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The Bending Properties of Some Punto-Di-Roma Wool Fabrics

by

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ABSTRACT

Seventeen wool lots, varying greatly in physical properties, were processed into Punto-di-Roma fabrics. Samples of each fabric were then subjected to cyclic bending experiments. The data collected were then converted into hysteresis curves from which some visco-elastic and other bending parameters were obtained. The fabric bending parameters were related to the fibre properties with the aid of multiple regression analyses and significant differences were found between the trends for the courses and wales. In the latter case, mean fibre diameter and fabric thickness, played equally significant rôles in determining the bending characteristics whilst in the former, fabric thickness was the most important. Bulk resistance to compression was found to play only a minor rôle. Comparisons with the flexural rigidities of the fabrics and also of some plain weave fabrics processed from the same wool lots were made. Significant differences were found in the responses of the knitted and woven fabrics to bending stresses, and these were explained in terms of fabric geometry.

INTRODUCTION

Effort has been directed towards the elucidation of the interrelationships between wool fibre and fabric properties[1-3]. The complex nature of the work however, and the fact that a natural fibre, with all its uncontrolled variability, is being studied, made it difficult to identify trends and to separate the effects of the various fibre properties. In an attempt to rectify this situation, SAWTRI, in 1976, embarked on a comprehensive study of a variety of knitted and woven fabrics[4-7] produced from a large number of wool lots.

These studies covered virtually all the commonly measured fabric physical properties, but little effort was made to elucidate the mechanisms responsible for the observed trends in fabric bending and wrinkling on one hand and fibre properties on the other. In these studies, the fabric bending length was measured by the cantilever method, and from this the fabric flexural rigidity was calculated[8]. In so doing, no allowance was made for the visco-elastic aspect of bending[9], making it impossible to carry out a complete analysis of the bending mechanism. Livesey and Owen[10], developed a procedure in which a fabric sample is taken through a slow stress/strain cycle, and from the hysteresis observed, the visco-elastic bending parameters could be determined (see Fig. 1). The various hysteresis characteristics and their significance was the subject of a previous report[11]. In this present report, the more fundamental fabric bending parameters have been measured on the Punto-di-Roma structures and related to the fibre properties so as to understand better the effect of the fibre properties on the fabric bending properties.

EXPERIMENTAL

Some 17 lots of wool varying greatly in diameter, length and crimp were spun into 25 tex Z610 yarns (see Table I), which were then knitted into a Punto-di-Roma structure at a machine tightness factor of 15 and a run-in-ratio of 1,5:1. After dry cleaning at 40°C, they were dried at 80°C, autoclaved (2 min. vacuum — 5 min. steam at 100°C — 2 min. vacuum) and finally decatised (3,5 min. steam — 5 min. cooling).

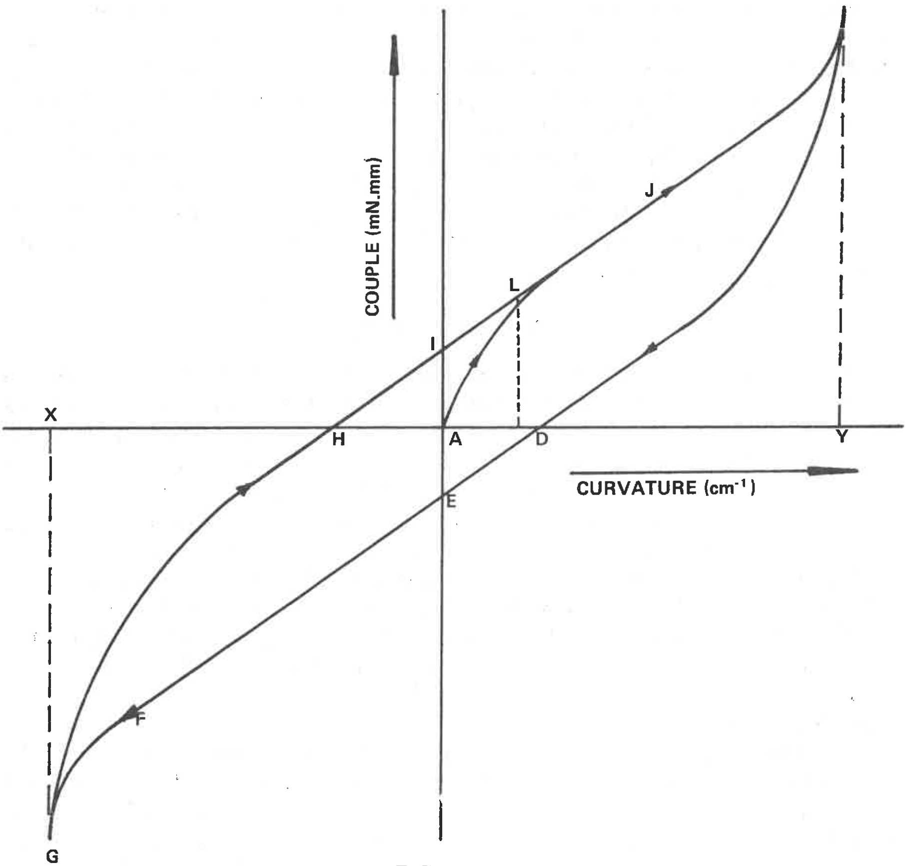

FIGURE 1
A typical hysteresis curve and definitions of associated fabric bending parameters

Fabric bending parameter	Definition	Symbol
Bending axis parallel to the courses	An axis of bending causing distortion of the wales	
Bending axis parallel to the wales	An axis of bending causing distortion of the courses	
Fabric resistance to bending	IE/2	C_o
Initial Flexural rigidity	Ratio of couple to curvature at L, (curvature 0,2 cm^{-1})	G_i
Lower curvature Flexural rigidity	Mean slope of DF and HJ	G_o
Final Flexural rigidity	Mean slope of JK and FG	G_ϕ
Residual curvature	HD/2	R_b
Hysteresis loss	Area of Loop	H_i

Hysteresis curves (see Fig 1) were obtained on three samples of each fabric according to the procedure developed by Livesey and Owen[10]. The data so obtained, were analysed by means of a computer programme which reproduced the hysteresis loops, and from them calculated the bending parameters.

Multiple regression analyses of the logs of the bending parameters were carried out on each fabric according to the following routine:

(a) Fabric property versus mean fibre diameter, CV of fibre diameter (CV_d), CV of fibre length (CV_L), mean fibre length, staple crimp, fabric mass and fabric thickness.
(b) Same as in (a) but replacing staple crimp by the bulk resistance to compression of a random mass of loose fibres[12].
(c) Fabric property versus mean fibre diameter and mean fibre length only.
(d) Same as in (a) but omitting fabric mass and fabric thickness.

RESULTS AND DISCUSSION

1. Correlation between fabric bending and wrinkling parameters

Details of the wool lots are given in Table I and the results obtained from the analyses of the hysteresis loops of the fabrics, are displayed in Tables II and III, together with the flexural rigidity (F) values obtained in earlier studies[14]. The coefficients of variation (CV) and the mean values of the results are also included.

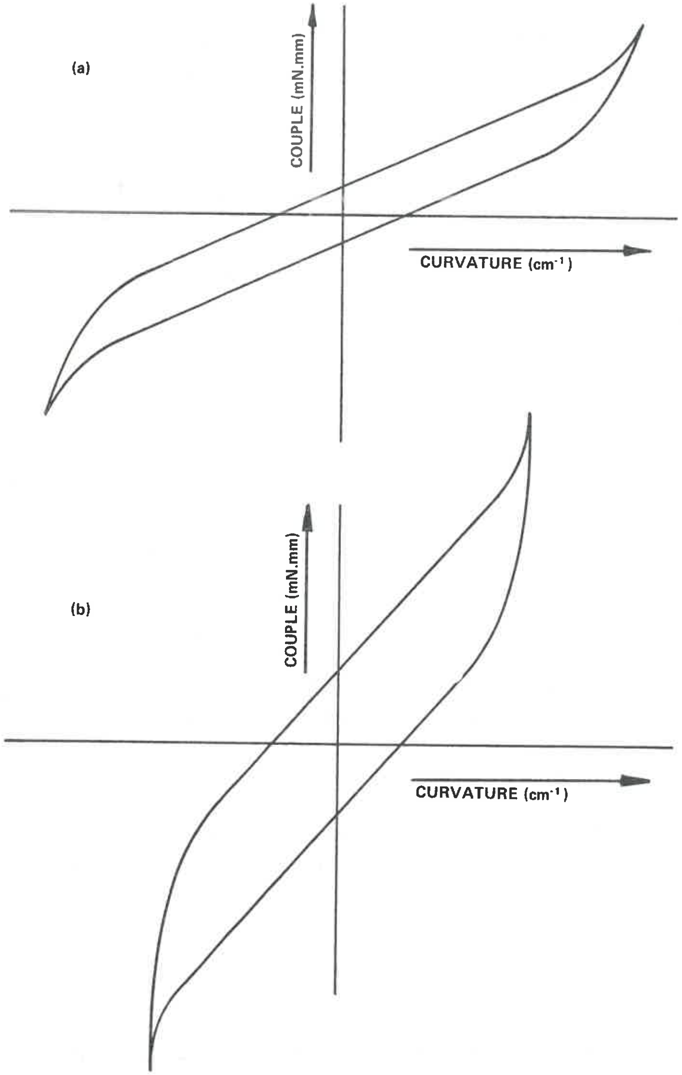

FIGURE 2

Typical bending hysteresis curves obtained for the Punto-di-Roma fabrics:

(a) Bending axis parallel to the wales

(b) Bending axis parallel to the courses

Figure 2 illustrates the different hysteresis curves obtained for bending of the courses and wales.

It is evident from Figure 2, and Tables II and III, that there is a significant difference between the bending mechanisms about the two principal axes. This feature, which has also been observed by others[13], is attributed solely to the different conformations of the loop geometry about the bending directions, and is characteristic of the behaviour of most weft knitted fabrics. For a bending axis parallel to the courses, bending is resisted by both the frictional and elastic components of the yarns and fibres, whereas in the alternative direction, the fabric distorts in a segmental fashion (i.e. by segmental movement of the yarns) resulting in a much lower fibre strain. Previous work on plain weave structures[11] showed no such trend, accentuating the rôle played by fabric construction in determining cloth bending properties and ultimately, qualities such as handle and drape.

TABLE I

DETAILS OF WOOL LOTS

Fabric No.	Mean Fibre Diameter of Tops (µm)	Fibre Length of Tops (mm)	CV of Fibre Length (%)	Staple Crimp (crimp/cm)	CV of Mean Fibre Diameter of Tops (%)	Resistance to Compression Tops[12] (mm)
BR						
3	22,4	84,3	37	3,5	22	16,8
6	20,8	75,9	42	4,5	20	19,3
8	24,3	75,9	44	4,1	22	19,0
15	19,2	69,7	42	6,2	21	21,7
16	25,4	82,7	34	2,5	22	14,8
21	21,7	80,0	41	3,8	18	14,6
24	26,5	67,6	47	2,6	23	14,2
25	24,6	70,5	41	3,3	18	14,6
26	22,5	64,5	49	5,7	20	22,1
27	22,3	69,1	48	5,2	19	20,4
28	24,7	76,5	44	3,0	22	14,7
33	24,1	64,7	40	5,9	19	21,1
35	21,1	60,1	48	5,9	22	22,5
42	19,6	70,9	40	4,1	23	14,0
44	23,2	68,1	34	3,0	24	14,8
52	19,0	68,9	31	4,5	23	15,0
57	18,5	62,5	43	6,0	23	20,3

TABLE II

NUMERICAL VALUES OF PARAMETERS MEASURED FROM THE HYSTERESIS CURVES OF THE PUNTO-DI-ROMA FABRICS FOR COURSE WAY BENDING AND THE FLEXURAL RIGIDITY F

BR No.	Go (mN.mm)	Co (mN.mm)	K_r (cm^{-1})	G_i (mN.mm)	R_b (%)	Gø (mN.mm)	H_i (%)	Ss (mN.mm)	F_c (mN.mm)
3	9,7	3,2	0,33	19,7	80,0	9,9	22,9	12,9	8,8
6	8,5	2,6	0,31	18,8	83,0	8,6	21,1	11,1	11,0
8	9,3	3,0	0,32	19,6	81,6	9,5	22,3	12,3	10,2
12	7,2	2,3	0,32	15,2	83,2	7,9	20,6	9,6	7,7
15	12,5	3,2	0,26	25,5	83,5	12,0	20,7	15,7	9,6
16	8,3	2,8	0,34	19,1	81,6	8,0	22,9	11,1	15,8
21	7,2	2,8	0,39	14,7	79,8	7,3	23,8	10,0	6,9
24	12,7	3,9	0,31	24,4	79,9	12,2	24,6	16,6	12,5
25	8,9	2,8	0,31	13,4	82,7	8,9	22,0	11,7	10,2
26	8,2	2,5	0,31	15,3	83,4	7,5	21,7	10,7	9,9
27	7,1	2,3	0,32	16,9	83,5	7,6	21,1	9,4	9,5
28	9,6	2,8	0,30	22,4	83,0	10,1	21,8	12,4	12,3
33	9,4	2,8	0,30	20,8	82,9	10,1	21,0	12,2	10,4
42	5,8	2,3	0,40	14,7	80,4	6,0	22,8	8,1	5,1
44	9,9	3,0	0,30	19,2	82,4	9,8	22,6	12,9	10,9
52	6,6	2,6	0,40	15,6	80,3	6,7	23,9	9,2	5,3
57	7,8	2,9	0,37	18,4	80,2	8,1	24,7	10,7	7,6
Mean	8,8	2,8	0,33	18,5	81,9	8,8	22,4	11,6	9,6
CV	21,3	14,2	11,9	18,9	1,7	19,5	5,8	19,1	27,6

TABLE III

NUMERICAL VALUES OF PARAMETERS MEASURED FROM THE HYSTERESIS CURVES OF THE PUNTO-DI-ROMA FABRICS FOR BENDING IN THE WALE DIRECTION AND THE FLEXURAL RIGIDITY F

BR No.	Go (mN.mm)	Co (mN.mm)	K_r (cm^{-1})	G_i (mN.mm)	R_b (%)	G_ϕ (mN.mm)	H_i (%)	Ss (mN.mm)	F_w (mN.mm)
3	16,5	6,3	0,38	40,3	70,4	15,1	33,9	33,8	14,4
6	13,6	5,5	0,40	30,6	71,4	14,3	32,6	19,1	19,1
8	16,3	6,7	0,41	37,9	62,3	16,2	35,0	23,0	18,7
12	14,6	5,3	0,36	32,5	73,8	13,9	31,2	19,9	11,9
15	17,9	6,2	0,35	28,3	71,8	15,9	33,2	24,1	17,4
16	19,3	6,8	0,35	48,6	69,7	17,8	35,2	26,1	23,5
21	10,8	5,6	0,52	35,7	66,5	11,0	36,0	16,4	10,8
24	22,6	8,4	0,37	63,0	63,3	20,8	40,2	31,0	21,7
25	13,7	5,3	0,38	47,2	71,9	14,8	31,1	19,0	19,4
26	17,6	6,4	0,37	55,2	70,0	17,5	34,9	24,0	20,5
27	12,5	5,4	0,43	45,0	70,5	12,4	33,7	17,9	18,7
28	16,8	7,4	0,44	30,5	64,5	15,5	27,8	24,2	18,5
33	21,2	6,7	0,32	53,7	71,1	20,8	33,7	27,9	20,8
42	12,5	6,1	0,49	33,0	66,6	13,0	35,3	18,6	10,6
44	14,3	6,8	0,47	29,7	65,0	14,1	37,7	21,1	14,8
52	10,2	5,9	0,58	25,3	63,3	11,0	37,6	16,1	9,3
57	15,4	6,7	0,44	33,0	66,5	14,5	36,3	22,1	14,5
Mean	15,6	6,3	0,42	39,4	68,2	15,2	35,0	22,0	16,7
CV	21,9	13,0	16,6	27,7	5,3	18,6	7,0	18,5	25,5

TABLE IV

SUMMARY OF STATISTICAL ANALYSES OF THE PUNTO-DI-ROMA BENDING PARAMETERS (COURSES AND WALES)

Direction of bending	**Bending parameter**	**Contribution of each independent variable to the overall correlation (%)**								**Significant regression Equations****	**Correlation coefficient**	**% fit**
		X_1	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**	**X_7**	**X_8**			
Parallel to courses	Go (mN.mm)	30	ns	*	*	*	*	*	*	$1,93\ X_1^{1,1}$	0,55	30
		ns	ns	ns	41	13	ns	ns	*	$0,39\ X_4^{3,14}\ X_5^{0,67}$	0,74	54
	Gi (mN.mm)	49	ns	ns	ns	ns	ns	12	ns	$0,01\ X_1^{2,45}\ X_7^{0,44}$	0,78	61
	Gø (mN.mm)	37	ns	*	*	*	*	*	*	$0,67\ X_1^{1,0}$	0,60	37
		ns	ns	ns	43	13	ns	ns	*	$1,48\ X_4^{2,68}\ X_5^{0,56}$	0,75	56
	Kr(cm^{-1})	ns	ns	ns	37	15	ns	ns	*	$6,27\ X_4^{-2,14}\ X_5^{-0,56}$	0,72	52
		ns	ns	ns	34	ns	ns	ns	19	$2,59\ X_4^{-1,87}\ X_8^{-0,4}$	0,73	53
	Co (mN.mm)	27	ns	ns	ns	ns	45	ns	*	$0,06\ X_1^{0,61}\ X_6^{0,93}$	0,85	72
	R_b (%)	ns	ns	27	ns	ns	40	ns	*	$8,73\ X_3^{0,54}\ X_6^{-0,35}$	0,82	67
	Hi (%)	ns	ns	21	ns	ns	46	ns	*	$288,4\ X_3^{-0,62}\ X_6^{0,48}$	0,82	67
	S (mN.mm)	31	ns	*	*	ns	ns	ns	*	$1,23\ X_1^{0,93}$	0,56	31
		ns	ns	ns	38	ns	ns	ns	*	$8,89\ X_4^{2,36}$	0,62	38
Parallel to Wales	Go (mN.mm)	ns	ns	ns	30	ns	ns	*	ns	$3,48\ X_4^{2,4}$	0,55	30
		23	ns	*	*	*	*	*	*	$0,54\ X_1^{0,89}$	0,48	23
	Gi (mN.mm)	ns	ns	ns	26	ns	ns	*	ns	$8,53\ X_4^{2,01}$	0,51	26
	Gø (mN.mm)	ns	ns	ns	31	ns	ns	*	ns	$3,72\ X_4^{2,25}$	0,55	31
	Kr (cm^{-1})	ns	ns	ns	26	ns	ns	*	ns	$1,94\ X_4^{-1,24}$	0,51	26
	Co (mN.mm)	ns	ns	ns	ns	ns	ns	ns	*	—	ns	—
	R_b (%)	ns	ns	ns	ns	ns	ns	*	31	$69,18\ X_8^{0,06}$	0,55	31
	Hi (%)	ns	ns	ns	ns	ns	27	*	*	$8,5\ X_6^{0,32}$	0,52	27
		ns	ns	ns	ns	ns	ns	ns	31	$38,9\ X_8^{-0,19}$	0,56	31
	S (mN.mm)	ns	ns	ns	28	ns	ns	ns	*	$5,25\ X_4^{2,07}$	0,53	28

X_1 = Mean fibre diameter (μm)
X_2 = Mean fibre length (mm)
X_3 = Fabric mass (g/m^2)
X_4 = Fabric thickness (mm)

X_5 = CV of fibre length (%)
X_6 = CV of fibre diameter (%)
X_7 = Staple crimp (cm^{-1})
X_8 = Bulk resistance to compression

* = Variable excluded from analyses
ns = non-significant at the 95% level
** = All regression equations are significant at the 95 % level or better

As in the case of the woven fabrics, the initial flexural rigidity (G_i) exceeded both the final (G_0) and lower curvature (G_ϕ) flexural rigidities. This indicates that in the initial stages of bending, movement is impeded by frictional restraints which decrease on further bending. Furthermore, the differences between G_i wales and G_i courses show that bending in the former direction is far more restricted than in the latter, and as such, lends credence to the adopted theory of segmental movement used to explain the differences in the bending behaviour of courses and wales. Larger coercive couples (C_0), residual curvature (K_r), hysteresis losses (H_i) and poorer bending recoveries (R_b) for bending parallel to the courses endorse this fact.

When the flexural rigidities of the fabrics obtained from the cantilever method[4] were compared with the visco-elastic bending parameters, the two following significant relationships only were found:

$F_w = 0,62 \,.\, G_\phi^{1,2}$ with $r = 0,79$ for bending parallel to the courses
$(n = 17)$

and

$F_c = 1,33\, K_r^{-1,74}$ with $r = 0,68$ for bending parallel to the wales.
$(n = 17)$

The above indicates that bending parallel to the courses is influenced far more by the elastic nature of fibres compared with bending in the other direction, where, because of the interlocking loop geometry, little pressure to distort is put on the fibres themselves.

In a previous study, Hunter *et al*[14] determined the wrinkle recoveries of these fabrics by applying the Monsanto wrinkling test. When an analysis was carried out of their crease recovery angles (θ) and the results obtained from the present hysteresis experiments, the following three significant regression equations were found for bending parallel to the courses only.

	r.
$\theta = 6,25 \times 10^{-7} \,.\, Go^{3,3}$	0,47
$\theta = 7,763 \times 10^{4} \,.\, Kr^{-2,5}$	0,63
$\theta = 18,8\, R_b^{0,3}$	0,50

The absence of significant regression equations when fabrics are bent about an axis parallel to the wales complements the previous findings which confine the influence of fibre characteristics to bending of the courses only.

2. Correlations between fibre properties and bending properties

Table IV summarises the significant regression equations obtained from analyses of the bending properties as dependent variables and fibre properties as independent variables.

For the bending axis parallel to the courses, mean fibre diameter (MFD) and fabric thickness emerged as being equally significant, CV of fibre length playing only a minor rôle. The contributions of staple crimp and resistance to compression were almost negligible. By comparison, variations in fabric bending properties parallel to the wales were dependent mainly upon fabric thickness with bulk resistance to compression and CV of fibre diameter having a small but significant effect.

Two significant regression equations were obtained relating the final flexural rigidity (G_o) of the fabrics to the fibre properties when the bending axis was parallel to the courses. The first of these gave a positive correlation with mean fibre diameter whilst the second showed that fabric thickness and CV of fibre length had the most pronounced effects. By comparison, for bending of the courses (i.e. bending axis parallel to the wales) themselves, G_o was affected mainly by fabric thickness, fibre diameter playing a minor rôle only.

Close inspection of the results reveals an association between fibre diameter and fabric thickness, which explains the apparent anomaly between the two regression equations.

Similar trends as was observed for G_o emerged for the initial flexural rigidity (G_i) the former being positively correlated with mean fibre diameter and staple crimp for bending parallel to the courses and with fabric thickness only, for the alternative direction.

The mean final flexural rigidity ($G_{\varnothing}$) for both directions of bending increased with increasing fabric thickness, and for the bending axis parallel to the courses a positive correlation with CV of fibre length was found also. The relationship between the bending rigidities and mean fibre diameter is not unexpected, since in theory, the resistance to bending of a solid rod is proportional to the fourth power of its diameter. The residual curvature (K_r), for both directions of bending, was affected almost exclusively by fabric thickness, an increase in the latter decreasing K_r. With the bending axis parallel to the courses, negative correlations were found between K_r and the CV of fibre length (15%) and bulk resistance to compression (19%). The coercive couple (C_o), for bending parallel to the course was correlated most significantly with CV of fibre diameter (45%) and mean fibre diameter (27%), C_o increasing with increases in both of these parameters. No significant regression equation was found between C_o and the fibre properties for bending in the other direction.

Recovery from bending parallel to the wales, R_b, increased with increases in bulk resistance to compression whereas for the other direction, R_b was found to increase with increases in fabric mass and with a decrease in CV of fibre diameter.

Hysteresis loss (H_i) was negatively correlated with fabric mass, but increased with an increase in CV of fibre diameter for bending parallel to the courses. By comparison, a negative correlation with bulk resistance to compression and a positive correlation with CV of fibre diameter emerged for bending in the other direction.

Subjective stiffness (S)[15] — a function of coercive couple and the final flexural rigidity — increased with an increase in fibre diameter and fabric mass for bending of the wales, and fabric mass only for the courses.

SUMMARY AND CONCLUSIONS

The main objective of this work was threefold: firstly, relating the visco-elastic bending fabric properties of some Punto-di-Roma fabrics to certain wool fibre properties; secondly, comparing the flexural ridigities of these fabrics with their visco-elastic bending parameters and finally comtrasting the behaviours of knitted and woven fabrics to bending stresses. To this end, 17 wool lots varying greatly in physical properties were spun into 25 tex Z610 yarns and knitted into a Punto-di-Roma structure at a machine tightness factor of 15 and a run in ratio of 1,5:1. The data for the woven fabrics were taken from a previous report.

The main finding of this study was a difference in the effect of the fibre properties on bending in the two directions (courses and wales). For bending parallel to the courses, fibre diameter and CV of diameter had an important effect on fabric bending, whereas in the other direction fabric thickness was of greatest importance.

Consistent with previous work, the initial flexural rigidity (G_i), in both directions of bending was found to be highest, indicating the existence of larger frictional constraints at the beginning of the stress/strain cycle than during subsequent bending. The lower curvature and final flexural rigidity moduli were both comparable in size when confined to a single bending direction. Comparison between directions, however, showed that bending characteristics of the course way yarns were much less dependent on the elastic nature of the fibres than were those in the alternative direction. This was attributed to the looser segmental movement of the courses which reduced the fibre strain, necessary to accommodate any geometrical change in the fabric. Residual curvature was found to decrease with an increase in fabric thickness for bending in both directions, and to increase with an increase in the bulk resistance to compression of the loose fibres for bending parallel to the courses. Hysteresis loss and subjective stiffness were higher in this direction of bending.

The flexural rigidities (F_c and F_w) measured by means of the cantilever method were comparable in magnitude to their lower curvature and final flexural rigidity counterparts. When analysed with the fabric bending characteristics, a significant positive correlation emerged between the flexural rigidity for bending in the wale direction (F_w) and the lower curvature elastic rigidity G_ϕ, whilst for the alternative direction of bending, F_c was shown to be positively correlated with residual curvature. Comparisons between the bending behaviour of the knitted and woven structures revealed significant differences, and these were attributed to the structure differences.

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