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Effect of Weave Structures on the Low Stress Mechanical Properties of Woven Cotton Fabrics

Abstract
The introduction of parameters such as CFF (crossing over firmness factor) FYF (floating yarn factor) and FFF (fabric firmness factor) by research workers to represent fabric structures has improved our understanding of them. In this study two groups of fabrics comprising different weaves with the same warp and weft count and sett were produced. Five fabrics in the first group and eleven fabrics in the second group were considered. The fabrics were evaluated for low stress mechanical properties, and correlation coefficients were calculated between the various parameters and properties. While the results showed that the correlation between shear, crease recovery, tensile, and air permeability was very good, the correlation between the hand value and parameters was poor. Bending rigidity and hysteresis were well correlated with the parameters in the second group of fabrics. The correlation between CFF and FFF is found to be excellent in both groups.

Key words: *crossing over firmness factor, floating yarn factor, fabric firmness factor, correlation, weave structure, low stress mechanical properties, cotton fabrics.*

Introduction

The structural design of a textile fabric is largely dictated by its end-use application. In the case of apparel and household fabrics, subjective factors such as drape, handle, wrinkle recovery, crease resistance, pilling, texture and softness are important. Consequently the rational design of apparel and household fabrics involves an understanding of the mechanical properties that control these subjective characteristics and their correlation with end-use performance.

Goswami [1] studied the shear behaviour of cotton polyester blended fabrics which had plain, basket and satin structures. He found that the yarn float length and yarn twist had a significant effect on the shear behaviour. It is a well known fact that weave structure affects most of the mechanical properties of woven fabric. Although some isolated studies were made in the past to correlate the weave structure to the mechanical properties of woven fabrics, they were incomplete and did not provide any useful information. With the introduction of parameters such as the Crossing over Firmness Factor (CFF) and Floating Yarn Factor (FYF), as suggested by Matsudaira [2], our understanding of fabric structure has improved. Milasius [3] suggested a parameter called the Fabric Firmness Factor (FFF), which takes into account both weave and sett. Matsudaira's parameters do not consider fabric sett. Although work on this aspect

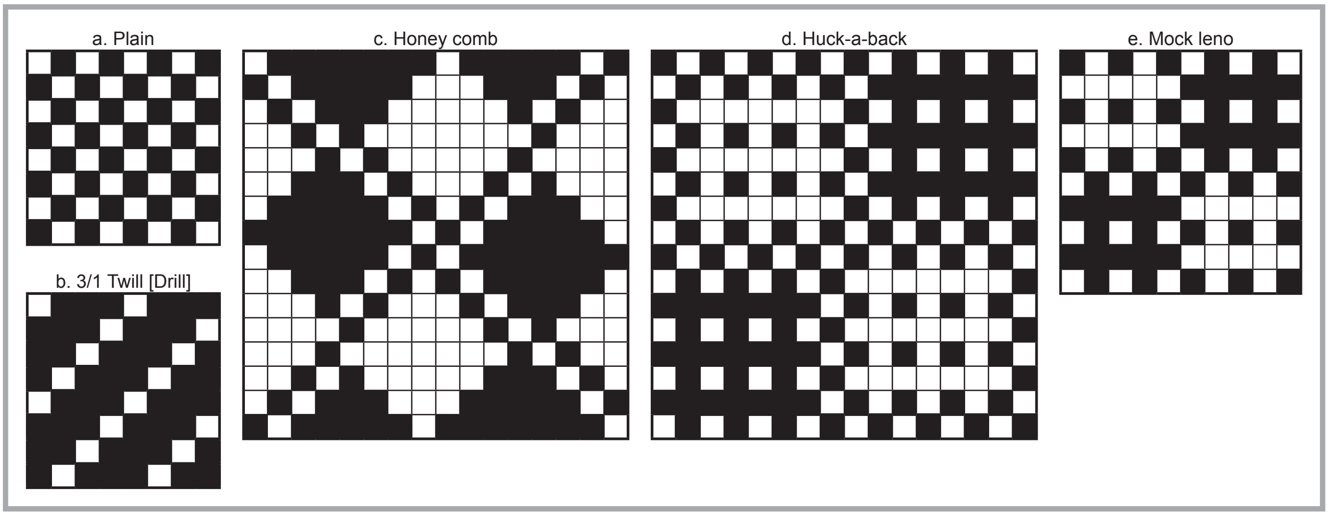

Figure 1. *Weave structures of group 1.*

Table 1. *Details of fabics of group 1.*

#	Weave cotton	Linear density		Ends and picks per decimeter		Yarn structure
		warp, tex	weft, tex	Ends → S_1	Picks → S_2	
a	Plain	59.05	59.05	157.5	157.5	2 fold
b	3/1 Twill [Drill]					
c	Honey comb					
d	Huck-a-back					
e	Mock leno					

was carried out by Hitomi Marino and Mitsuo Matsudaira [2], this was found to have limitations, which were pointed out by Milasius. Matsudaira [2] admitted the drawbacks in his paper and mentioned that further work in this area was desirable.

There are seven major parameters of a fabric structure which affect the properties. These are the type of fibre, warp and weft sett, the warp and weft linear density of the yarn and the fabric weave. Milasius took into account all these factors while suggesting integrated fabric structure factors. The weave factor has been found to affect fabric weaveability [4], the beat up force [5], fabric breaking force, the elongation [6] at break, fabric breakage and the relation [7] between raw materials [8] used and the fabric structure factor [9]. Padaki et al. [10] proposed the interlacement index and float index to quantify the structural influence of multilayer interlocked woven fabrics. Chen and Liu [11] have recently used the fabric firmness factor for relating fabric structural properties to the surface structure of silk fabrics. This paper is concerned with the effect of weave structures on the mechanical properties of fabrics using the parameters suggested by Matsudaira and Milasius.

Materials and methods

Two groups of fabrics were considered. In the first group 2/29.5 tex yarns were used in the warp and weft and woven on an automatic loom. The five fabric samples with different weave structures included a plain weave, 3/1 twill weave, Honey comb weave, Huck a back weave and Mock leno weave. All the fabrics had the same yarn and weave densities. The same finishing conditions were used. The weave structures of the samples included in group 1 are shown in ***Figure 1.***

Fabric structural parameters are given in ***Table 1***.

The second group consisted of eleven samples with different weave structures, woven on the same automatic loom. These are plain, 2/2 twill, 4/4 twill, 2/2 pointed twill, 8 thread hopsack, 8 thread weft sateen, 8 thread honey comb, 8 thread brighton honey comb, 8 thread huck-a-back, 8 thread crepe cord & 8 thread pin head crepe.

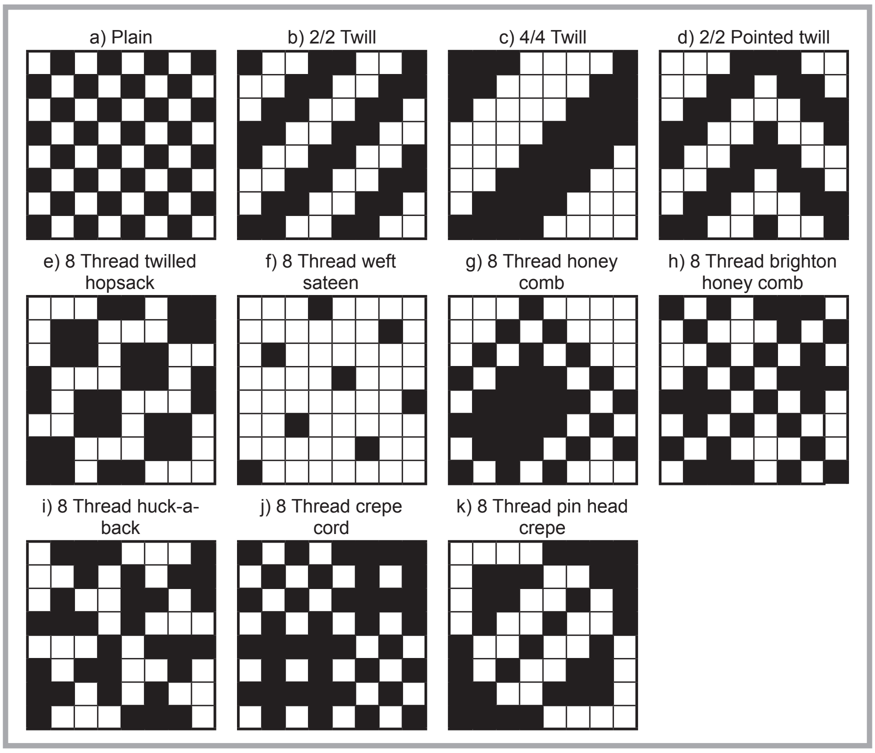

Figure 2. *Weave structures of group 2.*

Table 2. *Details of fabics of group 2.*

#	Weave cotton	Linear density		Ends and picks per decimeter		Yarn structure
		warp, tex	weft, tex	Ends → S_1	Picks → S_2	
a	Plain			210	220	
b	2/2 Twill			220	240	
c	4/4 Twill			210	220	
d	2/2 Pointed twill			220		
e	8 Thread twilled hopsack				230	
f	8 Thread weft sateen	30	30		210	Two fold
g	8 Thread honey comb			210	190	
h	8 Thread brighton honey comb				220	
i	8 Thread huck-a-back				200	
j	8 Thread crepe cord				210	
k	8 Thread pin head crepe			220		

2/14.75 tex cotton yarns were used in the warp and weft. The same finishing treatment was used on all the fabric samples so that comparison with weave structures was made possible. Thus two counts, one coarser and the other fine, were used.

The weave structures of the samples included in group 2 are shown in ***Figure 2***. Fabric structural parameters are given in ***Table 2***.

Determination of the parameters of the weave structures

Crossing over firmness factor (CFF)

This, as defined by Morino et al [1], is given by the following formula:

$$CFF = Nc/Ni \qquad (1)$$

where

Nc - Number of crossing-over lines in the complete repeat,

Ni - Number of interlacing points in the complete repeat.

Figure 3 gives details of a plain weave and its CFF.

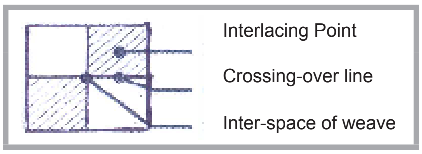

Figure 3. *Complete repeat of one pain weave.*

*Table 3. Correlation Coefficient of Group 1 Samples; * Significant at 1% level.*

Property	CFF	FYF	FFF
GSM	-0.5016	0.44863	-0.76209
Flexural rigidity	0.3219	-0.36598	-0.02493
Bending rigidity	-0.2828	0.244039	-0.5112
2HB	0.14679	-0.16292	0.037228
2HB/B	0.1248	-0.09092	0.361459
Air permeability	-0.5404*	0.503927*	-0.70321*
Drape coefficient	0.4418	-0.50001*	0.00817
Bursting strength	-0.3915	0.372745	-0.40298
Crease recovery	-0.9513*	0.923385*	-0.96841*
Shear by bias extension method	0.8222*	-0.82908*	0.650427*
Kawabata shear tester	0.9748*	-0.97705*	0.811077*

*Table 4. Correlation coefficient of group 2 samples; *significant at 1% level.*

PROPERTY	CFF	FYF	FFF
Tensile			
LT	0.512	-0.497	0.528
WT	0.674*	-0.642*	0.661*
RT	-0.507	0.485	-0.563
EMT	0.407	-0.378	0.374
Bending			
B	0.659*	-0.678*	0.514*
2HB	0.763*	-0.779*	0.614*
Shearing			
G	0.644*	-0.654*	0.581*
2HG	0.673*	-0.682*	0.612*
2HG5	0.659*	-0.669*	0.608*
Compression			
LC	0.142	-0.19	0.042
WC	-0.127	-0.094	0.306
RC	0.011	-0.09	-0.09
Surface Properties			
T	-0.117	-0.118	-0.354
MIU	0.9	0.12	-0.058
MMD	0.505	-0.499	0.153
SMD	0.37	-0.321	-0.118
Weight	0.134	0.145	-0.02
THV	0.074	-0.11	0.357

Table 5. Results of CFF, FYF and FFF relative humidity for group 1 fabrics.

#	Weave	CFF	FYF	FFF
a	Plain weave	2.00	0.00	0.60
b	3/1 twill	1.00	1.00	0.45
c	Honey comb	0.875	1.125	0.42
d	Huck a back	1.44	0.56	0.53
e	Mock leno	1.36	0.64	0.52

Table 6. Results of CFF, FYF and FFF calculated for group 2 fabrics:

#	Weave	CFF	FYF	FFF
a	Plain weave	2.00	0.00	0.59
b	2/2 Twill	1.00	1.00	0.50
c	4/4 Twill	0.50	1.50	0.33
d	2/2 Pointed twill	0.969	1.031	0.46
e	8 Thread twilled hopsack	1.00	1.00	0.60
f	8 Thread weft sateen	0.50	1.50	0.32
g	8 Thread honey comb	1.188	0.812	0.43
h	8 Thread brighton honey comb	1.50	0.50	0.53
i	8 Thread huck-a-back	1.25	0.75	0.47
j	8 Thread cord crepe	1.50	0.50	0.52
k	8 Thread pin head crepe	1.125	0.875	0.47

Floating yarn factor (FYF)

This is defined as follows:

$$FYF = ((Type_{I\sim IX} - 1) \times En)/Ni \quad (2)$$

where En - existing number of $type_{I\sim IX}$ in the complete repeat.

Fabric firmness factor (FFF)

This is calculated using the formula given by Milasius [2]:

$$\varphi = \sqrt{\frac{12}{\pi}}\frac{1}{P'}\sqrt{\frac{T_{average}}{\rho}} \times S_2^{\frac{1}{1+2/3\sqrt{T_1/T_2}}} S_1^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}} \quad (3)$$

where T_1, T_2 and $T_{average}$ are, respectively, the warp count, weft count and average count in Tex. P' is the Milasius weave factor and ρ is the fibre density. S_1 & S_2 are the ends and picks per decimeter.

Low stress mechanical properties

The low stress mechanical properties such as tensile, bending, shearing, compression, and surface properties were measured by the KES-FB system while maintaining standard atmospheric conditions, namely 25 ± 2 °C and 65 ± 2% relative humidity. For the first group of samples the bending rigidity by cantilever, air permeability, drape, bursting strength and crease recovery properties were also measured. In addition to measuring shear properties by Kawabata's shear test, they were also measured using bias the extension method, as suggested by Buckenham [12].

Results and discussion

Table 3 gives the correlation coefficient between mechanical properties and the weave parameters of group 1 samples, and ***Table 4*** shows the correlation coefficient between mechanical properties and the weave parameters of group 2 samples.

In the case of group 1 fabric samples, CFF gives an indication of the frequency of interlacing yarn. It is apparent that plain weave shows a higher value of CFF and honey comb a lower value. The Milasius [3] fabric firmness factor also shows the same trend, although the methods of calculation are quite different.

Table 7. *Variations in FFF.*

#	Count, tex		Picks per dm	Weave	FFF
	Warp	Weft			
1	30	30	126.0	Plain	0.53
2			141.7		0.57
3			149.6		0.59
4			157.5		0.60
5			173.2		0.64

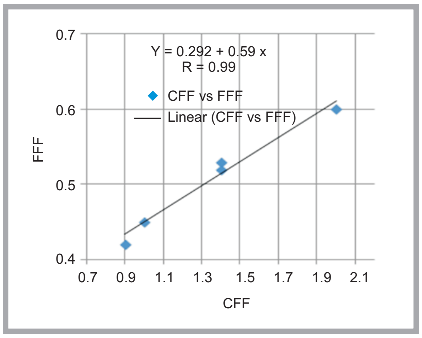

Figure 4. *Correlation between CFF & FFF for group 1.*

In the case of group 2 fabrics, the same trend has been noticed. The fabric firmness factor is likely to be different since it takes into account fabric sett. It is interesting to note that the addition of CFF and FYF is 2.

It is noticed that the correlation between CFF (crossing over firmness factor) and the crease recovery shear is high and significant for group 1 samples. The correlation between air permeability and the weave parameters is also high and significant. Since CFF & FYF are interrelated in the sense that the sum of these two parameters is 2, the correlation between the floating yarn factor (FYF) and mechanical properties is negative. Thus the correlation between FYF and the mechanical properties is a mirror image of CFF and other properties. Since shear parameters are relevant to technical textiles, particularly in designing them for end uses such as conveyor belts and sail cloth, this correlation between the various weave parameters and properties will assist a great deal. Moreover since the shear parameters correlate well with the CFF & FFF in both the groups, it is considered to be a very critical parameter for woven fabric. This also means that it will suffice if shear and bending parameters are measured for correlating weave structures to mechanical properties. This also shows that the models which have been developed for predicting the shear properties of fabrics by Leaf & Sheta [13], Grosberg, Leaf and Park [14] have to be modified in view of the good relation between the weave structure and shear. As regards group II samples, again it is noticed that the correlation between tensile energy (WT) and the weave parameters is significant. Also bending and shearing properties correlate well with the weave parameters. This again shows that it is possible to predict these properties precisely. The presence of floats in fabrics is responsible for the decrease in shear parameters.

Table 5 gives the CFF and FYF values of group 1 fabric samples, and ***Table 6*** gives the CFF and FYF values of group 2 fabric samples.

Since the correlation between CFF and FFF for both the groups is very high, it can be concluded that this relationship is independent of the counts and sett used. The influence of fabric sett on the fabric integrated factor shows that the variations in this parameter are significant, as ***Table 7*** demonstrates.

An examination of the data given in ***Table 7*** shows that there is a 20% increase in FFF at a pick density of 173.2 in comparison with 126. In view of the above, it is felt that Milasius' method of representing fabric structure is desirable and can be used for quantifying the fabric properties.

The correlation between CFF & FFF is excellent, as noticed in ***Figure 4***.

Conclusions

There exists a positive correlation between CFF and bending and shear properties. The same comments hold good for FYF and mechanical properties also. Most of the correlation coefficients are in line with FYF and CFF. As the float length increases, the shear rigidity decreases, and the converse is true for CFF. These are in agreement with the findings of Morino and Matsudaira. It is interesting to note that the correlation between the weave parameters and compression and surface properties is very poor. THV and surface parameters have very poor correlation with weave parameters. Tensile properties, save in one or two cases, also bear very little relation with weave parameters. The above findings show that bending and shearing parameters can only be predicted with the weave structures. With an increase in float length, the bending and shear rigidities show a decrease. Milasius's parameter merits consideration as it includes fabric sett. Matsudaira's parameter can be used as it is quite simple to compute for fabrics. Shear parameters are found to be independent of the yarn count used in the current study and are highly dependent on CFF & FFF, which will suffice if only the shear and bending parameters of fabrics are determined. Fabrics become soft with a larger value of FYF.

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