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Analysis of Impact Air-permeability of Fabrics

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Abstract
In this paper, the methodology of studies on the impact air-permeability of fabrics is presented. Stands for the static and dynamic investigation of textiles are described. A mathematical model of the pressure drop in a fabric resulting from the impact of air flow through the product has also been submitted. A measure of impact permeability in the form of an index for arranging fabrics with respect to their flow properties is given. Characteristic features of the structure of a woven fabric from a group of products of negative, positive and small index are shown.

Key words: *impact air-permeability, impact permeability index, woven fabrics, air flow.*

Introduction

In many flat textile products, appropriate air-permeability is their most important feature [1, 2]. This feature especially refers to parachutes, tents, tarpaulins, sails and vehicle airbags. Aeration is also an important feature of filtration fabrics.

Wawszczak and Strzembosz [3, 4] presented an aerodynamic method in their studies of textiles, which enables the estimation of the internal structure. The authors elaborated a new criterion diagram for the physical modelling of fluid flow in filtration nonwovens [5]. The method consists in blowing an air stream through the specimen. The authors measured pressure drops at different mass fluxes.

The majority of textile products, fabrics in particular, are used not only in static but also in dynamic conditions. The behaviour of textile products is determined by the conditions which they are used in. Significant differences in their behaviour indicate that their air-permeability should be studies in two stages [6].

The first stage involves investigating a textile product specimen subjected to fixed airflows. The static research is executed on a specially constructed stand [7]. In static conditions the air is sucked from the atmosphere into a pneumatic system through the test specimen (Figure 1).

Permeability is affected by volume flux w and pressure p_s, which is the difference in pressure on both sides of the specimen. These quantities are measured in static conditions after they have reached time-constant stable values. Figure 2 presents, for example, the static characteristic for the woven fabric (raw material: polyester + cellulose) denoted as M4. Parameters of the fabric are given in Table 1.

The dependence of the pressure on the volume flux in static conditions for woven fabrics is approximated by a straight line:

$$p_S(w) = a \cdot w \qquad (1)$$

At the second stage the specimen under study is subjected to transient airflows on a specially constructed stand for dynamic investigations (Figure 3) [8].

On the stand the same specimen of a porous structure is placed as a barrier in a circular grip mounted on the upper base of a cylinder. Inside the cylinder is a tight piston. The impact of the downward movement of the piston in the cylinder causes a transient airflow through the porous membrane. The impact movement of the piston is a technical representation of a unit step – one of many possible dynamic interactions. The mathematical model and results of simulation of the piston displacement in a cylinder is described in the paper [9].

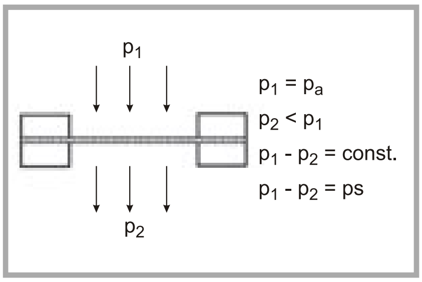

Figure 1. *A simplified schematic diagram of a measuring position (static conditions).*

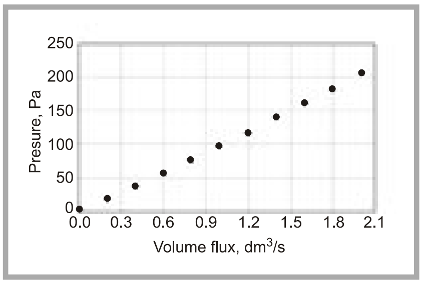

Figure 2. *An example of a static characteristic of the fabric.*

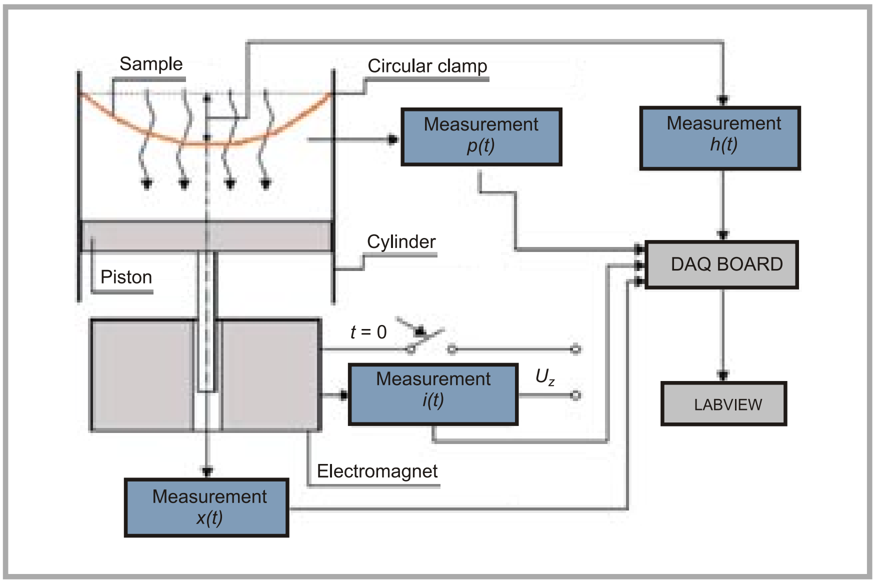

Figure 3. *A simplified schematic diagram of a measuring position (dynamic conditions).*

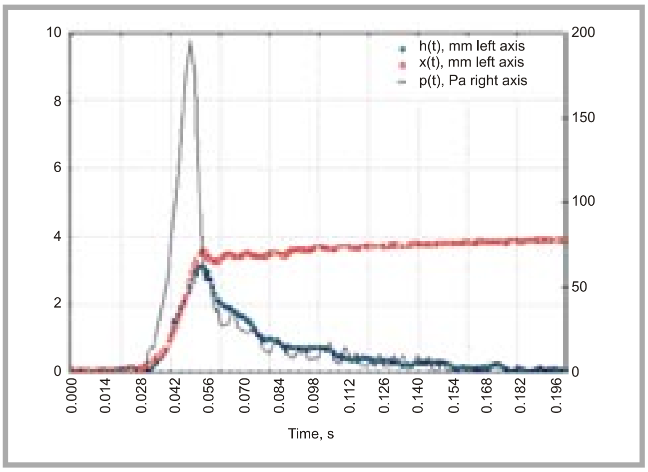

Figure 4. *An example of the dynamic characteristics of the fabric.*

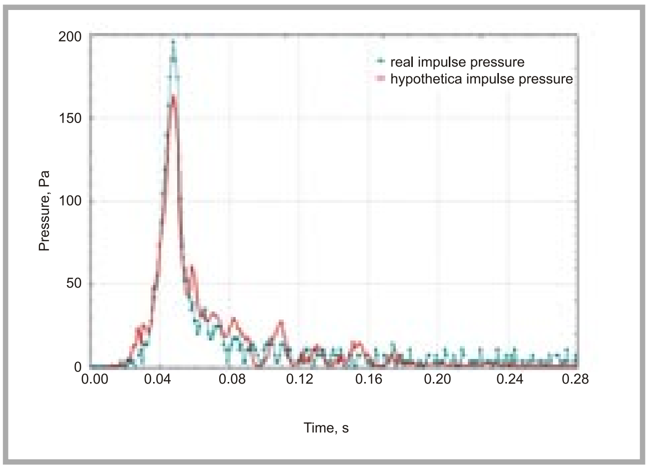

Figure 5. *Hypothetical and real impulse pressure for/on the fabric.*

In dynamic conditions (during transient airflow through the specimen) the following are measured [6, 8]:

- dependence of the air pressure difference on time, $p(t)$ (transducer FPM-02PG of Fujikura, measuring range: ± 13.79 kPa)
- linear displacements of the piston $x(t)$ (transducer PJx50+WG04 of Peltron, measuring range: 0-50 mm)
- deflection $h(t)$ of the fabric placed in the circular clamp (transducer Z4M-W100RA of OMRON, measuring range: ±40 mm)
- and the electromagnet current $i(t)$ (direct voltage transducer PU80-A.30.7.0.00.0, resistant shunt, measuring range of the current: 20 A).

The feature of a textile product which highlights differences in the behaviour of its structural elements during fixed and transient airflows is called impact permeability [10]. Static $p_s(w)$ and dynamic characteristics $p(t)$ define the flow properties of the flat textile products studied [11]. Figure 4 presents the dynamic characteristics of the fabric - M4.

A modernised index of the impact air-permeability of fabrics

Based on the comparative studies carried out and assuming that the product properties will remain the same irrespective of the conditions of use, a hypothetical decrease in the pressure $p'(t)$ on the reference fabric is predicted [12]. By analysing changes in the geometric parameters of the space between the specimen and the moving air-tight piston on the stand for dynamic investigations, a hypothetical decrease in the pressure $p'(t)$ on the reference fabric was determined by the relationship:

$$p'(t) = a\left[\pi r^2 \frac{dx(t)}{dt} - \frac{\pi}{2}\left[r^2 + h^2(t)\right]\frac{dh(t)}{dt}\right] \quad (2)$$

where a – the slope of the static characteristic $p_s(w)$ (formula 1).

Figure 5 presents the hypothetical and real impulse pressure obtained for an example of the fabric - M4. To approximate of the hypothetical impulse pressure, a neural network was used [13].

Moreover, the dependence of the piston displacement velocity $V_x = dx/dt$ in the cylinder on the time, and the dependence of the fabric deflection velocity $V_h = dh/dt$ on the time for the fabric – M4 is shown in Figure 6. These velocities are necessary to find a hypothetical impulse pressure from formula (2).

Having the hypothetical, formula (2), and real pressure impulse, one can determine the index of the impact permeability, IP, from the formula:

$$IP = \frac{1}{n}\sum_{i=1}^{n} \frac{\max\limits_{t \geq 0} p_i(t)}{\max\limits_{t \geq 0} p_i(t) + \max\limits_{t \geq 0} p'_i(t)} - 0.5 \quad (3)$$

where n – the number of measurements, $i = 1, 2, ..., n$.

The IP index thus determined is the result of modernisation of the former air-permeability index [14]. The IP index results from differences in fabric behaviour that occur during fixed and transient airflows. The IP index given by formula (3) has a special construction. The IP index

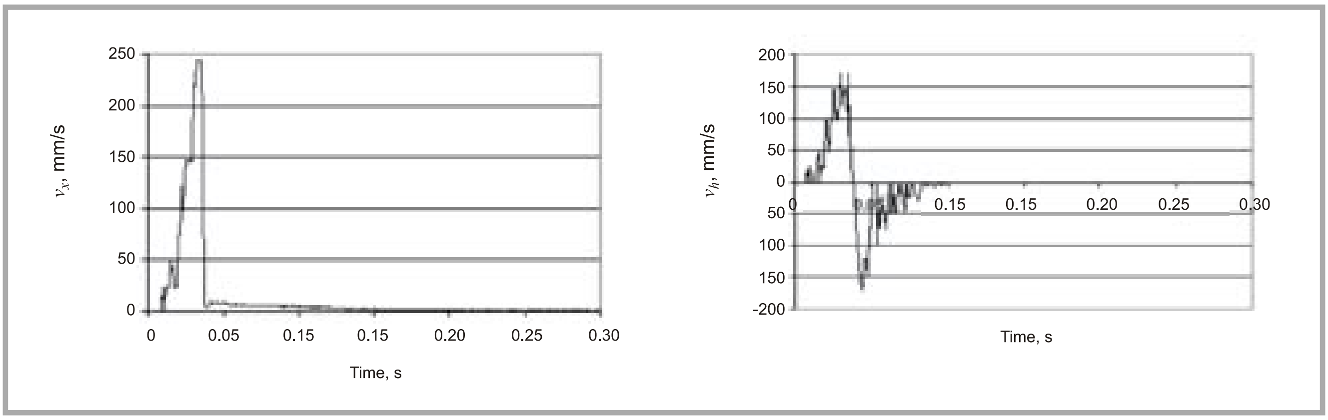

Figure 6. *Velocities V_x and V_h for the fabric.*

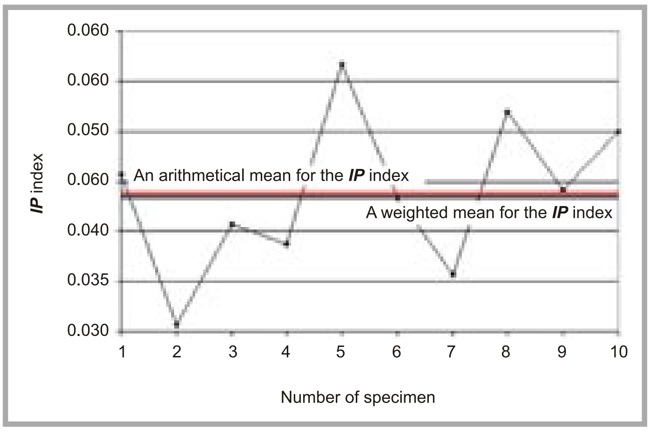

Figure 7. The IP index values for the fabric.

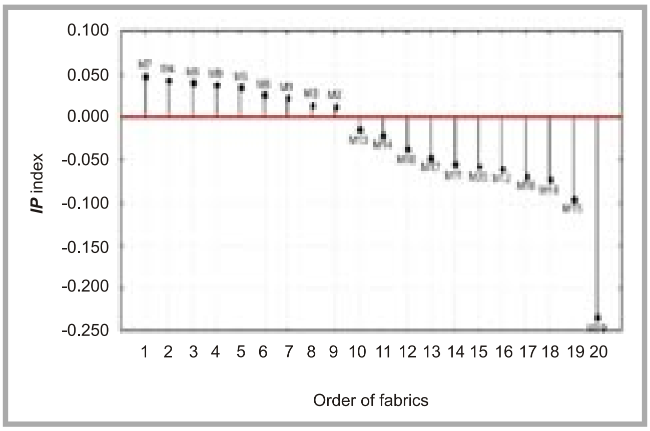

Figure 8. Arranged fabrics.

values are within the range of (-0.5; 0.5). The sign of the IP index permits to quickly estimate the differences in the behaviour of fabric in fixed and transient airflow conditions. The negative values of the *IP* index indicate that the shapes and sizes of the inter-thread canals will cause a reduction in the airflow resistance of fabric in transient flow conditions compared to fixed conditions. The positive values testify that the shapes and sizes of the inter-thread canals will bring about an increase in the airflow resistance on the fabric in transient flow conditions compared to fixed conditions. The zero values of the *IP* index testify to the fact that the pressure difference that occur on both sides of the fabric is the same irrespective of the investigation conditions. Hence, the fabric structure, shapes and sizes of its pores, should not undergo changes during transient airflows compared to fixed airflows.

The values of the index of the impact permeability, IP, were determined for ten (n = 10) specimens obtained from the fabric - M4. The valuesreceived are shown in Figure 7.

Next, the arithmetical mean for the *IP* index of the fabric - M4 was determined. The value of the arithmetical mean equals 0.0438 (Figure 7). The coefficient of variation amounts to 3% in this case. In comparison with the arithmetical mean, the weighted mean for the *IP* index was calculated. The weighted mean equals 0.0433 (Figure 7).

Arranging fabrics with respect to their flow properties

The impact air-permeability index of fabrics determined according formula (3) arranges textile products with respect to their flow properties. To identify the properties of fabrics characterised by definite values of the IP index in static and dynamic conditions, 20 different fabrics were studied. The studies were carried out using a designed experiment [15]; a stable-system design was selected [15, 16]. The structural parameters of the fabrics and the threads unstitched from them are shown in Table 1. They have been arranged from the greatest to the smallest value of the IP index obtained. The zero values of the twist given in Table 1 were obtained for flat filaments. These

Table 1. Parameters of fabrics and values of the impact permeability index.

Woven fabric denotation	Impact permeability index IP,	Thick-ness,	Number of warp threads	Number of weft threads,	Linear density of warp,	Linear density of weft,	Warp twist,	Weft twist,	Crimp of warp,	Crimp of weft,
	-	mm	1/cm	1/cm	tex	tex	twist/m	twist/m	%	%
M7	0.0487	0.75	35	21	44.6	44.6	254	230	6.7	4.0
M4	0.0438	0.76	36	23	50.4	47.2	270	250	12.0	3.7
M8	0.0411	0.75	35	18	51.0	53.7	149	121	10.7	8.0
M9	0.0380	0.69	36	23	50.7	47.1	271	262	9.4	2.9
M5	0.0359	0.74	35	19	52.0	49.6	154	139	9.8	5.5
M6	0.0268	0.42	43	24	24.9	26.3	378	378	3.1	6.5
M1	0.0233	0.72	35	19	43.0	54.3	153	131	6.7	6.7
M3	0.0151	0.36	38	35	29.3	20.3	206	195	3.4	0.3
M2	0.0131	0.62	22	33	26.4	40.9	214	167	11.6	11.6
M13	-0.0135	0.48	82	30	9.6	25.5	0	0	8.7	0.0
M14	-0.0197	0.38	45	32	20.6	19.4	215	0	12.2	3.1
M10	-0.0377	0.67	38	22	50.0	48.5	269	277	9.7	4.5
M17	-0.0467	0.65	27	25	48.9	50.3	271	258	2.1	7.1
M11	-0.0540	0.66	27	23	57.3	58.3	228	228	5.9	7.1
M20	-0.0562	0.41	43	24	25.1	25.7	290	200	2.5	5.9
M12	-0.0592	0.75	56	25	41.1	38.7	278	278	7.7	1.5
M16	-0.0677	0.27	44	35	12.2	18.5	0	0	6.5	0.0
M18	-0.0719	0.67	49	40	26.6	24.4	0	0	26.0	13.0
M15	-0.0941	0.28	48	26	19.7	8.5	0	0	3.2	0.3
M19	-0.2330	0.33	45	33	19.4	35.1	244	172	3.4	12.4

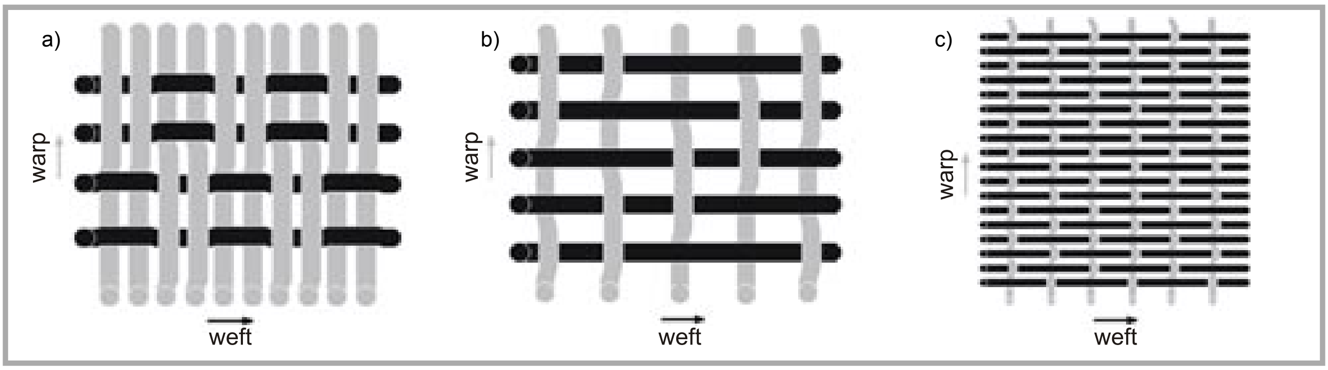

Figure 9. *Structure example of fabrics of: a) negative IP index, b) positive IP index, c) small value of IP index.*

concern warp threads of fabrics, such as M13, M15, M16, M18, and weft threads of fabrics, such as M14, M15, M18. The zero values of the twist and weft crimp of fabrics M13 and M16 were obtained for yarns made of microfibres.

The fabrics arranged with respect to the IP index value have also been presented in graphical form (Figure 8).

Based on the set of structural parameters of the woven fabrics studied, textile products of negative, positive and small value of impact permeability were characterised. The choice of fabric weave was based on preliminary investigations. The investigations depended on the assessment of the weave influence on the *IP* index sign.

The fabrics for which a negative value of the impact permeability index was obtained are characterised by a large number of warp threads and a small number of weft threads. The shapes and sizes that the pores of the product of a negative index will assume should cause a decrease in the airflow resistance of the fabric in dynamic conditions compared to static conditions. In an extreme case, the number of weft threads can be so small that the warp threads will spread apart due to the dynamic air stream. Lack of support for the warp threads by the weft threads will cause the inter-thread space to enlarge in dynamic conditions. The fabric thus built will have an unstable, loose structure and will be liable to bagging.

In order to exemplify the textile product structure of a negative index, a fabric denoted as M18 was chosen. A simplified image of the structure of the fabric is shown in Figure 9.a.

The selected parameters of the fabric are the following:
number of warp threads – 49./cm
number of weft threads – 40./cm
linear density of warp – 26.6 tex
linear density of weft – 24.4 tex.
This is a fabric of hopsack weave.

Fabrics of a positive index are products made of thick yarns. These yarns are not clumped, which facilitates airflow. However, on the other hand, there is the small crimp of the weft, hindering the airflow through the fabric. The shapes and sizes that the pores of such a product will assume will cause an increase in the airflow resistance of the fabric in dynamic conditions compared to static conditions. The fabric threads, interlacing with one another, form a stable but thin structure. The small crimp of the weft will render the fabric rigid, which will hinder the deflection of the warp threads under the influence of the airflow.

In order to exemplify the textile product structure of a positive index, the fabric denoted as M5 was chosen. A simplified image of the structure of the fabric is shown in Figure 9.b.

The selected parameters of the fabric are following:
number of warp threads – 35./cm
number of weft threads – 19./cm
linear density of warp – 52.0 tex
linear density of weft – 49.6 tex.
This is a fabric of shaded twill weave.

Next, fabrics of a relatively small value of the *IP* index, $IP \in$ [-0.0200; 0.0200], were identified. These fabrics do not belong to thick products. They are characterised by a small linear mass of both thread systems and small crimp of the weft. The weft and warp threads form a rigid and clumped fabric. In such a system, great thickness of the weft threads, will cause an increase in the airflow resistance of the textile product. The conditions of the airflow can be improved by large crimp of the warp. A fabric thus built should behave in a similar manner both in static and dynamic conditions.

In order to exemplify the textile product structure of a small index value, the fabric denoted as M14 was chosen. A simplified structure of the fabric is shown in Figure 9.c.

The selected parameters of the fabric are following:
number of warp threads – 45./cm
number of weft threads – 32./cm
linear density of warp – 20.6 tex
linear density of weft – 19.4 tex.
This is a fabric of plain weave.

Conclusions

1. Studies of the impact permeability of fabrics and comparative studies, allow this feature to be shaped at the design and construction stage.
2. A modernised index of the impact permeability of fabrics arranges textile products with respect to their flow properties.
3. A sign of the index of the impact permeability is the same for all specimens obtained from the same woven fabric. The index can take other signs for different woven fabrics.
4. The woven fabrics of a negative value of the *IP* index studied are characterised by a loose structure, resulting from a very small number of weft threads compared to warp threads. Other fabrics investigated, which are characterised by a positive *IP* value of the index, are not clumped; however, they are thick and rigid. Fabrics characterised by a small *IP* value of the index are thin, clumped and rigid.

Editorial note

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