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Effect of weave parameters on air resistance of woven fabrics produced from compact doubled yarn

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The effect of weave parameters, namely crossing-over firmness factor (CFF), floating yarn factor (FYF) and fabric firmness factor (FFF) and geometrical properties such as areal density, thickness and porosity of woven cotton fabrics on air resistance has been studied. A series of cotton woven fabrics comprising eleven weave structures and having common count in warp & weft and fabric sett has been produced. Samples are divided into four groups on the basis of their weave and geometrical parameters each group designed to represent a particular effect. Air resistance is determined by performing the standard test KES- F8 – API. The results show a strong correlation among CFF, FYF and FFF with air resistance. Fabrics having long floats are characterized by lower air resistance and those having no float display higher air resistance. Thickness is found to be well correlated with air resistance. Thus, in addition to CFF, FYF and FFF, thickness should also be taken into consideration for predicting air resistance of fabrics.

Keywords: Air resistance, Cotton fabric, Crossing-over firmness factor, Doubled yarns, Fabric firmness factor, Floating yarn factor, Geometrical parameters

1 Introduction

Doubling is a value addition process which enhances the strength and uniformity. The textile and apparel industries have been benefitted by the use of doubled yarn in 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 use them to maximum extent. Designers of fabric products also look to be benefited from the doubling of compact yarns.

Coulson and Dakin[1] were the pioneers in investigating the properties of two fold yarns. The world-wide consumption of two fold staple yarns is next to single ring spun yarns and exceeds that of rotor yarns. As 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] have 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 has led to a slight drop in shear rigidity and higher air permeability of fabrics. Thus, the effect of doubled yarn structure on the properties of fabrics has been examined.

The subject of air permeability has attracted the attention of many research workers. These studies have addressed the relationship between air permeability and structural properties of fabrics, namely mass per unit area, fabric thickness, and porosity, type of yarn and finishes but without weave parameters. Generally, it has been found that as fabric mass and thickness increase, air permeability decreases. Subramaniam *et al*.[3] have studied the air permeability of blended non-woven fabrics. The subject of air permeability has also been studied by Debnath *et al*.[4]. They stressed the importance of porosity in predicting air permeability of nonwoven fabrics. The prediction of air permeability by a model was done by Saldaeva[5] of Nottingham University, considering the use of a commercial finite element package. A CFD model using CFX 10, was developed for predicting air permeability. Fatahi and Yazdi[6] were the first research workers to correlate weave parameters to air permeability; they have predicted air permeability from weave structure by multiple regression equations. They have not given any data on FFF (fabric firmness factor), mass per unit area,

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thickness and porosity which also have a significant effect on air permeability.

Prediction of air permeability by neural network has been carried out by Tokarska[7] and Debnath *et al*[8]. Recently, Afzal *et al*.[9] have carried out an extensive study on air permeability of polyester cotton blended interlock knitted fabrics. They found that fabric thickness and areal density significantly affect the air permeability. Fatahi and Yazdi[6], using the parameters CFF (crossing over firmness factor) and FYF (floating yarn factor), have predicted air permeability of woven fabrics. They have not calculated 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 on air permeability was also investigated by Cheng and Cheung[10]. Kane *et al*[11] found that weft knitted fabrics made from compact yarns possess higher air permeability in comparison to those produced from conventional yarns.

Xiao *et al*.[12] have studied the importance of compression on through thickness and permeability in technical textile. They have studied the effect of low air pressure compression on thickness and permeability. The effect of air pressure drop on thickness was investigated. Fabric permeability was shown to be highly related to thickness. Air permeability has also been predicted by porosity measurement. Hydraulic and diameter of pores, the number of macro pores and the total porosity of woven fabrics were considered. Rombaldoni *et al*.[13] have dealt with the effect of carbon dioxide dry cleaning on air permeability of men's suiting. Zhu *et al*.[14] have studied the air permeability and thermal resistance of textile under heat convection. A newly developed device was used for evaluating the thermal resistance of textiles. It has been shown that with the increase in pore size and the ratio of pore area to total area of fabric, the air permeability increases and thermal resistance decreases. Pore size and the ratio of pore area have a significant effect as compared to porosity value. Angelova *et al*.[15] discussed the computational modeling and experimental value of the air permeability of woven structure on the basis of 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 values and the simulated values was noted.

Air permeability of multi layer cotton fabrics, as affected by structure and yarn colour has been studied by Urbas[16] It has been 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 has been studied by Wehner *et al*.[17] It was found that fabric structure, number of bonding points, yarn twist and yarn cross over points affect the air permeability of woven and non-woven fabrics. Xiao *et al*.[18] have stressed the importance of 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 characterize dynamic air permeability has been developed. Backer[19] was the pioneer who emphasized the role of interstices on air permeability of fabrics. He has calculated minimum horizontal pore areas and then related them to air permeability of fabrics. Backer's work remains as a precursor to air permeability studies of fabrics.

Many studies have been focused on the air permeability of knitted fabrics, which underline the importance of fabric mass, thickness and porosity[20]. A novel approach for measuring the air permeability of air bags by shock weaves which are reflected by fabric structure is discussed by Wang *et al*.[21].

In this paper, study on the effect of weave parameters, such as CFF (crossing over firmness factor), FYF (floating yarn factor), FFF (fabric firmness factor) and fabric geometrical properties, namely, areal density, thickness and porosity on air resistance has been reported. Earlier work by Fatahi and Yazdi[6] on air permeability was conducted only considering CFF and FYF, the FFF was not computed in view of its complexity. The present work includes this parameter (FFF) for relating it to air resistance of woven fabrics for the first time and reports the results.

2 Materials and Methods

Compact spun yarns (60s Ne) were produced from the cotton mixing and they were doubled. Table 1 shows the properties of single and doubled yarns.

2.1 Fabric Production

Eleven fabric samples, which were identical in warp and weft sett but different 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 (Fig. 1). While the plain weave has more interlacement of warp and weft yarns, the 2/2 weave have ridges on the fabric surface and the 8 thread weft sateen has weft floats. Crepe weave is a derivative of the plain weave.

Table 1 — Single yarn properties

Parameters	Single yarn	Doubled yarn
Count, tex	9.74	19.08
Twist, TP/cm	12.71	9.27
Twist multiplier ($tex^{0.5}$ × twist / cm)	39.66	40.92
Unevenness level %	11.13	9.92
Thin (-50%) km^{-1}	8	0
Thick (+50%) km^{-1}	65	17.5
Neps (+ 200%) km^{-1}	145	62.5
Hariness	3.11	5.42
CV % (Hairiness)	5.99	6.9
Strength (cN)	175.5	318.9
CV % (Strength)	9.2	6.9
Elongation, %	4.07	4.37
CV% (Elongation)	9.1	7.3
RKM	18.35	17.11

2.2 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 of 1.2%, wetting agent of 0.5 %, lubricant oil of 0.3%, stabilizer (sodium silicate) of 0.2%, at 90^0 C for 45 min.

2.3 Test Methods

Porosity

All the tests were carried out at 65% RH ±2%, and 25ºC±2 ºC. The porosity of cotton fabric was determined using the following equation:

$$\text{Porosity (\%)} = 1-\frac{\rho_{fab}}{\rho_{fib}},$$

where ρ_{fab} is the fabric bulk density; and ρ_{fib}, the fibre density of cotton which is 1.55 g/c (ref. 22).

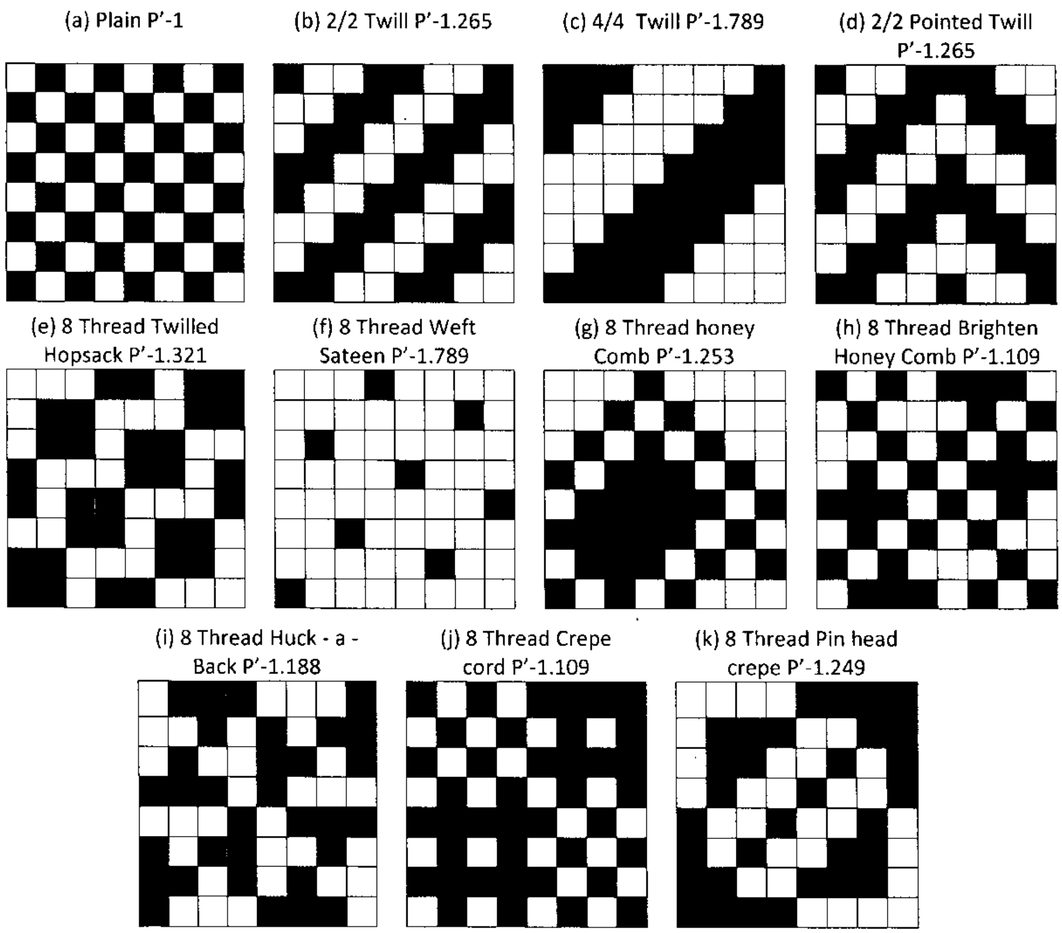

Fig. 1 — Weave structures with weave factor

Bulk density of the fabric was calculated using the following equation:

$$\text{Fabric bulk density (g/cm}^3\text{)} = \frac{\text{GSM/10000}}{\text{Thickness of fabric, cm}}$$

Thickness, GSM and Air Resistance

Thickness was measured on thickness tester using ASTM D1777 standards. GSM (gram per square meter) was measured by using ASTM D3776 standards. Air resistance was measured by KES – F8 API air permeability tester which is a constant rate of air flow with different pressure measurement method. Testing was performed according to ASTM D737 standards . The mean of five readings was taken for each fabric in bleached state.

2.4 Parameters of Weave Structures

Crossing-over Firmness Factor

Crossing-over firmness factor (CFF) is defined as under:

$$\text{CFF} = \frac{\text{Number of crossing over lines in complete repeat}}{\text{Number of interlacement point in complete repeat}}$$

Ogawa[23] originally coined this term. However, it was not clearly understood for further investigation. In order to obviate this, Morino *et al.* [24] redefined the CFF, as under:

CFF= N_c/N_i

where N_c is the number of crossing-over lines in the complete repeat ; and N_i , the number of interlacing points in the complete repeat

Details of CFF for plain weave structure are shown in Fig. 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 and four interlacing points. Hence, CFF becomes 2.

Floating Yarn Factor

The floating yarn factor (FYF) is defined as follows:

$$\text{FYF} = \frac{(\text{Type}_{1\sim IX} - 1) \times (\text{Existing number of type}_{1\sim IX}\text{ in complete repeat})}{\text{Number of interlacement point in complete repeat}}$$

FYF evaluate the length of parts of floats. Details of floating yarn are given in Fig. 3.

Fabric Firmness Factor

Fabric firmness factor (FFF) was computed using the following formula:

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

where $\rho = \frac{S_1\rho_1 + S_2\rho_2}{S_1 + S_2}$; $T_{av} = \frac{S_1T_1 + S_2T_2}{S_1 + S_2}$;

T_1, T_2 and T_{av} are the warp count, weft count and average count in tex respectively; P_1, the Milasius weave factor[25,26]; ρ, the fibre density; and S_1 & S_2 the ends and picks per decimeter respectively.

Weave Factor

Weave factor (P) represents the number of interlacements of warp and weft which are obtained from weave matrix. FYF proposed by Morino *et al*.[24] can be taken as a measure of floats in the fabric. It has a high correlation with weave factor. Since the calculation of weave factor is quite complicated, it was calculated by software [http://www.textiles.ktu.lt/Pagr/En/Cont/pagrE.htm][27].

3 Results and Discussion

The fabric geometrical properties and weave structures are given in Table 2. The fabrics have been divided into four groups (Table 3) according to their CFF and FFF values. Each group is characterized by a particular effect such as no floats, short floats, bigger floats and biggest floats. Group 1 fabrics have high CFF 2.00 and FFF 0.49, group 2 fabrics having CFF

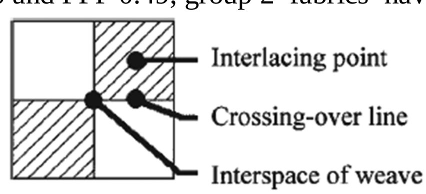

Fig. 2 — Details of CFF

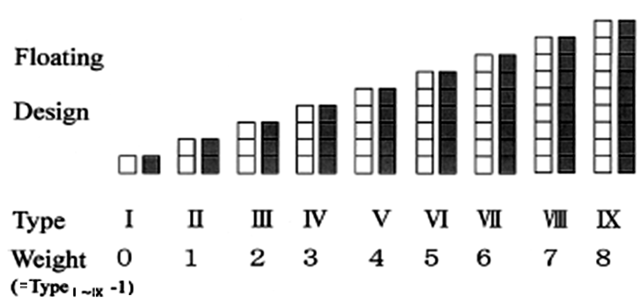

Fig. 3 — Details of FYF

Table 2 — Fabric particular [Warp and weft count 19.08, tex]

Fabric	Ends / cm	Picks /cm	GSM	Thickness cm	Porosity %	CFF	FYF	FFF	Weave factor (P')	Air resistance kPa.s/m
Plain	22	23	112	0.034	77.78	2.00	0.00	0.49	1.00	0.073
2/2 Twill	23	25	144	0.044	77.98	1.00	1.00	0.4	1.265	0.05
4/4 Twill	23	24	128	0.047	81.69	0.50	1.50	0.28	1.789	0.03
2/2 Pointed twill	23	23	140	0.047	80.31	1.00	1.00	0.39	1.265	0.05
8 Thread twilled hopsack	23	24	120	0.047	83.12	1.00	1.00	0.38	1.321	0.027
8 Thread weft Sateen	22	22	124	0.051	83.79	0.50	1.50	0.27	1.789	0.02
8 Thread honey comb	23	20	108	0.048	87.88	1.19	0.81	0.37	1.253	0.03
8 Thread brighten honey comb	22	23	108	0.059	87.71	1.50	0.50	0.44	1.109	0.03
8 Thread huck - a – back	22	22	116	0.055	85.84	1.25	0.75	0.4	1.188	0.033
8 Thread crepe cord	23	23	152	0.058	82.65	1.50	0.50	0.44	1.109	0.04
8 Thread pin head crepe	22	22	148	0.048	79.61	1.13	0.88	0.38	1.249	0.02

Table 3 — Grouping of Fabric [Warp and weft count 19.08, tex]

Group	Fabric	GSM	Thickness cm	Porosity %	CFF	FYF	FFF	Weave factor (P')	Air resistance kPa.s/m
Group 1	Plain	112	0.034	77.78	2.00	0.00	0.49	1	0.073
	8 Thread brighten hony comb	108	0.059	87.71	1.50	0.50	0.44	1.109	0.03
Group 2	8 Thread crepe cord	152	0.058	82.65	1.50	0.50	0.44	1.109	0.04
	2/2 twill	144	0.044	77.98	1.00	1.00	0.40	1.265	0.05
	2/2 Pointed twill	140	0.047	80.31	1.00	1.00	0.39	1.265	0.05
	8 Thread twilled hopsack	120	0.047	83.12	1.00	1.00	0.38	1.321	0.027
	8 Thread Pin head crepe	148	0.048	79.61	1.13	0.88	0.38	1.249	0.02
	8 Thread honey Comb	108	0.048	87.88	1.19	0.81	0.37	1.253	0.03
Group 3	8 Thread huck - a - back	116	0.055	85.84	1.25	0.75	0.4	1.188	0.033
	4/4 Pointed twill	128	0.047	81.69	0.50	1.50	0.28	1.789	0.03
Group 4	8 Thread weft sateen	124	0.051	83.79	0.50	1.50	0.27	1.789	0.02

1.5 and FFF 0.44, group 3 fabrics have CFF 1 - 1.25 and FFF 0.37 - 0.40 and group 4 fabrics have CFF 0.5 and FFF 0.27 - 0.29.

It is evident that lower CFF and FFF are associated with lower value of air resistance. Table 4 gives the correlation coefficient between weave parameters and air resistance as well as between fabric geometrical properties and air resistance. It can be observed that there exists a significant correlation between CFF and air resistance. Also, the correlation between FFF and air resistance is highly significant and correlation between fabric thickness and air resistance is also good and significant.

Another interesting observation is the highly significant correlation between CFF and FFF, as both parameters give the same information. This is in substantial agreement with the findings of Sankaran and Subramaniam[28]. Since the correlation between CFF and air resistance is greater than thickness that the correlation between thickness and air resistance, the prediction of air resistance can be made well by using CFF. The correlation between porosity and air resistance is poor. With the exception of plain weave, in all other cases the values of air resistance are low. This shows that floats in the fabrics cause a reduction in air resistance. The bigger the value of FYF, the longer is the floats and vice-versa. Since the correlation between CFF and FFF is positive and is highly significant, both can be considered for grouping the samples.

Thus, air resistance can be predicted from the CFF, FYF and FFF in view of their higher correlation with the air resistance. Correlation between FYF and weave factor is found to be high and significant (0.919).

Table 4—Correlation matrix

Property	Air Resistance	Thickness	GSM	Porosity	CFF	FYF	FFF	Weave factor
Air Resistance	1.000							
Thickness	-0.615*	1.000						
GSM	0.041	0.078	1.000	-0.550				
Porosity	-0.589	0.775**	-0.550	1.000				
CFF	0.613*	-0.138	-0.212	-0.074	1.000			
FYF	-0.616*	0.138	0.215	0.072	-1.000**	1.000		
FFF	0.634*	-0.118	-0.058	-0.153	0.960**	-0.959**	1.000	
Weave Factor	-0.524	0.028	0.054	0.063	-0.920**	0.919**	-0.978**	1.000

*Significant at 0.05 level (2-tailed).
**Significant at 0.01 level (2-tailed).

4 Conclusion

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. The weave parameters CFF, FYF and FFF are significantly correlated to air resistance of the fabrics. Fabrics with longer floats have lower air resistance in comparison to the fabrics having shorter floats and no floats at all, such as 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 (CFF, FYF and FFF), thickness should also be taken into consideration for designing the fabrics for the application areas, such as air bags and filtration fabrics.

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