THEORETICAL PREDICTION OF THE AIR PERMEABILITY OF ACRYLIC PLAIN WEFT KNITTED FABRICS

التنبوء الرياضي بنفاذية الهواء لأقمشة تريكو اللحمة السادة المصنوعة من الاكريليك

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خلاصة ـ فى هذا البحث أمكن التوصل الى معادلة رياضية للتنبوء بنفاذية الهواء لأقمشة التريكو السادة وذلك باستخدام موديل هندسى لربط نفاذية الهواء للقماش مع(سمك القماش ـ قطر الخيط ـ عدد الاعمدة، وعـــدد الصفوف فى وحدة الطول) وذلك بمعرفة فرق الضغط على سطحى القماش • ومن ناحية أخرى فان القياسات المعملية لنفاذية الهواء للقماش قد أمكن الحصول عليها للتأكد من صحة المعادلة الرياضية • النتائج المحسوبة بواسطة المعادلة النظرية التى قد تم التوصل اليها وجد أنها قريبة الى حد كبير من النتائج المعملية المقاسة•

In this paper, on the base of a geometrical model an attempt is made to derive an equation relates the air permeability to the plain knitted fabric parameters of fabric thickness, yarn diameter, wale and course spacings with knowing pressure drop. The air permeability measurements are carried out to demonstrate the accuracy of this equation. Experimental measurements made are shown to be in good agreement with the theoretical predictions.

1. INTRODUCTION

Due to the manner in which yarns and fabrics are constructed, a large proportion of the total volume occupied by a fabric is airspace. The distribution of this airspace influences a number of important fabric properties such as warmth and protection against wind and rain in clothing and efficiency of filtration in industrial cloths. A common example of the later is found when the domestic vacuum cleaner bag is considered; the fabric must allow air to pass but at the same time prevent the passage of dust and dirt[1].

The air permeability of textile fabrics which is determined at a constant pressure drop, greatly depends on the porosity, amount and size of open pores and also on the thickness of the fabric. Textile fabrics used for manufacturing summer clothings must have the highest air permeability, while winter outerwear garments must be of low permeability[5] In apparel fabrics, the air permeability may be defined as the volume of air measured in cubic centimetres passed per second through 1 cm^2 of the fabric at a pressure of 5 mm of water[3].

Several authors have attempted to explain air permeability characteristics by theoretical deriviations. Air permeability of knitted fabrics is linearly related to the theoretical cover factor[4]. Dianich[5-7] states that plain weaves are most suitable for retaining good air permeability after several launderings and that an all-linen fabric is better than a linen-polyester fibre, linen-triacetate or polyester fibre-triacetate blend in terms of air permeability[5]. In struct purl-knitted, rib-knitted and plain-knitted structures are sho that order, in their air permeability. Air pressure drop and fib some influence[7]. Semak[8] also reports details of tests on knit that the fibre type has no effect on the air permeability. He be type does have an influence on structural changes such as d He uses a model to demonstrate that a reduction of up to 50 as a result of such structural changes.

Previous study lakes concerning the theoretical prediction of air permeability of plain weft knitted fabrics with knowing its geometrical parameters.

The aim of this work is to derive a mathematical formula to express the air permeability of plain knitted fabrics as a function of fabric thickness, yarn diameter, wale and course spacings at a constant pressure drop.

2. THEORY

2.1 Assumptions

1- The fabric pores are circular in shape.
2- The pores are aligned and the air resistance of their deviation is neglected.
3- Fabric thickness is equal to pore length.

2.2 Nomenclature

d = Yarn diameter, m
A = Wale spacing, m
B = Course spacing, m
S = Stitch density, m^{-2}
t = Fabric thickness, m
L = Overall length of the pore, m
r = Pore radius, m
P = Equivalent pore diameter, m
n = Number of pores per unit area, m^{-2}
μ = Air dynamic viscosity, $(N.Sec)/m^2$
Δp = Pressure drop across the length L, N/m^2
q = Volume rate of flow per one pore, $m^3/Sec.$
F = Cross-sectional area of the porous material, m^2
W_0 = Resultant volume rate of flow, $m^3/Sec.$
Q = Rate of flow (air velocity), $m^3/(m^2 . Sec)$.

2.3 Calculation of Equivalent Pore Diameter of Knitted Fabric.

In the present work the fabrics are assumed to be of different yarn diameters, different wale spacings and of different course spacings as a general case. The planed structure of the stitch is shown in Fig. 1. The axis of the yarn in the planed condition is composed of circular arce and straight lines.

The structure repeat of plain stitch with height B and width A can be taken into consideration for calculating the equivalent pore diameter. Each repeat of this stitch is consisted of six pores which are Z, Z_1, Z_2, M, M_1 and M_2 where $Z_1 = Z_2 = Z/2$; $M_1 = M_2 = M/2$. Therefore, it is needed to calculate only the area of pores Z and M.

2.3.1 Calculation of Pore Area Z:

From Fig. 1 it will be seen that the radius of the circular portion of the central axis is equal to $OY + YE = A/4 + d/2$.
From triangle O'AE,
$(A/4)/\text{Sin}\ (90 + \theta) = (A/4 - d) / \text{Sin}\ \beta$

$\therefore \beta = \text{Sin}^{-1}\ (A/4 - d). \text{Sin}\ (90 + \theta) / (A/4)$, where $\theta = \tan^{-1} d/B$
whereas $\gamma = 180 - (\beta + \theta + 90)$, hence $\alpha = 2\ (\beta + \theta)$

The area of segement EXL $= 1/2\ (A/4)^2\ (\pi\alpha - \text{Sin}\alpha)$ . . . (1)

and the area of trapezoid ÁELK $= A/4 \cos\alpha/2\ (A/4 - d + A/4. \text{Sin}\alpha/2)$ (2)

From Equations 1 and 2 the area of pore Z can be calculated as follows:

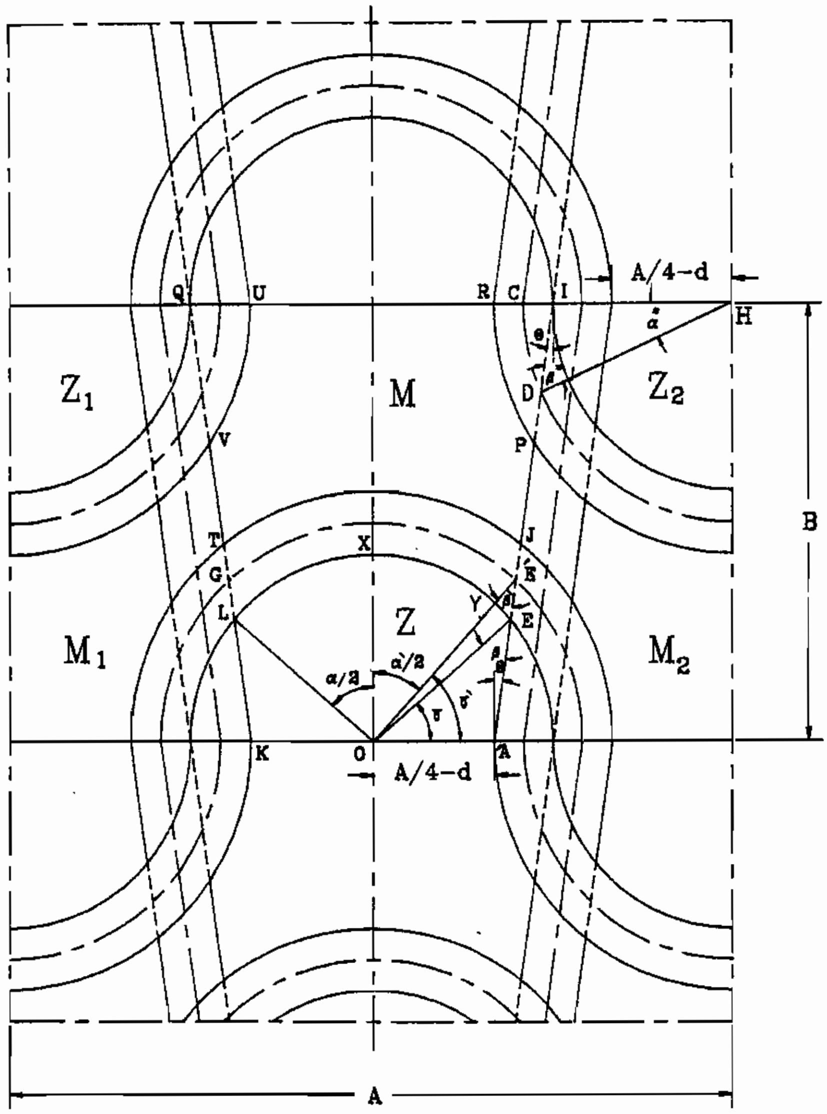

Fig. 1

The planed structure of plain stitch

Area Z = area EXL + area $\acute{A}$ELK

or

$$\text{Area } Z = 1/2\,(A/4)^2\,(\pi\alpha - \sin\alpha) + A/4\,\cos\alpha/2\,(A/4 - d + A/4.\,\sin\alpha/2 \qquad (3)$$

Since the other areas Z_1 and Z_2 are also determined.

2.3.2 Calculation of Pore Area M

From triangle $\acute{A}O\acute{E}$,

$(A/4 + d/2) / \sin(90 + \theta) = (A/4 - d) / \sin\acute{\beta}$

$\beta = \sin^{-1} (A/4 - d) \sin(90 + \theta) / (A/4 + d/2)$

whereas, $\acute{\gamma} = 180 - (\theta + \acute{\beta} + 90)$, hence $\acute{\alpha} = 2(\acute{\beta} + \theta)$

The arc length $\acute{E}G = 2\pi(A/4 + d/2).\acute{\alpha}/360$

$$\text{Hence, the area of section } EJTL = 2d\,\pi\,(A/4 + d/2).\acute{\alpha}/360. \qquad \ldots(4)$$

From triangle IHD,

$\overset{*}{\beta} = \sin^{-1} A/4.\,\sin(\theta + 90) / (A/4 + d/2)$

and $\overset{*}{\alpha} = 180 - (\theta + \overset{*}{\beta} + 90)$

Arc length CD = $2\pi(A/4 + d/2).\ \overset{*}{\alpha}/360$

$$\text{Hence, the sum of areas } IPR \text{ and } QUV = 4\,d\pi(A/4 + d/2).\ \overset{*}{\alpha}/360 \qquad \ldots(5)$$

$$\text{Trapezoid area } IELQ = A/4\,(1 + \sin\alpha/2)\,(B - A/4.\,\cos\alpha/2) \qquad \ldots(6)$$

Then, from Equations 1, 4, 5 and 6 the pore area M can be calculated as follows:

Area M = area IELQ - area EJTL - areas (IPR + QUV) - area EXL

or

$$\text{Area } M = A/4\,(1 + \sin\alpha/2)\,(B - A/4\,\cos\alpha/2) - 2d\,\pi(A/4 + d/2).\,\acute{\alpha}/360 - 4d\,\pi\,(A/4 + d/2).\,\overset{*}{\alpha}/360 - 1/2\,(A/4)^2\,(\pi\alpha - \sin\alpha) \qquad \ldots(7)$$

Since the other areas M_1 and M_2 are also determined. Therefore, the equivalent pore diameter $\acute{p}$ can be calculated as follows:

$$\acute{P} = \left(\sum_{i=1}^{6} P_i\right) / 6\,, \qquad \ldots(8)$$

where $P_1 = (4Z/\pi)^{1/2}$, $P_2 = (4Z_1/\pi)^{1/2}$, $P_3 = (4Z_2/\pi)^{1/2}$,

$P_4 = (4M/\pi)^{1/2}$, $P_5 = (4M_1/\pi)^{1/2}$ and $P_6 = (4M_2/\pi)^{1/2}$.

2.4 Calculation of Air Permeability of Fabrics

The theory of fluid flow through a porous media (such as plain weft knitted fabric) is too complicated to introduce a complete analytical solution. By applying the Poiseuill's law[9] for the stream line flow through a straight circular capillary or pore, we get :

$q = \pi \Delta p \, r^4 / 8 \mu L$ m^3 / Sec

But, $W_o = q.\, n.\, F$

$W_o = \pi \Delta P.\, r^4 .\, n.F / 8 \mu L$ m^3 / Sec

$Q = W_o / F = \pi \Delta p.\, r^4 .\, n / 8 \mu L$ $m^3 / (m^2 .\, Sec)$

By using the assumption No. 3, one obtain:

$$Q = \pi \Delta p \, \acute{P}^4 \, n / 128 \, \mu t, \quad m^3 / (m^2 .\, Sec) \quad \ldots (9)$$

where, n = 6S . . . (10)

Then by substituting from Equation 10 in Equation 9 yields:

$$Q = 6 \, S \pi \Delta p \, \acute{P}^4 / 128 \, \mu t \quad m^3 / (m^2 .\, Sec.).$$

Therefore, the air permeability of plain knitted fabric can be calculated as follows

$$\frac{Q}{\Delta p} = 6 \, S \pi \acute{p}^4 / 128 \, \mu t \quad m^3 / (N .\, Sec) \quad \ldots (11)$$

where $\acute{P}$- average equivalent pore diameter in metres which is calculated from Eq. 8.
S- stitch density, m^{-2}
t- fabric thickness, m
μ- air dynamic viscosity, (N. Sec) / m^2.

3. EXPERIMENTAL

Plain weft knitted fabrics were made from acrylic fibre-yarns of different counts and different tight stitch length versions. The following characteristics of the fabrics were determined: stitch length, number of wales and courses per 100 mm, mass of 1 m^2 of fabric, fabric thickness, equivalent pore diameter and air permeability. Air permeability was measured with a Japanese Joyosaiki Tester at a pressure of 5 mm of water.

4. RESULTS AND DISCUSSION

The results of equivalent pore diameter and air permeability at different yarn counts are presented in Table I. It could be seen from this table that the value of equivalent pore diameter varies very slightly from one yarn count to the other. From Equation 8 it could also be seen that the average equivalent pore diameter is affected by the yarn diameter, wale and course spacings. In Fig. 2 the fabric air permeability measured at 5 mm of water is compared with the corresponding fabric air permeability calculated from the fitted Equation (11) to the different tested fabrics. The values of air permeability were correlated well (r = 0.9896), with a slope of 0.939 and an intercept of 0.179.

Table 1
Parameters of Plain Weft Knitted Fabrics

Fabric No.	Linear density, (Tex)	Stitch length, (mm)	Number of wales per (100 mm)	Number of courses per (100 mm)	Mass of 1 m^2 of fabric, (g/m^2)	Fabric thickness, (mm)	Equivalent pore diameter, (mm)	Air permeability.10^2, $m^3/(N.sec)$	
								Calculated	Measured
1	4x21	8.60	35.84	70.42	299.17	2.58	0.539	6.150	6.586
2	"	8.96	35.21	68.97	279.25	2.61	0.561	6.837	7.006
3	"	9.30	34.72	67.57	269.02	2.62	0.581	7.571	7.369
4	"	9.79	34.01	66.23	261.30	2.64	0.603	8.380	8.831
5	"	10.28	33.33	64.52	249.96	2.68	0.630	9.377	10.197
6	6x21	9.65	31.99	62.11	441.53	3.09	0.552	4.435	4.596
7	"	10.20	31.90	61.73	391.90	3.11	0.560	4.615	4.719
8	"	10.63	31.75	60.98	359.29	3.12	0.573	4.972	5.163
9	"	11.06	31.50	60.24	352.69	3.14	0.587	5.346	5.375
10	"	11.43	31.25	59.52	341.51	3.16	0.602	5.727	5.994
11	8x21	10.85	27.17	57.64	530.17	3.21	0.542	3.117	3.370
12	"	11.24	27.03	56.82	495.36	3.23	0.570	3.730	3.533
13	"	11.52	26.90	56.24	490.99	3.25	0.589	4.144	4.153
14	"	11.75	26.79	55.71	482.60	3.27	0.604	4.519	4.331
15	"	12.09	26.67	54.95	479.44	3.30	0.624	5.014	4.731
16	10x21	11.5	25.91	53.76	641.65	3.30	0.479	1.652	2.332
17	"	11.7	25.77	53.19	623.31	3.34	0.523	2.279	2.600
18	"	12.0	25.64	52.63	598.30	3.36	0.553	2.805	2.870
19	"	12.2	25.54	52.19	578.10	3.37	0.573	3.171	2.965
20	"	12.4	25.46	51.81	563.30	3.37	0.589	3.489	3.114

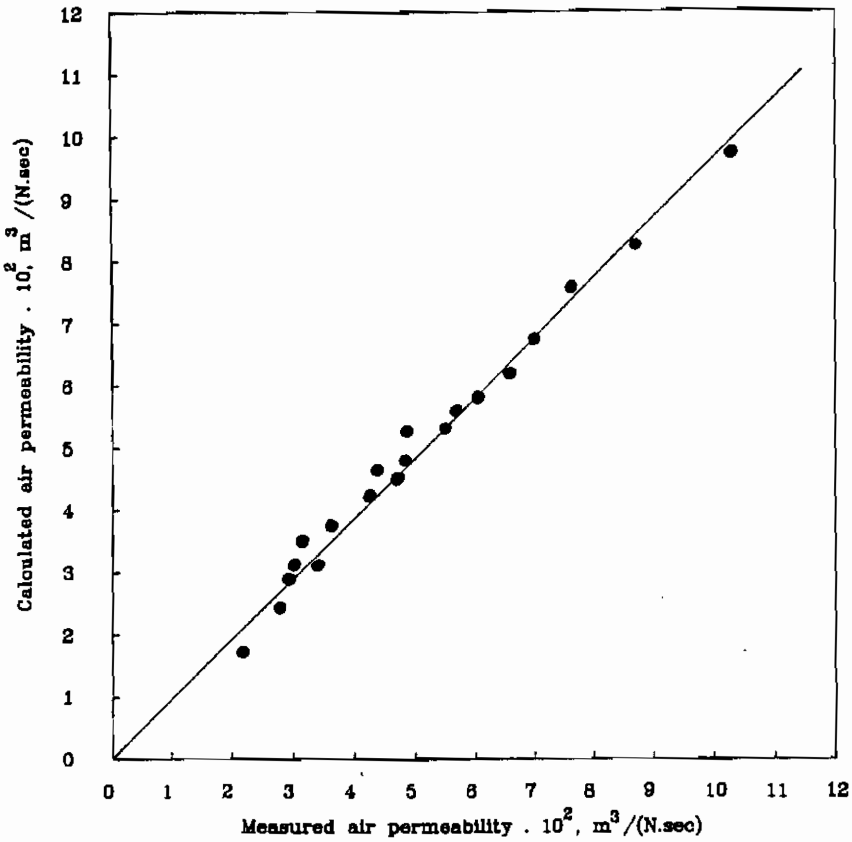

Fig. 2

Comparison between measured and calculated air permeability of plain knitted fabrics

5. CONCLUSIONS

The air permeability was calculated for a geometrical model of plain weft knitted fabric by means of knowing its geometrical parameters. The comparison between both calculated and measured values was then possible. The good agreement shown by Table I and Fig. 2 supports the validity of the derived Equation 11 at least within the range of fabric characteristics used. From such study a good prediction of fabric air permeability could be calculated with knowing fabric thickness, yarn diameter, wale and course spacings at a constant pressure drop.

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