2 Methods

Warp, weft and fabric cover factors are calculated according to equations 1–3:

$$K_1 = \frac{n_1}{\sqrt{N_1}} \tag{1}$$

$$K_2 = \frac{n_2}{\sqrt{N_2}} \tag{2}$$

$$K_C = K_1 + K_2 - \frac{K_1 \times K_2}{K_1 + K_2} \quad (3),$$

where K_1 is the warp cover factor, K_2 is the weft cover factor, K_c is the fabric cover factor, N_1 and N_2 represent yarn linear density, and n_1 and n_2 represent thread density.

Fabric thickness (ASTM D1777)

A Shirley carpet thickness tester was used to measure the thickness (d) of samples. Fifteen measurements were taken for each sample at different places at a load of 2.267 kg.

Mass per unit area (ASTM D3776)

The mass per unit area of a fabric sample is given as the average of three weight measurements of pieces of fabric with a surface area of 100 cm^2.

Air permeability (IS 10056-1984)

The air permeability of fabrics was measured using a MAG air permeability tester. A minimum of ten measurements were taken for each sample.

$$AP = \frac{r^* \times 1000}{60 \times 60A} = \frac{1000 \times r}{3600 \times A} \quad (4),$$

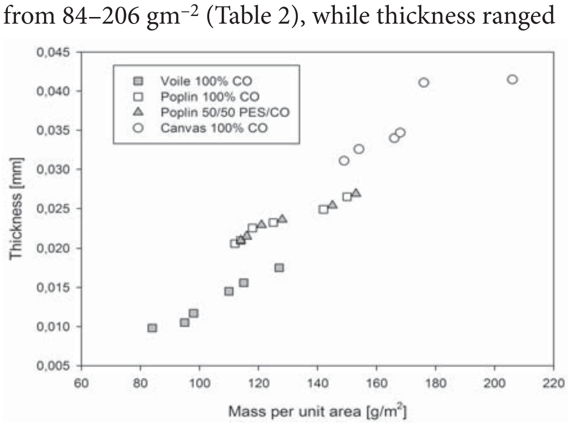
where AP represents air permeability (cm^{3}s^{-1}cm^{-2}), r^* is a rotameter reading (lh^{-1}), and A is a tested area with a diameter of 4 cm or 10 cm.

Table 1: Technical data regarding fabric samples

Sample no.	Type of fabric	Raw material	Yarn linear density [tex]		Thread density [cm^{-1}]	
			Warp	Weft	Warp	Weft
1	voile	100% CO	9.84	9.84	35.4	31.5
2	voile	100% CO	9.84	9.84	37.8	31.5
3	voile	100% CO	9.84	9.84	39.4	31.5
4	voile	100% CO	9.84	9.84	43.3	31.5
5	voile	100% CO	9.84	9.84	43.3	35.4
6	voile	100% CO	9.84	9.84	48.8	43.3
7	poplin	100% CO	14.8	14.8	38.6	31.5
8	poplin	100% CO	14.8	14.8	39.4	31.5
9	poplin	100% CO	14.8	14.8	38.6	36.2
10	poplin	100% CO	14.8	14.8	43.3	35.4
11	poplin	100% CO	14.8	14.8	53.1	35.4
12	poplin	100% CO	14.8	14.8	53.1	40.9
13	poplin	50% PES, 50% CO	14.8	14.8	38.6	31.5
14	poplin	50% PES, 50% CO	14.8	14.8	39.4	31.5
15	poplin	50% PES, 50% CO	14.8	14.8	35.4	35.4
16	poplin	50% PES, 50% CO	14.8	14.8	43.3	35.4
17	poplin	50% PES, 50% CO	14.8	14.8	43.3	31.5
18	poplin	50% PES, 50% CO	14.8	14.8	51.2	23.6
19	canvas	100% CO	29.5	29.5	22.0	23.6
20	canvas	100% CO	29.5	59.1	22.0	24.4
21	canvas	100% CO	29.5	59.1	16.5	18.1
22	canvas	100% CO	36.9	36.9	23.6	19.7
23	canvas	100% CO	29.5	59.1	18.9	18.1
24	canvas	100% CO	36.9	36.9	23.6	23.6

3 Results and discussion

The mass per unit area of the selected fabrics ranged from 84–206 gm^{-2} (Table 2), while thickness ranged from 9.8–41.5 μm (Table 2). All four groups of selected samples demonstrated very high linear correlation coefficients between thickness and mass per unit area (Figure 1).



Sample no.	Correlation coefficients, r_{xy}
Nos. 1–6 (Voile 100% CO)	0.985938085
Nos. 7–12 (Poplin 100% CO)	0.981917587
Nos. 13–18 (Poplin 50/50 PES/CO)	0.987604626
Nos. 19–24 (Canvas 100% CO)	0.887425433

Figure 1: Dependence of thickness on mass per unit area, and linear correlation coefficients

The experimental results of the air permeability of 100% cotton voile fabrics samples no. 1 to no. 6 are shown in Table 3. Figure 2 graphically illustrates the high linear correlation (correlation coefficient, $r_{xy} = -0.9918$) between the thickness of voile samples

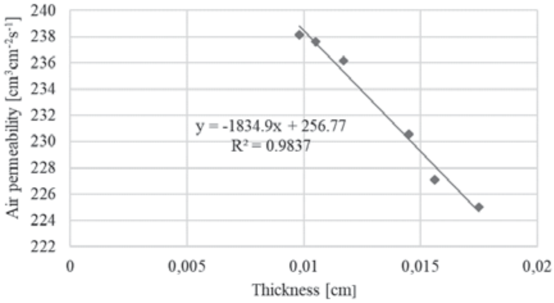


Figure 2: Air permeability of voile fabrics made from 100% cotton depending on their thickness

Table 3: Air permeability of voile fabrics made from 100% cotton

Sample no.	Air permeability [$cm^3cm^{-2}s^{-1}$]		Relative difference [%]
	Measured	Calculated a)	
1	238.13	238.13	0.00
2	237.63	236.84	0.33
3	236.18	234.64	0.655
4	230.56	229.51	0.46
5	227.08	227.49	–0.18
6	225	224.005	0.44

a)Values were calculated using the linear equation: $AP = -1834.9d + 256.77$.

Table 2: Mass per unit area, thickness and cover factors of fabric samples

Sample no.	Mass per unit area [gm^{-2}]	Thickness [mm]	Warp cover factor	Weft cover factor	Fabric cover factor
1	84	0.0098	11.62	10.33	16.48
2	95	0.0105	12.39	10.33	17.08
3	98	0.0117	12.91	10.33	17.50
4	110	0.0145	14.20	10.33	18.55
5	115	0.0156	14.20	11.62	19.42
6	127	0.0175	16.00	14.20	22.68
7	112	0.0206	15.49	12.65	21.17
8	114	0.0210	15.81	12.65	21.43
9	118	0.0225	15.49	14.55	22.54
10	125	0.0232	17.39	14.23	23.79
11	142	0.0249	21.35	14.23	27.04
12	150	0.0265	21.35	16.44	28.50
13	114	0.0210	15.49	12.65	21.17
14	116	0.0215	15.81	12.65	21.43
15	121	0.0229	14.23	14.23	21.35
16	128	0.0236	17.39	14.23	23.79
17	145	0.0254	17.39	12.65	22.72
18	153	0.0269	20.55	9.48	23.54
19	149	0.0311	12.52	13.41	19.46
20	154	0.0326	12.52	13.86	19.80
21	166	0.0340	13.28	10.28	17.76
22	168	0.0347	15.00	12.50	20.68
23	176	0.0411	15.58	10.29	19.34
24	206	0.0415	15.00	15.00	22.50

and the measured air permeability. A high correlation coefficient (r_{xy} = –0.96594) is also seen between the mass per unit area and air permeability of these samples. This proves the significant effect of mass per unit area and mass per unit area on the air permeability of voile samples. Of the six voile fabrics, sample no. 1 demonstrated the highest air permeability, as well as the lowest values of mass per unit area and thickness. The relative difference between measured and calculated air permeability was less than 1% for all samples in this group.

Table 4 presents the measured results of the air permeability of 100% cotton poplin fabric. A high correlation coefficient (r_{xy} = –0.98095) between the mass per unit area and air permeability of samples no. 7 to no. 12 was also seen in this case. The correlation coefficient between thickness and air permeability (r_{xy} = –0.99241) was also very high here (Figure 3). Air permeability was the highest for sample no. 7, while the thickness and mass per unit area were the lowest for sample no. 7 among all six poplin fabrics made from 100% cotton. The relative difference between measured and calculated air permeability was less than 1% for all samples in this group.

Table 5 presents the air permeability of poplin fabrics made from 50% polyester and 50% cotton. Of the six fabrics in this group (samples no. 13 to no. 18), sample no. 13 demonstrated the highest value of air permeability, as well as the lowest thickness and mass per unit area. A correlation coefficient between mass per unit area and air permeability was again very high (r_{xy} = -0.98168), and was also high between thickness and air permeability (r_{xy} = –0.99311) (Figure 4). The relative difference between measured and calculated air permeability was less than 1% for all samples in this group.

Table 4: Air permeability of poplin fabrics made from 100% cotton

Sample no.	Air permeability [$cm^3cm^{-2}s^{-1}$]		Relative difference [%]
	Measured	Calculated [a)]	
7	220.41	219.65	0.346
8	216.38	217.58	–0.55
9	212.01	209.83	1.03
10	204.30	206.22	–0.94
11	197.29	197.44	–0.07
12	189.51	189.17	0.18

[a)] Values were calculated using the linear equation: $AP = -5165.2d + 326.05$.

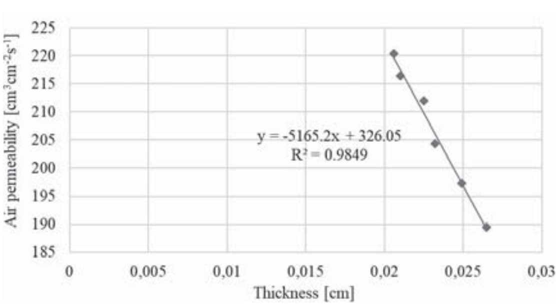


Figure 3: Air permeability of poplin fabrics made from 100% cotton depending on their thickness

Table 5: Air permeability of poplin fabrics made from 50% polyester and 50% cotton

Sample no.	Air permeability [$cm^3cm^{-2}s^{-1}$]		Relative difference [%]
	Measured	Calculated [a)]	
13	218.40	217.80	0.275
14	214.93	215.18	–0.117
15	209.44	207.85	0.76
16	201.67	204.18	–1.25
17	194.58	194.75	–0.09
18	187.64	186.895	0.40

[a)] Values were calculated using the linear equation: $AP = -5238.1d + 327.8$.

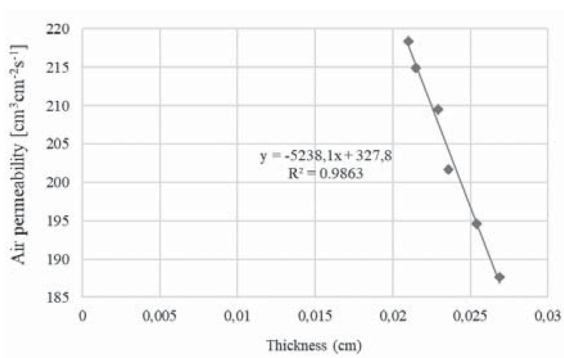


Figure 4: Air permeability of poplin fabrics made from 50% polyester and 50% cotton depending on their thickness

Table 6 presents the results of air permeability for 100% cotton canvas fabrics. Sample no. 19 demonstrated the highest air permeability and the lowest mass per unit area and thickness. A high level of correlation was calculated between mass per unit area and air permeability (r_{xy} = –0.90973), and between thickness and air permeability (r_{xy} = –0.90973) (Figure 5). The relative difference between measured and calculated air permeability was less than 2%.

Table 6: Air permeability of canvas fabrics made from 100% cotton

Sample no.	Air permeability [$cm^3cm^{-2}s^{-1}$]		Relative difference [%]
	Measured	Calculated [a]	
19	201.67	200.88	0.39
20	198.81	199.28	–0.24
21	197.29	197.79	–0.256
22	196.81	197.05	–0.12
23	193.75	190.24	1.81
24	186.74	189.82	–1.65

[a] Values were calculated using the linear equation: $AP = -1063.4d + 233.95$.

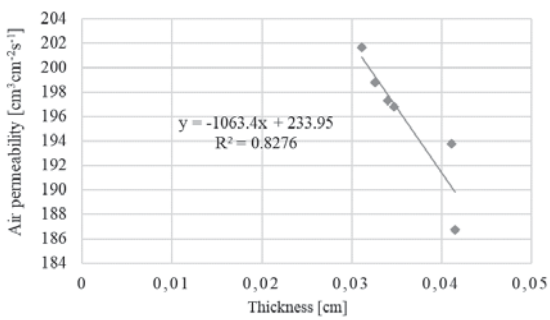


Figure 5: Air permeability of canvas fabrics made from 100% cotton depending on their thickness

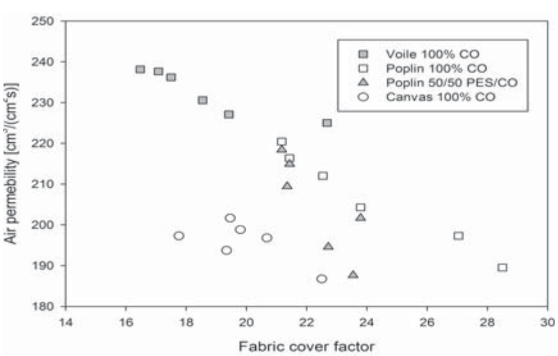
Air permeability demonstrated a high linear correlation with the fabric cover factor for voile and poplin fabrics made from 100% cotton (Figure 6).

4 Conclusion

During our research, we studied 24 plain fabrics to identify the proper shirting fabric, taking into account air permeability. The thickness and mass per unit area of fabrics were gradually increased from 100% cotton voile to 100% cotton canvas fabrics. There is a high level of linear correlation between the mass per unit area and thickness of the fabric samples (Figure 1). This correlation has a significant effect on the air permeability value of samples. Lower values of thickness indicate voids between warp and weft yarns in the fabric. The volume of voids in a woven fabric affects its air permeability. Increasing thread density (i.e. the number of warp and weft yarns per unit area) causes a decrease in porous volume and an increase in the thickness of a sample, which results in a decrease in the air permeability value.

Samples with a lower value of mass and thickness demonstrated a higher air permeability value. A lower thickness value indicates that there are voids between warp and weft yarn in the fabrics.

Higher air permeability means more air flow through the fabric. The new findings from this research work are that, of all plain-weave constructions, 100% cotton voile is the best fabric for summer, while 100% cotton canvas is the best fabric for winter in terms of human comfort.



Sample no.	Correlation coefficients, r_{xy}
Nos. 1–6 (Voile 100% CO)	–0,913772576
Nos. 7–12 (Poplin 100% CO)	–0,985412814
Nos. 13–18 (Poplin 50/50 PES/CO)	–0,837468448
Nos. 19–24 (Canvas 100% CO)	–0,680288513

Figure 6: Dependence of air permeability on the fabric cover factor, and their linear correlation coefficients

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