MACRO FLUID ANALYSIS OF LAMINATED FABRIC PERMEABILITY

by

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A porous jump model is put forward to predict the breathability of laminated fabrics by utilizing fluent software. To simplify the parameter setting process, the methods of determining the parameters of jump porous model by means of fabric layers are studied. Also, effects of single/multi-layer fabrics and thickness on breathability are analyzed, indicating that fabric breathability reduces with the increase of layers. Multi-layer fabric is simplified into a single layer, and the fabric permeability is calculated by proportion. Moreover, the change curve of fabric layer and face permeability, as well as the equation between the fabric layer and the face permeability are obtained. Then, face permeability and pressure-jump coefficient parameters setting of porous jump model could be integrated into single parameter (i. e. fabric layers), which simplifies the fluent operation process and realizes the prediction of laminated fabric permeability.

Key words: *breathability, porous media, fluent, pressure-jump coefficient, fabric layers*

Introduction

To predict multi-layer fabric breathability by utilizing fluent software, porous jump model is applied, which makes porous model simplify processing for fabric. Three parameters need to be set, including face permeability, m^2, porous medium thickness, in, and pressure-jump coefficient, C_2. As for each additional layer of fabric, the thickness of the fabric shall be tested, and meanwhile, the remaining two values require complex calculations. In this paper, these parameters can be integrated into one parameter to simplify the fluent parameters setting process.

Theory

Porous jump conditions are utilized to model a thin *membrane* that has known velocity (pressure-drop) characteristics. In essence, it is a 1-D simplification of the porous media model available for cell zones. Examples of uses for the porous jump condition include modeling pressure drops through screens and filters, and modeling radiators when you are not concerned with heat transfer. This simpler model should be applied whenever possible (instead of the full porous media model), because it is more robust and can yield better convergence 1 . The thin porous medium possesses a finite thickness over which the pressure change is defined as a combination of Darcy's Law and an additional inertial loss term [2]:

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$$\Delta p \qquad \frac{\mu}{\alpha} v \quad C_2 \frac{1}{2} \rho v^2 \quad \Delta m \tag{1}$$

where μ is the laminar fluid viscosity, α – the permeability of the medium, C_2 – the pressure-jump coefficient, v – the velocity normal to the porous face, and Δm – the thickness of medium.

According to the eq. (1), a simple and uniform porous media, the use of additional momentum source term can be simplified:

$$S_i \quad C_2 \frac{1}{2} \rho |v| v_i \quad (i \quad x, y, z) \tag{2}$$

Pressure-jump coefficient, which is determined by additional momentum source term of the porous media's momentum equation, can be calculated from the eq. (2):

$$C_2 \qquad \frac{\Delta p}{\frac{1}{2} \rho v^2} \tag{3}$$

where Δp signifies the resistance of channel's per unit length.

Similarly, face permeability calculation is as same, for the eq. (1), as air is vertically through the fabric, thus face permeability, α, can be shown in eq. (4):

$$\alpha \qquad \frac{\Delta m \mu v}{\Delta p} \tag{4}$$

Thus, the face permeability and pressure-jump coefficient, C_2, can be calculated through eqs. (3) and (4).

Experimental

Fabric samples were six same-type polyester-cotton plain fabrics. Warp, weft densities and the size were, respectively, 169 (root/10 cm), 244 (root/10 cm), and 20 20 cm^2. First of all, air permeability and thickness of single-layer fabric were tested. Then, the no.1 sample was made as the first layer superposition, and permeability and thickness of each increasing superposition were tested until the 6th layer. Meanwhile, air permeability test results were rounded to 2%, and variation coefficient was rounded to 0.1%. In addition, pressure of sample thickness test was 100 CN/cm^2 [3, 4].

Results and discussion

The test results of permeability and thickness of six fabrics are displayed in tab. 1.

Fabrics were superimposed sequentially, and the permeability and thickness of multi-layer fabrics was tested. The data can be shown in tab. 2.

Relations between fabric layers and air permeability are shown in fig. 1, and the permeability of the fabric decreased by the continuous superposition of layers. The relation between fabric permeability and layers comply with the law of power function: $y = 1754x^{-0.5981}$, $R^2 = 0.998$, which can accurately describe the permeability changing trends. According to the tab. 2 data to fit the relation curve of fabric thickness and permeability shown in the fig. 2, the air permeability decreases with the increasing thickness, and their relationship shows the power-law function. According to eq. (1), if the permeability, α, and pressure-jump coefficient, C_2, are taken as an unknown, the thickness would be their function. Thus, if the thickness of different layers fabrics is compressed to one layer, it is equal to narrowing fabric aperture. Then, it

Table 1. Test data of single fabric permeability and thickness

No.	Permeability			Thickness			
	Average rate of permeability [mms^{-1}]	Variation coefficient [%]	95% confidence intervals	Nozzle numbers	Average thickness [mm]	Variation coefficient [%]	95% confidence intervals
1#	1775.5	2.5	1775.5 46.9	10	0.26	4.1	0.26 0.01
2#	1762.2	3.7	1762.2 68.4	8	0.26	1.1	0.26 0.01
3#	1874.3	3.3	1874.3 65.8	8	0.25	0.4	0.25 0.00
4#	2075.9	2.3	2075.9 49.1	6	0.25	1.4	0.25 0.01
5#	2076.6	1.5	2076.6 31.8	6	0.25	0.9	0.25 0.01
6#	2145.5	2.2	2145.5 49.5	6	0.24	1.1	0.24 0.01

Table 2. The permeability and thickness data of different layers fabrics

Test results / Layers	Permeability			Thickness		
	Average value [mms^{-1}]	Variation coefficient [%]	95% confidence intervals	Average value [mm]	Variation coefficient [%]	95% confidence intervals
2	1140.3	5	1140.3 59.5	0.51	2.8	0.51 0.01
3	899.2	4.9	899.2 45.9	0.74	2.6	0.74 0.02
4	761.7	3.5	761.7 27.8	0.97	4.4	0.97 0.05
5	690.7	2.5	690.7 18.5	1.22	3.6	1.22 0.05
6	594.4	3.8	594.4 23.6	1.44	3.6	1.44 0.06

is to make a corresponding equivalent of the fabric permeability. Hence, after being simplified into a single layer thickness, the fabric layers rather than fabric thickness are only considered.

It is assumed that compressing all laminated fabric thickness into a single fabric thickness, Δm = 0.26 mm, and making corresponding equivalent of proportion calculation of fabric permeability, then the permeability and pressure-jump coefficient could be obtained. The relation curve of fabric layers and face permeability, as well as the fabric layers and pressure-jump coefficient can be shown in figs. 3 and 4.

According to the figs. 3 and 4, the relation between simplified fabric layer and permeability, simplified fabric layer, and pressure-jump coefficient comply with the law of power function:

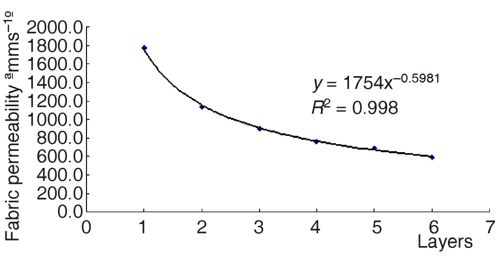

Figure 1. Relation of fabric layers and permeability

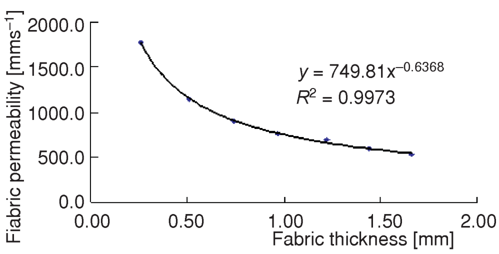

Figure 2. Relation of fabric thickness and permeability

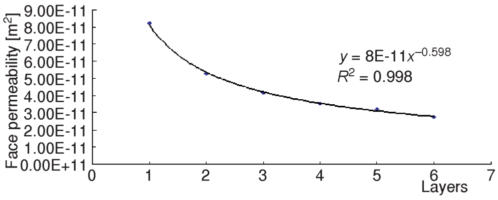

Figure 3. Permeability of multi-layer fabric is simplified into a single layer

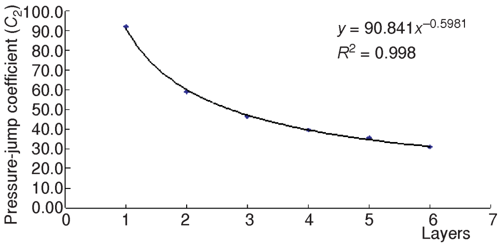

Figure 4. Pressure-jump coefficient of multi-layer fabric is simplified into a single layer

$y = 8e - 11x^{-0.598}$ and $y = 90.841x^{-0.5981}$. The same correlation is $R^2 = 0.998$, indicating that the fitting formula gets close to true value. As can be seen from the figure, the permeability and the pressure-jump coefficient remains a power law function after equivalence. Thus, the simplified experimental data is feasible. Furthermore, the two equations can be adopted for the prediction of laminated fabric permeability and pressure-jump coefficient.

Conclusions

Take the fabric as porous media, the fabric permeability of different layers can be predicted with fluent software. To simplify the parameter setting process, the method of determining the parameters of jump porous model by means of fabric layers is studied as well.

The single and multi-layer fabric breathability and thickness were tested. The fabric breathability reduced with the increasing layers by the law of power function. It is assumed that laminated fabric thickness is compressed into a single fabric thickness. Following data processing equivalence, the relation between fabric layers and face permeability is: $y = 8e - 11x^{-0.598}$. The relation between fabric layers and pressure-jump coefficient is: $y = 90.841x^{-0.5981}$. When fluent was utilized to simulate the air permeability of fabric, face permeability and pressure-jump coefficient can be calculated by these two formulas. Then, the laminated fabric permeability can be predicted.

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