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Predicting Air Permeability from the Parameters of Weave Structure

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Abstract
In this study, air permeability of woven fabrics is predicted from the parameters of weave structures. Air permeability is an important property of fabrics and has a decisive influence on the utilisation of fabric for some technical and clothing applications. There is no doubt that predetermination of the air permeability in woven fabric is vital, and modelling the effective parameters shows the role of the factors as well as the prediction of the property. To promote the design of woven fabrics, we can define the crossing over firmness factor (CFF) and floating yarn factor (FYF) as the parameters of the weave structures for predicting air permeability values. All the parameters are related to air permeability. Multiple regression equations of air permeability are derived from those parameters of weave structures and the values predicted almost exactly agree with the values measured from the FAST system.

Key words: *air permeability, weave structure, woven fabric.*

■ Introduction

Air permeability is an important property of fabrics and has a decisive influence on the utilisation of fabric for some technical (filters, parachutes, and sails) and clothing applications [1]. The main structural parameters which have an influence on fabric air permeability are the fabric density, warp and weft linear densities and the weave [2]. This property is defined as 'the rate of air flow through a material under a differential pressure between the two fabric surfaces' and is expressed in cubic feet per square foot per second (cubic centimetre per square centimetre per second) [3]. In fact, the ease with which air can pass through a fabric depends upon the air channels existing between the two surfaces of the fabric [4, 5]. Naturally the number, shape and size (dimensions) of the channel affect the ratio of air flow of the fabric. The air channels inside woven fabric (porosity) can be classified into the following groups [6]:

1. Those which represent the void space contained within the fibre walls (Intra fibre porosity) and are dependent upon the structure of the fibre.
2. Those which represent the void space contained between fibres in the yarn (Inter fibre porosity) and are dependent upon the fibre fineness, cross-section shape, surface contour yarn twist and spinning methods.
3. Those which represent the void volume contributed by interstices between the yarns (Inter yarn porosity) and are dependent upon the weave structures (weave type and fabric tightness) [7].

Concerning this, Burleigh etal [7] stated that the inter yarn and inter fibre porosity mainly contributes to the effective porosity. They also mentioned that the inter fibre and inter yarn porosity depends upon the fibre fineness, fibre shape, type of weave number of the thread density and yarn twist.

Undoubtedly, predetermination of the air permeability in woven fabric is vital, and modelling the effective parameters shows the role of the factors as well as the prediction of the property. Therefore, many efforts have been made to model woven fabric air permeability. The primary model to analyse fabric air permeability is given by Robertson [8]. He considered a wire mesh as a simplified model of a fabric and each pore space between the cross-over of the warp and weft to be a nozzle with an equal discharge coefficient. His work was continued by Hoerner [9], who used wire mesh for his model too, assumed that the wire mesh and a screen fabric both behave similarly under the same conditions and argues that the pressure drop is due to friction between the air and contact surface area of the medium, as well as to the speed of flow. Actually he believed that the airflow through a fabric is similar to that through a tube, but with the effect of a greater aspect ratio. As a result his model was simple but not accurate enough. Saidenov [10] sug-

Table 1. Improvements in air permeability modelling.

Order	Researcher	Model	Parameters	Weakness
1	Robertson [8]	$Q = CA_2 \sqrt{\dfrac{2gh}{1 - A_0^2}}$	pore space between cross-over of yarns	too much error
2	Hoerner [9]	$\Delta p = \alpha \, \rho U u_s$	air flow and pressure drop	not accurate enough
3	Saidenov [10]	$\Delta P = \alpha U + b U^2$	viscosity of air, density of fabric, void geometry and air velocity	limited to filament plain weave fabric
4	Milasius [12]	$\varphi = \sqrt{\dfrac{12}{\pi}} \dfrac{1}{P_1} \times \sqrt{\dfrac{T_{average}}{\rho}} \times S_2^{\frac{1}{1+\frac{2}{3\sqrt{\frac{T_1}{T_2}}}}} \times S_1^{\frac{2}{\sqrt[3]{\frac{T_1}{T_2}}}{1+\frac{2}{3\sqrt{\frac{T_1}{T_2}}}}}$	yarn counts, fabric density	complicated calculations
5	Ogulata [13]	$Q = m \times A_c \times U$	air flow velocity, cross-section and perimeter of pore	just useable for plain weave
6	Fatahi [14]	*Air permeability=(α)CFF+(β)FYF+(γ) (α, β, γ - constants)*	fabric weave, yarn densities, and fabric densities	-

gested a two term equation for the prediction of fabric air permeability under a pressure drop, in which the viscosity of air, the density of fabric, the void geometry and air velocity were the main model parameters. However, his model was suitable for predicting the air permeability of plain weave filament cloths only. Actually his model can be used for filament fabrics with a plain weave [11]. R. Milašius [12 - 14] worked on the dependency of air permeability on various integrated fabric firmness, such as fabric density and yarn counts. In fact, he brought structural parameters into account. Naturally the weak point of the model predicted was the dependency of the prediction on too many parameters. In addition the model could not be used for 2/2 rib fabrics. Afterwards Ogulata [15] used a capillary model of porous systems on Darcy's law and investigated theoretical values to establish a simple theoretical model. His model is just useable for plain weave, hence its use is limited. **Table 1** shows a summary of works that have been done on woven fabric air permeability.

However, in this experimental study we modelled the air-permeability of woven fabrics based on 8 manufactured fabric samples in which the fabric weave (CFF & FYF), yarn densities (d_f & d_w) and fabric densities (p_f & p_w) were varied. The model shows the relationship between air permeability and the fabric structural parameters mentioned above. The model given has the advantage of simplicity and can be used for all weaves.

■ Experimental

The yarns were 20 tex viscose/polyester for the warp and 30 tex viscose/polyester for the weft. We chose eight fabric samples with different weave structures, including a plain weave, 2/2 twill weave, 2/6 twill weave, crape weave, rib weave, warp rib weave, basket weave, and dice weave. All the samples were gray woven fabric in which only the textile structure changes and withthe same yarn and weave densities (24/cm warp, 22/cm weft). The weave designs and their features are shown in **Tables 2** and **3**, respectively. The plain weave, 2/2 twill weave, and dice weave are three fundamental textile weaves with the following characteristics: Plain weave has much interlacing of warp and weft yarns; 2/2 twill weave shows ridges on the fabric surface, and the dice weave has a lot of floating yarns. The other woven fabrics

are derivatives of these three weaves. In other words, the crape weave is a derivative of the plain weave, and the 2/6 twill weave is a derivative of the twill weave. Therefore, these textiles include mixed features of the three foundation weaves.

Definition of the parameters for the weave structure

Crossing-over Firmness Factor (CFF)
This factor was originally defined by Ogawa [17], but the definition is obscure and cannot be used for further investigation. He proposed the factor based on the type of crossing conditions of two warp and two weft yarns within ten warp and ten weft yarns. The type he proposed is not authentic and cannot be applied to
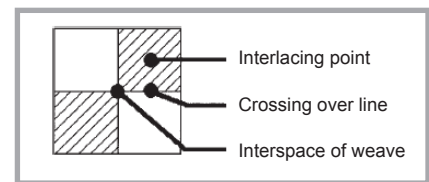

Figure 1. *Complete repeat of plain weave [18].*

more complicated structures with more than ten warp and ten weft yarns. Therefore, Morino [18 - 20] redefined the crossing-over firmness factor as follows.

The plain weave structure is shown in **Figure 1**. The crossing-over line number is counted as 1 when the interlacing point changes e.g. the warp yarn changes from

Table 2. *Various designs of textile weaves.*

Textile weave	Complete repeat	Textile weave	Complete repeat
Plain weave		Warp rib	
2/2 twill weave		Basket weave	
2/6 twill weave		Dice weave	
Rib		Crape weave	

Table 3. *Specifications of the fabrics.*

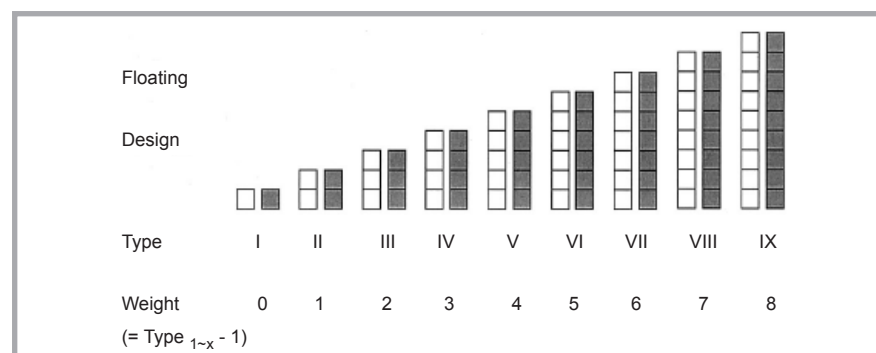| Sample index	Warp setting	Weft setting	Textile weave	Weft count, tex	Warp count, tex)
1			Plain		
2			Crape		
3			Warp rib		
4	24/cm	22/cm	Rib	30/1	20/2
5			2/2 twill		
6			Basket		
7			2/6 twill		
8			Dice		

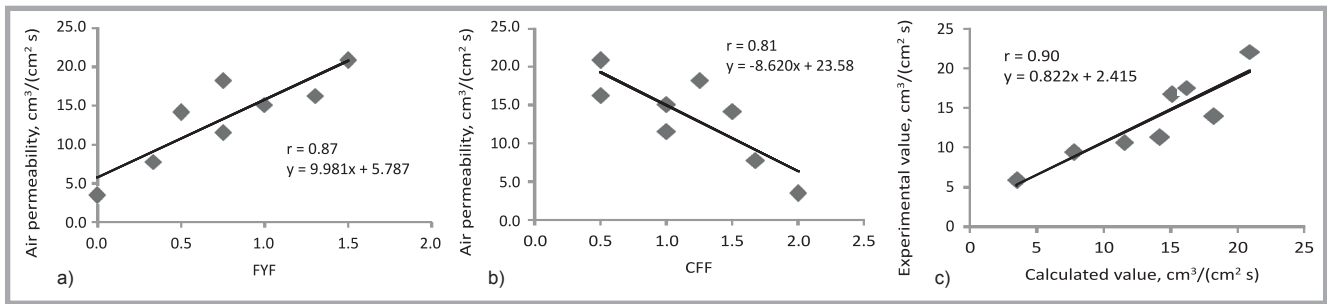***Figure 2.*** *Nine types and weights of floating yarns [18].*

Figure 3. Relationship between air permeability and: a) FYF, b) CFF and agreement of air permeability (c).

over to under the weft yarn, or vice versa in the warp direction. The number is summed up in the complete repeat. In the case of the plain weave, there are eight crossing-over lines in the complete repeat and four interlacing points. Therefore, the CFF becomes 2.0.

Floating Yarn Factor (FYF)
First we chose the floating yarn type, shown in ***Figure 2***, and then we decided each weight, also shown in ***Figure 2***. The floating yarn factor is defined as follows [18 - 20]:

Measuring mechanical properties
Air Permeability was measured by shierly apparatus under high sensitivity conditions. The temperature was 20 °C ± 0.5 °C and the relative humidity - 65% ± 5%.

■ Results and discussion

The results of the CFF and FYF calculated are shown in ***Table 4***. The CFF becomes bigger if the frequency of interlacing yarns is larger. Therefore, the plain weave has the largest CFF and the Dice

Table 4. *Results of the CFF and FYF calculated.*

Textile weave	CFF	FYF
Plain weave	2	0
2/2 twill weave	1	1
2/6 twill weave	0.5	1.5
Warp rib	1.5	0.5
Basket weave	1	1
Dice weave	0.5	1.5
Rib	1.25	0.75
Crape	1.67	0.33

Table 5. *Correlation coefficients between the air permeability and weave structure parameters.*

Fabric property	CFF	FYF
Air Permeability	0.81	0.87

weave the smallest for the same warp and weft yarn densities.

On the other hand, the FYF becomes larger with a longer floating length. Therefore, the Dice weave has the largest FYF and the plain weave the smallest. We assume that the CFF becomes larger with a smaller FYF.

First we determine the correlation coefficients between the air permeability property of the fabrics and the parameters of the weave structures, CFF and FYF, the results of which are shown in ***Table 5***. The significance level for all is 5%. We found that the air permeability is influenced by both the CFF and FYF; hence we can declare that the air permeability property of the fabrics has a relationship with the CFF and FYF. Both the CFF and FYF are strongly related to the air permeability. As an example, the result between the air permeability and FYF is shown in ***Figure 3.a***. There is a clear positive correlation, and the FYF becomes larger with a larger air permeability, meaning that the fabric becomes softer with a large FYF.

On the other hand, the results of the relationship between the air permeability and CFF shown in ***Figure 3.b*** give a negative correlation with the CFF, becoming larger with a smaller air permeability. This means that the fabric becomes harder with a large CFF. According to these results, air permeability is considered to be related to both the CFF and FYF. Therefore, we conducted a multiple regression analysis [21, 22] using those parameters as predictor variables. The result of the multiple regression equation is

$$\text{Air permeability} = 13.24 \times (CFF) + 24.01 \times (FYF) - 20.55$$

Here, if we compare the absolute values of the partial regression coefficient, the FYF value (24.01) is bigger than the CFF

value (13.24), meaning that the effect of the FYF is larger than that of the CFF on air permeability. If we can determine the values of CFF and FYF, it is possible to predict the value of air permeability by the multiple regression equation.

For example, in the case of the Dice weave, if we enter 0.5 into the CFF and 1.5 into the FYF, the value of air permeability of the weave is predicted by this equation, which is 22.1. On the other hand, the air permeability value of the weave measured is 20.9. This difference is only 5%, meaning there is no practical difference between the two fabrics. The regression accuracy is shown in ***Figure 3.c***. The multiple correlation coefficient is high - +0.91, and the values predicted nearly agree with the values of the air permeability system measured (5% significance level).

■ Conclusions

The Air permeability of fabric is one of the most important properties of technical fabrics. The Air permeability depends on the shape and value of pores and interthread channels, which are dependent on the structural parameters of the fabric. In order to predict the air permeability property of fabric from the parameters of the weave structure, we defined the weave structure parameters and studied the relationship between them. We conclude that we can define the crossing-over firmness factor (CFF) and floating yarn factor (FYF) as the parameters of the weave structure for predicting air permeability. From this experimental research the following conclusion can be drawn.

Fabric air permeability is dependent upon the fabric structure and parameters defined from the weave structure.

The relationship between the parameters and air permeability is modelled to

contain the highest number of effective parameters and reveal a correlation of above 90%.

The equations extracted from the models will be helpful in designing woven fabrics as we can determine the fabric air permeability even before a fabric is produced.

The differences in weave structures mainly affect the fabric properties. Multiple regression equations of air permeability are derived from the weave structure parameters, and the values predicted almost exactly agree with the values from the measurement system measured.

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