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# Effect of Weave Parameters on the Air Resistance of Woven Fabrics

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**Abstract**
*An investigation of the effect of weave parameters, namely Crossing Floating Factor (CFF), Floating Yarn Factor (FYF) and Fabric Firmness Factor (FFF) and the geometrical properties of woven cotton fabrics such as the areal density, thickness and porosity on air resistance is reported. A series of cotton woven fabrics comprising eleven weave structures and having a common count in the warp and weft and fabric sett was produced. Essential data such as the CFF, FYF, FFF, areal density, thickness and porosity were obtained. They were divided into four groups on the basis of their CFF and FFF, with each one designed to represent a particular effect. Air resistance was determined by performing the standard test KES- F8 – API. Analysis of the results shows a strong correlation between the CFF, FYF, FFF and air resistance. Fabrics which have long floats were characterized by lower air resistance, and the fabric which had no float displayed higher air resistance. The thickness is found to be well correlated with air resistance. Thus in addition to the CFF, FYF and FFF, the thickness should also be taken into consideration for predicting the air resistance of fabrics.*

**Key words:** *doubled yarns, Crossing Floating Factor (CFF), Floating Yarn Factor (FYF) and Fabric Firmness Factor (FFF) thickness, mass per square meter, air resistance.*

## Introduction

Doubling is a valuable additional process which enhances strength and uniformity. The textile and apparel industries have benefitted a great deal from the use of doubled yarn by introducing innovative and technical textiles. The advent of new types of yarns such as compact yarns makes it imperative to study the potential of doubling these yarns with a view to using them to the maximum extent. The designers of fabric products also look to benefit from the doubling of these yarns produced from conventional yarns.

Coulson and Dakin [1] were pioneers in investigating the properties of two- fold yarns. The world wide consumption of two-fold staple yarns is next to that of single ring spun yarns and exceeds that of rotor yarns. While the advantages of doubled yarns are numerous, there have been many attempts to produce a doubled yarn by resorting to siro spun at low cost. Onder et al. [2] studied the mechanical properties and air permeability of high weight wool blend apparel fabrics. The mechanical responses in uniaxial tensile and tear tests of grey state fabrics and low deformation characteristics were reported by them. The use of siro spun yarn led to a slight drop in shear rigidity and higher air permeability of fabrics. Thus the effect of the doubled yarn structure on the properties of fabrics was examined.

The subject of air permeability has attracted the attention of many research workers. These studies have addressed the relationship between the air permeability and structural properties of fabrics, namely the mass per unit area, fabric thickness, porosity, type of yarn and finishes, but without weave parameters. Generally it has been found that as the fabric mass and thickness increase, the air permeability decreases. Subramaniam et al. [3] studied the air permeability of blended non-woven fabrics. They stressed the importance of porosity in predicting the air permeability of nonwoven fabrics. The prediction of air permeability by a model was done by Saldaeva [4] of Nottingham University, which makes use of a commercial finite element package. A CFD model using CFX 10 was developed for predicting air permeability. Iman Fatahi and Alamdar Yazdi [5] were the first research workers to correlate weave parameters to air permeability, They predicted air permeability from weave structure by means of multiple regression equations. However, in their work they did not give any data on the FFF, mass per unit area, thickness and porosity, which also have a significant effect on air permeability.

The prediction of air permeability by a neural network was carried out by Tokarska [6]. Recently Ali Afzal et al. [7] carried out an extensive study on the air permeability of polyester cotton blended interlock knitted fabrics and found that fabric thickness and areal density significantly affected air permeability. Iman Fatahi and Alamdar Yazdi [5], using the parameters CFF (Crossing over firmness factor) and FYF (Floating yarn factor), predicted the air permeability of woven fabrics. They did not calculated the FFF as they felt that the equations given by Milasius were quite complicated. Their model should be treated with caution as other parameters such as thickness, area of density and porosity also affect air permeability.

The role of porosity in air permeability was also investigated by Cheng and Cheung Cil et al. [8]. Kane et al [9] found that weft knitted fabrics made from compact yarns possessed higher air permeability in comparison to those produced from conventional yarns.

Xiao et al. [10] studied the importance of compression in relation to the thickness permeability in technical textile. They studied the effect of low air pressure compression on through thickness through permeability (TTP). The effect of a drop in air pressure on thickness was investigated. Fabric through thickness permeability (TTP) was shown to be highly related to thickness. Air permeability was also predicted by porosity measurement. The hydraulic and diameter of pores, the number of macro pores and the total porosity of woven fabrics were considered. Rombaldoni et al. [11] dealt with the effect of carbondioxide dry cleaning on the air permeability of men's suiting. Zhu et al. [12] studied the air permeability and thermal resistance of textile under heat convection. A newly developed device was developed for evaluating the thermal resistance of textiles, and it was shown that with an increase in the pore size and the ratio of the pore area to the total area of fabric, the air permeability increases and the thermal resistance decreases. Pore size and the ratio of the pore area have a significant effect compared with the porosity value. A paper by Angelova et al., [13] discusses the computational modeling and experimental value of the air permeability of the woven structure on the basis of the simulation of jet systems. The flow through the interstices between the warp and weft threads is modeled as an “in-corridor” - ordered jet system, formed by nine jets issuing from nine pores of the woven structure. A good correlation between the experimental and simulated values was noted for five fabrics which were manufactured

The air permeability of multi layer cotton fabrics as affected by the structure and yarn colour was studied by Urbas et al. [14] It was demonstrated that by suitable choice of construction and yarn colours, it is possible to have good air permeability and UV protection. The effect of relative humidity on air permeability was studied by Wehner et al. [15] It was found that the fabric structure, number of bonding points, yarn twist and yarn cross over points affected the air permeability of woven and non woven fabrics. Xiao et al. [16] stressed the importance of the dynamic air permeability of woven fabrics. Dynamic air permeability can be determined when a porous medium is tested under transient pressure conditions. A reliable approach to measure and characterise dynamic air permeability is developed. Backer [17] was the pioneer who emphasised the role of interstices in the air permeability of fabrics. He calculated the minimum horizontal pore areas and then related them to the air permeability of fabrics. Backer’s work remains a precursor to air permeability studies of fabrics.

A number of papers discuss the air permeability of knitted fabrics, which underline the importance of fabric mass, thickness and porosity in it [18]. A novel approach for measuring the air permeability of air bags by shock waves which are reflected by the fabric structure is discussed by Wang et al. [19].
This paper focused attention on the effect weave parameters such as the CFF (Crossing Floating Factor), FYF (Floating Yarn Factor), FFF (Fabric Firmness Factor) and fabric geometrical properties, namely, areal density, thickness and porosity, have on air resistance. Earlier work by Fatahi and Alamdar Yazdi [5] on air permeability was conducted only by considering the CFF and FYF. The parameter FFF was not computed in view of its complexity. The present work considers this parameter to relate it to the air resistance of woven fabrics for the first time, and reports the findings.

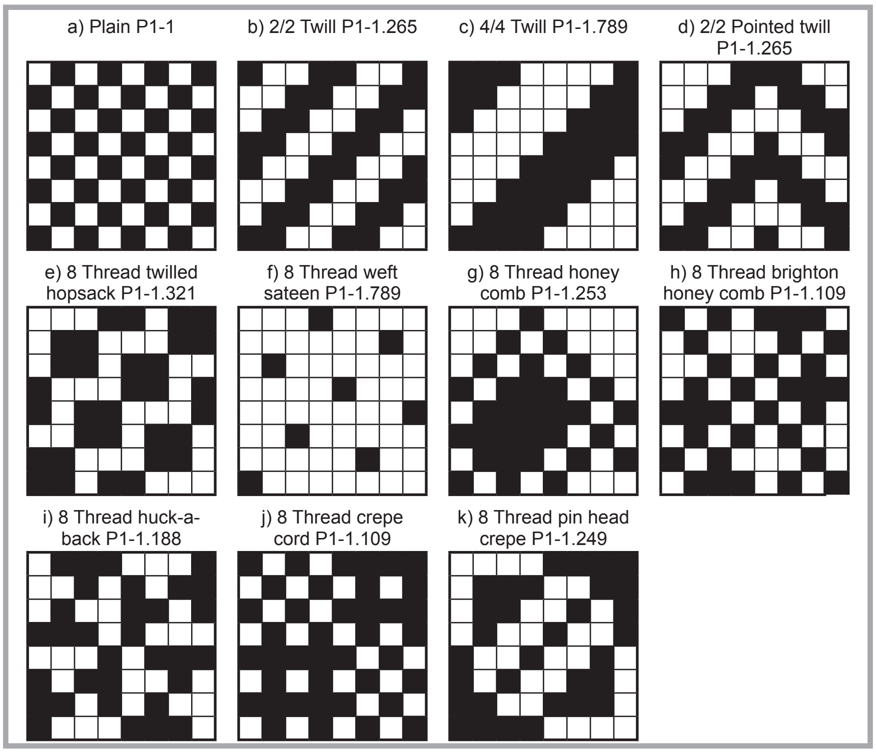
a) Plain P1-1
b) 2/2 Twill P1-1.265
c) 4/4 Twill P1-1.789
d) 2/2 Pointed twill P1-1.265
e) 8 Thread twilled hopsack P1-1.321
f) 8 Thread weft sateen P1-1.789
g) 8 Thread honey comb P1-1.253
h) 8 Thread brighton honey comb P1-1.109
i) 8 Thread huck-a-back P1-1.188
j) 8 Thread crepe cord P1-1.109
k) 8 Thread pin head crepe P1-1.249

*Figure 1. Weave structures with weave factor (P1).*

## Experimental

### Materials

***Yarns used for the production of fabrics***
9.8 tex ring spun yarns were produced from cotton mixing and were doubled.

### Methods

***Fabric production***
Eleven fabric samples identical in thewarp and weft sett but differing in weave structure were woven on an automatic loom. Weave structures include plain, 2/2 twill, 4/4 twill, 2/2 pointed twill, 8 thread twilled hopsack, thread weft sateen, 8 thread honey comb, 8 thread brighten honey comb, 8 thread huck-a-back, 8 thread crepe cord and 8 thread pin head crepe, given in ***Figure 1*** (see page 66). While the plain weave has more interlacement of warp and weft yarns, the 2/2 weave has ridges on the fabric surface and the 8 thread weft sateen has weft floats. The crepe weave is a derivative of the plain weave.

***Weave factor***
The weave factor (P1) represents the number of interlacements of warp and weft which are obtained from the weave matrix. It may be noted that Milasius et al., [20, 21] proposed two weave factors, P1 and P’, in their study. We have calculated P1, which was elaborated by them. The FYF proposed by Morino et al. [24] can be taken as a measure of floats in the fabric. It has a high correlation with the weave factor. Since calculation of the weave factor is quite complicated, it was made by software which can be found on the website http://www.textiles.ktu.lt/Pagr/En/Cont/pagrE.htm [20].

***Fabric processing***
These fabrics were subsequently bleached with hydrogen peroxide with a M:L ratio of 1:10, hydrogen peroxide concentration of 1.5%, caustic soda 1.2%, wetting agent 0.5 %, lubricant oil - 0.3%and stabiliser (sodium silicate) - 0.2%, at 90 °C for 45 min.

***Measurement of porosity***
All the tests were carried out at Rh 65 ± 2%, and 25 ± 2 ºC.

The porosity of cotton fabric was determined by the following equation.

$$\text{Porosity} = (1 - \rho_{fab}/\rho_{fib}) \times 100 \text{ in } \%$$

where, $\rho_{fab}$ is the fabric bulk density and $\rho_{fib}$ is the fibre density of cotton fibre, which is 1.55 g/cm$^3$ [25] The bulk density of the fabric is calculated from the following equation.

$$\text{Fabric bulk density} = \text{GSM}/10000/\text{TF in g/cm}^3$$

where, GSM - represents grams per square meter, TF - thickness of fabric in cm.

***Measurement of thickness***
The thickness was measured using a thickness tester by following ASTM D1777 standards.

***Measurement of surface mass*** **(***gram per square meter***)**
GSM (Gram per square meter) was measured by using the ASTM D3776 standard.

***Measurement of air resistance***
Air resistance was measured by a Kawabata KES – F8 API air permeability tester (Kato tech Co. Ltd, Japan), which has a constant rate of air flow with different pressure measurement methods. Testing was performed according to ASTM D737. The mean of five readings was taken for each fabric in a bleached state.

### Definition of the parameters of the weave structures

***Crossing-over firmness factor (CFF)***
It is defined as bellow:

$$\textbf{CFF} = A/B$$

where, A - Number of crossing over lines in the complete repeat, B - Number of interlacent point in the complete repeat.

Ogawa [26] originally coined this term. The only disadvantage was that it was not clearly understood for further investigation. In order to obviate this, Morino et al [22 - 24], redefined the CFF as below,

$$\text{CFF} = N_c/N_i$$

where, $N_c$ - number of crossing-over lines in the complete repeat, $N_i$ - number of interlacing points in the complete repeat.
Details of the CFF for a plain weave structure are shown in ***Figure 2***. The crossing-over line number is counted as 1 when the interlacing point changes, for example, the warp yarn changes from 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 plain weave, there are eight crossing over lines in the complete repeat (c1 to c4 warp crossing over line and c5 to c8 weft crossing over line) and four interlacing points (i1 and i2 warp interlacement points and i3 and i4 weft interlacement points). Hence crossing over lines are 8 and interlacement points are 4. Therefore the CFF becomes 2.

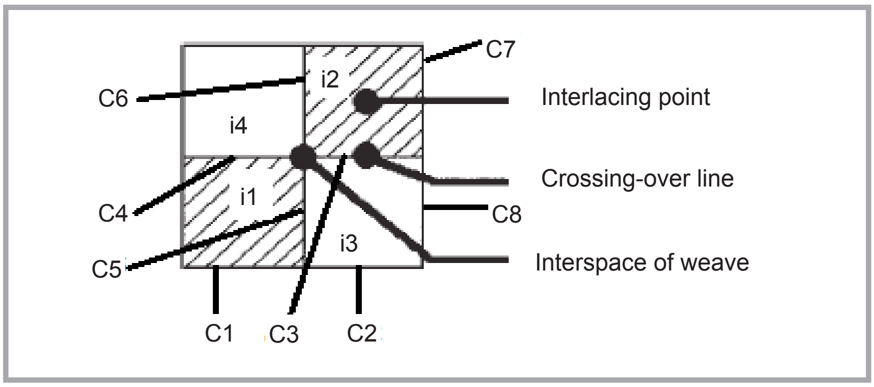

***Figure 2.*** *Details of CFF.*

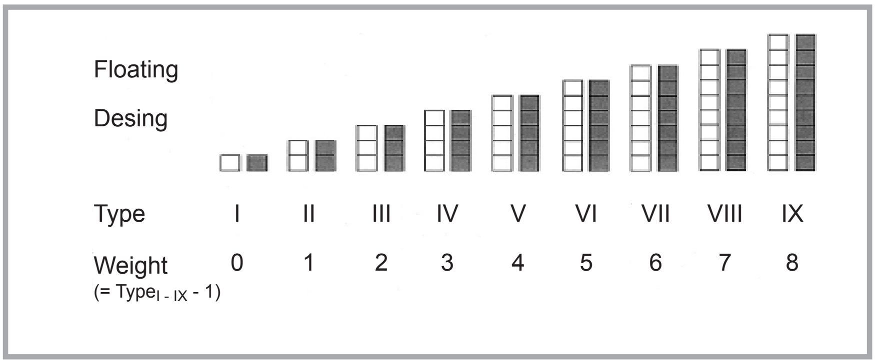

***Figure 3.*** *Details of FYF.*

***Floating yarn factor***
***Figure 3*** shows details of the floating yarn type from which each the weight was decided.

The floating yarn factor is defined as follows:

$$\text{FYF} = (\text{Type}_{\text{I - IX}} - 1)\times N_e/N_i$$

where, FYF evaluates the length of parts of floats, $N_e$ - existing number of type $_{\text{I - IX}}$ in the complete repeat, $N_i$ - number of interlacing points in the complete repeat.

***Fabric firmness factor***
This was computed using the formula given by Milasius [21 - 23].

$$\varphi = \sqrt{\frac{12}{\pi}}\ \frac{1}{P_1}\ \sqrt{\frac{T_{av}}{\rho}}\ S_2^{\frac{1}{1+\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}}\ S_1^{\frac{\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}{1+\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}}$$

where, $\rho = \frac{S_1\rho_1 + S_2\rho_2}{S_1 + S_2}$ and

$$T_{av} = \frac{S_1T_1 + S_2T_2}{S_1 + S_2}$$

$T_1$, $T_2$ and $T_{av}$ are, respectively, the warp count, weft count and average count in tex. $P_1$ is the Milasius weave factor and ρ is the fibre density. $S_1$ and $S_2$ are the ends and picks per decimeter.

## Results and discussion

The fabric geometrical properties and weave structures as well as fabric groupings are given in ***Table 1***. The fabrics have been divided into four groups according to their CFF and FFF values. Each group is characterised by a particular effect such as no floats, short floats, bigger floats and the biggest floats. Group 1 fabrics have a high CFF and FFF (2 and 0.49), group 2 fabrics - CFF 1.5 and FFF 0.44, group 3 fabrics - CFF values from 1 to 1.25 and FFF from 0.37 to 0.40, and group 4 - fabrics have CFF values of 0.5 and FFF of 0.27 to 0.29.

It may be seen from ***Table 1*** that the CFF becomes higher with an increase

***Table 1.** Fabric particulars.*

| Group | Fabric type | Areal density, | Thickness | Porosity | CFF | FYF | FFF | Weave factor | Warp & weft count | Air resistance | Ends/cm | Picks/cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unit | g/cm2 | cm | % | -- | -- | -- | P1 | tex | kPa·s/m | - | - |
| 1 | Plain | 108 | 0.0336 | 78.57 | 2 | 0 | 0.49 | 1 | 19.68 | 0.17 | 22 | 23 |
| 2 | 8 Thread brighten hony comb | 108 | 0.057 | 87.36 | 1.5 | 0.5 | 0.44 | 1.109 | | 0.06 | 22 | 23 |
| | 8 Thread crepe cord | 156 | 0.057 | 81.75 | 1.5 | 0.5 | 0.44 | 1.109 | | 0.05 | 23 | 23 |
| 3 | 2/2 Twill | 156 | 0.041 | 75.00 | 1 | 1 | 0.4 | 1.265 | | 0.077 | 23 | 25 |
| | 2/2 Pointed twill | 116 | 0.044 | 82.42 | 1 | 1 | 0.39 | 1.265 | | 0.05 | 23 | 23 |
| | 8 Thread twilled hopsack | 128 | 0.0454 | 81.20 | 1 | 1 | 0.38 | 1.321 | | 0.04 | 23 | 24 |
| | 8 Thread pin head crepe | 152 | 0.0526 | 80.73 | 1.13 | 0.88 | 0.38 | 1.249 | | 0.047 | 22 | 22 |
| | 8 Thread honey comb | 108 | 0.0464 | 84.48 | 1.19 | 0.81 | 0.37 | 1.253 | | 0.047 | 23 | 20 |
| | 8 Thread huck - a - back | 124 | 0.0534 | 84.51 | 1.25 | 0.75 | 0.4 | 1.188 | | 0.04 | 22 | 22 |
| 4 | 4/4 Pointed twill | 132 | 0.0476 | 81.51 | 0.5 | 1.5 | 0.28 | 1.789 | | 0.047 | 23 | 24 |
| | 8 Thread weft sateen | 124 | 0.0474 | 82.56 | 0.5 | 1.5 | 0.27 | 1.789 | | 0.03 | 22 | 22 |

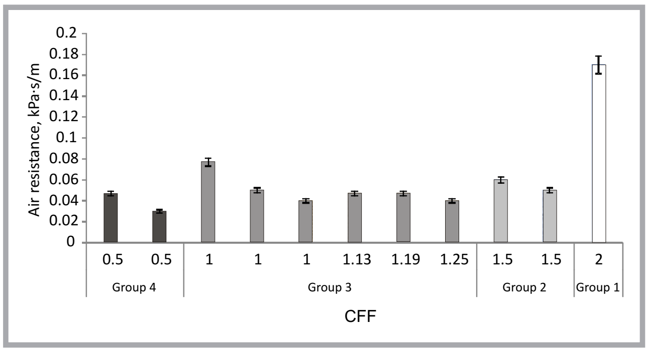

**Figure 4.** *Graphical relationship between air resistance and CFF.*

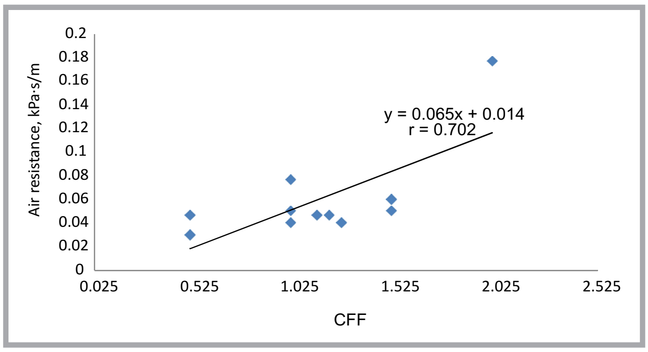

**Figure 5.** *Relationship between air resistance and CFF.*

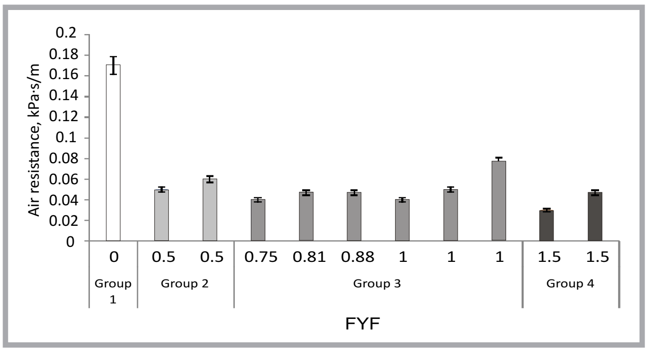

**Figure 6.** *Graphical relationship between air resistance and FYF.*

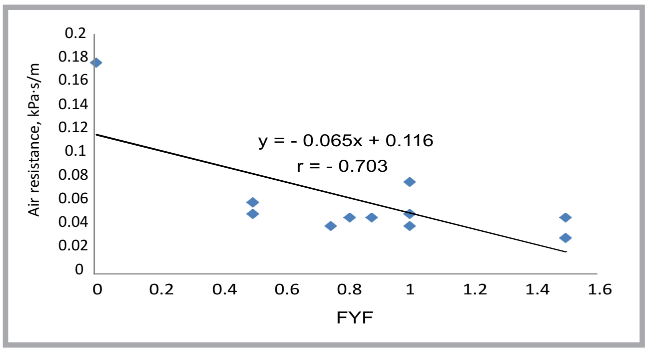

**Figure 7.** *Relationship between air resistance and FYF.*

in interlacements. The FYF becomes larger with a longer floating length. Therefore sateen and 4/4 pointed twill show large values of FYF.

### Effect of CFF on air resistance

***Figures 4** & **5*** illustrates the relationship between the CFF and air resistance, and ***Figure 5*** gives the regression equation and correlation. It is apparent that as the CFF increases, the air resistance increases due to the absence of floats and more interlacements. This is in agreement with the findings of Iman Fatahi and Alamdar Yazdi [5]. The correlation between the CFF and air resistance is 0.702, which is significant. This shows that the fabric becomes harder with a large CFF.

### Effect of FYF on air resistance

The trend in air resistance as affected by the FYF is depicted in ***Figures 6***, and ***7*** gives the regression equation and correlation. It is the mirror image of the CFF. The correlation between the FYF and air resistance is negative, namely -0.703, and is significant. This is also in substantial agreement with the findings of Iman Fatahi and Alamdar Yazdi [5] The FYF represents the number of floats and is positively correlated with the weave factor P1. The reduction in air resistance with an increase in FYF is due to the presence of floats.

### Effect of FFF on air resistance

***Figures 8*** and ***9*** illustrate the relationship between the FFF and air resistance, from which it is apparent that as the FFF increases, air resistance increases; a trend also noticed between the CFF and air resistance. It may be noted that this relationship is reported for the first time as determination of this parameter was found to be complicated, as pointed out by Iman Fatahi and Alamdar Yazdi [5]. Padaki et al. [27] also did not compute the FFF in their studies. The correlation between the

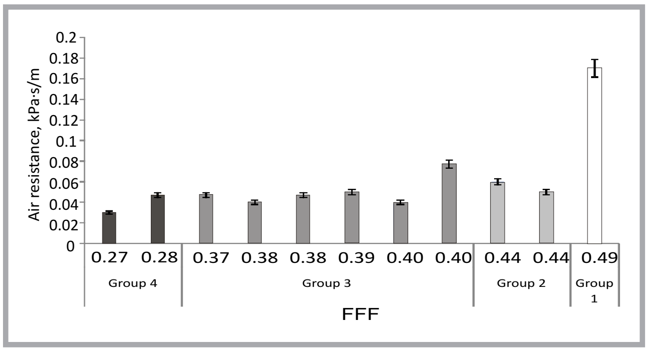

***Figure 8.*** *Graphical relationship between air resistance and FFF.*

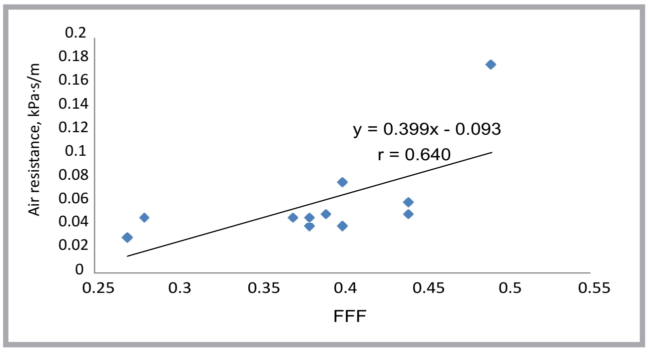

***Figure 9.*** *Relationship between air resistance and FFF.*

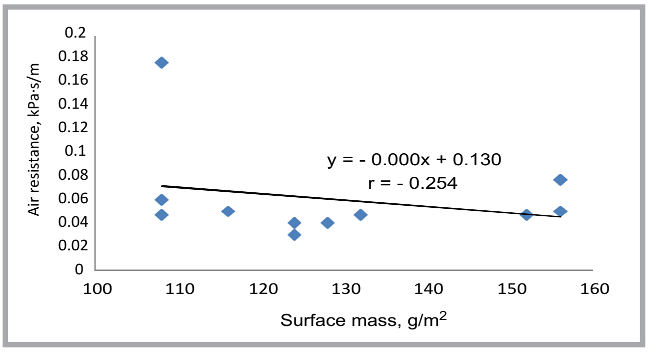

***Figure 10.*** *Relationship between air resistance and surface mass.*

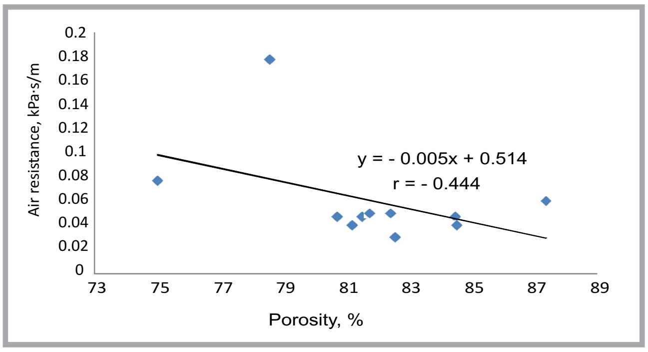

***Figure 11.*** *Relationship between air resistance and porosity.*

FFF and air resistance is a little lower (r = 0.640) in comparison to the correlation between the CFF and air resistance (r = 0.702).

The comments that have been mentioned on the significance of the CFF hold good for the FFF as well. The trends between the CFF and air resistance and between the FFF and air resistance are similar.

### Effect of surface mass on air resistance

***Figures 10*** & ***11*** illustrates the relationship between the surface mass and air resistance, from which it is clear that the relationship is poor.

### Effect of porosity on air resistance

The relationship between porosity and air resistance is found to be poor. ***Figure 11*** illustrates the trend of porosity and air resistance.

### Effect of thickness and air resistance

***Figure 12*** shows the relationship between the thickness and air resistance, from which it can be noticed that the correlation is significant (r = -0.677). This in substantial agreement with the findings of Ali Afzal et al. [7].

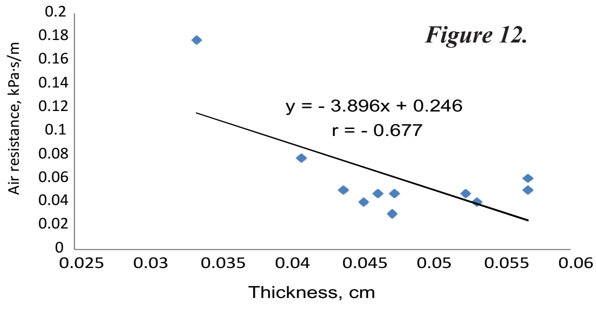

***Figure 12.***

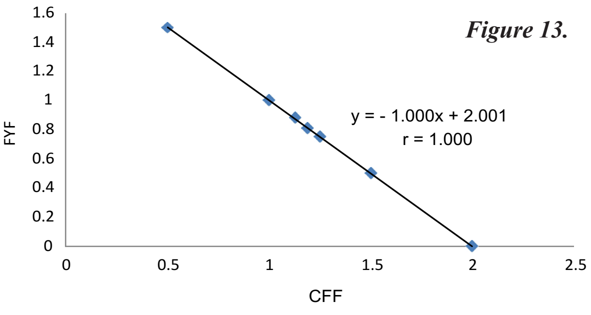

***Figure 13.***

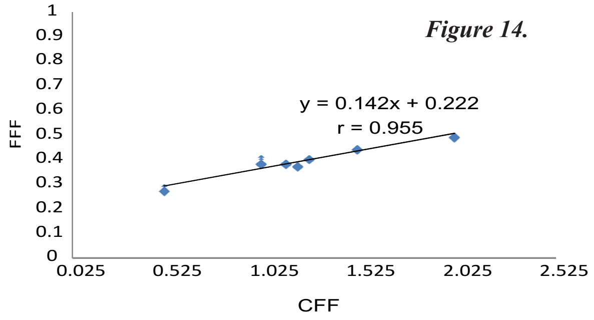

***Figure 14.***

***Figure 12.*** *Relationship between air resistance and thickness.*

***Figure 13.*** *Relationship between CFF and FYF.*

***Figure 14.*** *Relationship between CFF and FFF.*

### Interrelationship between other parameters

It is also interesting to note the significantly higher correlation between the FYF and CFF (***Figure 13,*** see page 71), and between the weave factor and CFF and FFF (***Figure 14,*** see page 71). No doubt this was pointed out by Sankaran and Subramaniam [28].

Iman Fatahi and Alamdar Yazdi [5] pointed out in their paper that air permeability is strongly affected by the CFF and FYF. It should be mentioned that in addition to the CFF and FYF, the weave structural parameter FFF and geometrical parameter also affect air resistance.

## Summary and conclusions

The fabrics were divided into four groups on the basis of weave parameters CFF and FFF. Lower values of CFF and FFF are associated with longer floats.Weave parameters CFF, FYF and FFF are significantly correlated to the air resistance of the fabrics. Fabrics with longer floats have lower air resistance in comparison to those with shorter floats and no floats at all, namely plain weave. It is found that thickness is also strongly correlated to air resistance. Thus it is suggested that, in addition to the weave parameters, namely, CFF, FYF and FFF, thickness should also be taken into consideration for designing fabrics for application in air bags and filtration fabrics.

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