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THE CHARACTERISTICS OF DOUBLE PIQUE WOOL FABRICS KNITTED AT DIFFERENT RATIOS OF YARN INTAKE

Part II: Some additional physical properties

by

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ABSTRACT

This paper, which is a continuation of Technical Report No. 95, reports on some additional physical properties of Swiss and French double piqué fabrics knitted with the same yarn at three different ratios of yarn intake.

The thickness, flexural rigidity, elastic properties, handle, air permeability, wrinkle recovery, abrasion resistance and felting shrinkage of these fabrics were measured and related to a new tightness factor which is based on a previously developed cover factor for double piqué fabrics. Into this cover factor was incorporated the k_s-factor for each quality in order to take into account the changes which occur in the geometry of the fabric during steaming and wet relaxation.

The most favourable fabric was obtained when knitting Swiss double piqué at median ratio of yarn intake.

INTRODUCTION

The object of this investigation was to examine the various properties of the Swiss and French double piqué fabrics previously[1] examined for their dimensional properties.

The physical properties of knitted fabrics have been assessed by numerous authors[2–11]. However, nobody has as yet examined the influence of the ratio of yarn intake on the properties of double piqué fabrics.

EXPERIMENTAL

Fabrics

The following fabric qualities were examined:

Qual. I : Swiss double piqué, knitted at *median* ratio of yarn intake (medium fabric tightness).

Qual. II : Swiss double piqué, knitted at *high* ratio of yarn intake (loose fabric construction).

Qual. III: Swiss double piqué, knitted at *low* ratio of yarn intake (tight fabric construction).

Qual. IV: French double piqué, knitted at *median* ratio of yarn intake (medium fabric tightness).

Qual. V : French double piqué, knitted at *high* ratio of yarn intake (loose fabric construction).

Qual. VI: French double piqué, knitted at *low* ratio of yarn intake (tight fabric construction).

Relaxation procedure

Dry relaxation: After knitting, the fabrics were laid flat on a smooth surface and exposed for four weeks to the standard atmosphere for testing (20°C, 65% R.H.). After this treatment, the fabrics were considered to be in a dry relaxed state.

Steaming: The test samples were steamed singly on the bottom bed of a Hoffman Press for 20 sec followed by 20 sec exhaust.

Wet relaxation: After soaking the dry relaxed samples for two hours in water at 38°C as described earlier[1], they were removed from the bath, gently squeezed, carefully smoothed by hand and allowed to dry in the standard atmosphere for two weeks.

Tightness factor

The tightness factor was calculated according to the formula:

$$Tf = \frac{2\,k_s}{l'\sqrt{\text{w.c.}}} \times \left(1 + \frac{l - l'}{l}\right)$$

where k_s = the relationship between stitch density (S) and average stitch length (l) for the particular fabric concerned = $S \times l^2$.

l' = the reduced average stitch length[1] in inches.

w.c. = worsted count.

Compressional tests

Fabric thickness was determined by two methods, using the Instron tester as described by Smirfitt[2] and the Shirley thickness tester as described in Method 85 of the South African Bureau of Standards.

The hardness of the fabric was calculated from the Instron thickness values[13] by means of the formula:

$$\text{Hardness} = \frac{P_2 - P_1}{T_1 - T_2}$$

where T_2 = thickness under pressure P_2 (70 g/cm^2)

T_1 = thickness under pressure P_1 (5 g/cm^2)

The compressional resilience of the fabrics was determined on the Shirley thickness tester[12].

Bending properties

The flexural rigidity (G) was determined by the constant angle cantilever test[14,15] employing the Shirley stiffness tester.

The coursewise flexural rigidity (G) was taken as an indication of the sagging propensity of the fabric.

$$G = 0.10 \times w \times c^3$$

where w = fabric weight (g/m^2)

c = bending length (mg. cm)

Elastic properties

Test samples 2 × 16 cm, cut parallel to the wales and to the courses were tested on the Instron at a jaw distance of 10 cm, a crosshead speed of 2 cm/min, a chart speed of 10cm/min and a maximum extension cycling point of 30%. Two stress/strain cycles were obtained and the elastic recovery was calculated by means of the formula:

$$\frac{L' - L}{L' - Lo} \times 100$$

where L' = the extended length under load

L = the total length after recovery

Lo = the original sample length

The load (in g) necessary to extend the fabrics 30% in width and 10% in length was also determined[19].

Handle[20]

The handle was assessed subjectively according to the method of paired comparisons[21], where the observers were asked to judge the samples according to their degree of softness.

The samples were also tested on the Thwing Albert Handle-O-Meter, model 211–2 with a slot opening of 20 mm. Four tests were carried out on each sample, testing both sides of the fabric in both the lengthwise and widthwise directions and the mean of the four readings was determined.

Tailorability[22]

Tailorability was assessed according to the method of paired comparisons. The observers were asked to judge the fabrics according to their suitability for "styling".

Air permeability

The test samples were examined on the Karl Frank No. 843a Air permeability tester, type Verseidag, where the measuring range was 300 – 3000 l/m^2/sec, the testing surface was 20 cm^2 and the negative pressure was 20 mm water column.

Wrinkle recovery

The test samples were conditioned in an atmosphere of 20°C and 85% R.H. prior to wrinkling and tested on the FRL Wrinkler[23], using a torque of 500 g/cm. The specimens remained twisted for 5 min; recovery took place at 20°C and 65% R.H. The first photograph of the wrinkled specimens was taken after one minute and the second after five minutes of recovery.

Pilling propensity

The test samples, cut at a 45° bias, were examined on the Martindale[26] abrasion tester. The abrading tables were loaded with a bottom layer of lined sponge rubber[27] (⅛″ thick) to eliminate riding, followed by a similarly sized piece of warp knitted Nylon shirting and finally the test samples. The cloth pattern holders were loaded with the same materials and in the same order. On two abrading heads the face sides of the test samples were rubbed self on self and the reverse sides on the remaining two heads.

The multidirectional rubbing movement was used and no weight was added to the top of the abrading head. All pills formed on both fabric sides after 1500 rubbing cycles were counted and weighed. For this purpose, pills firmly attached to the test samples were pulled off.

The square of the number of pills was multiplied by the mean pill weight to evaluate the pilling propensity.

Resistance to abrasion

From each quality, ten circular samples of 4.5 cm diameter, were cut out and weighed[27]. Four of the test samples were mounted face up and four face down in the sample holder of the Martindale abrasion tester[26] while the remaining samples were kept as control samples[28]. The abrading tables were covered with standard worsted fabric as the abradant[29,30]. Some ⅛ inch thin neoprene backing was placed underneath the test samples and underneath the abradant[31].

The number of rubbing cycles was arbitrarily fixed at 9000, a point at which all the fabrics had lost more than 6% in weight through abrasion without any holes being formed.

After every 500 cycles, fluff and pills were brushed from the test samples. After 9000 cycles, the test samples were removed from the apparatus, placed in a standard atmosphere of 20°C and 65% R.H. for twenty-four hours and then weighed together with the control samples. The weight loss was calculated and the number of rubbing cycles corresponding to a 6% loss in weight was determined.

Felting shrinkage[32]

The samples were tested[33] for felting shrinkage in a 50 litre Cubex.

RESULTS AND DISCUSSION

Results referring to Swiss double piqué are graphically presented by solid lines, whereas broken lines refer to French double piqué. In both cases, a distinction is made between dry relaxed (X), steamed (●) and wet relaxed (O) fabrics. Also, the roman numerals in the graphs refer to the various knitted structures as outlined under *Experimental*.

Tightness factor

Smirfitt[2] proposed to incorporate the k_s-factor into the conventional cover factor in order to take into account the changes which occur in the geometry of the fabric during wet relaxation. This idea was adopted and the cover factor

formula which has been developed earlier[1] for double piqué fabrics, has been modified accordingly. However, the k_s-factors calculated previously[1] were multiplied by two, in order to take into consideration the number of stitches on *both* sides of the fabric[45].

In this report, the term *tightness factor,* as proposed by Postle[44], is used in preference to the classical term *cover factor*.

Table I below contains details on the dimensional properties of the various structures and has been taken from a previous report[1]. The newly calculated tightness factor (Tf) values have been added for the various states of relaxation.

TABLE I

The dimensional properties of the Swiss and French double piqué fabrics examined earlier[1]

Structure		Swiss double piqué			French double piqué		
Detail	Quality	I	II	III	IV	V	VI
Ratio of yarn intake		2.07:1	2.59:1	1.64:1	2.17:1	2.56:1	1.64:1
Average stitch length		0.146″	0.152″	0.129″	0.143″	0.154″	0.130″
Reduced average stitch length		0.126″	0.133″	0.109″	0.123″	0.135″	0.110″
Stitch shape (R)*		1.20	1.19	1.41	1.45	1.28	1.92
k_s: dry relaxed		19.7	17.8	17.7	19.3	18.6	20.2
steamed		20.9	19.5	18.7	21.0	20.2	21.5
wet relaxed		22.6	20.9	21.1	22.9	23.2	25.0
Tf: dry relaxed		59.9	50.6	63.0	60.2	52.1	71.5
steamed		63.7	55.7	66.8	65.5	57.3	76.3
wet relaxed		68.6	59.4	75.2	71.4	65.0	88.6

$$*R = \frac{\text{c.p.i.}}{\text{w.p.i.}}$$

Compressional tests

Thickness

Some authors[2,8] reported thickness to be linearly related to the tightness factor, while Knapton[34] maintains that thickness becomes independent of the tightness factor as soon as the fabric is completely relaxed by soaking in water at 40°C for 24 hrs, followed by hydro-extraction and tumble drying at 70°C for 1 hr.

In Fig. 1 fabric thickness (Shirley thickness gauge) is plotted against the tightness factor.

It would appear that

a) the thickness of French double piqué was linearly related to the tightness factor for all states of relaxation, whereas no such relationship existed for Swiss double piqué;

b) French double piqué was thicker than the corresponding Swiss double piqué fabrics;

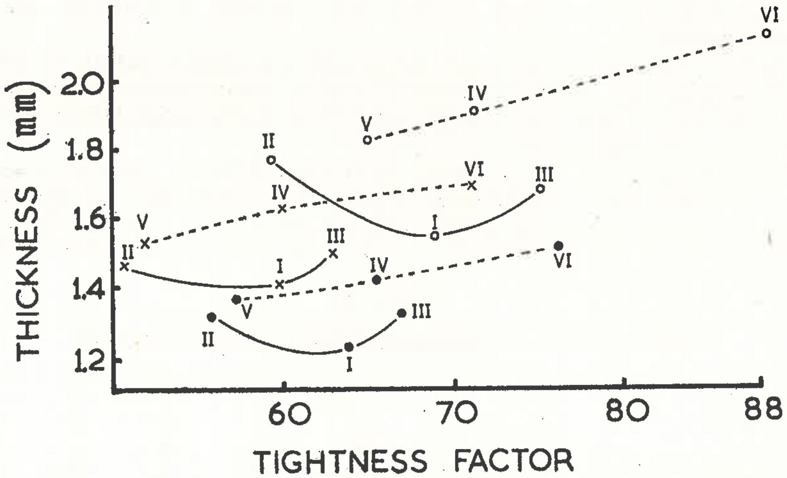

Fig. 1: Thickness of dry relaxed, steamed and wet relaxed double piqué fabrics.

c) the differences in thickness in going from one structure to another were much greater than the differences in thickness for the different ratios of yarn intake within the same structure;

d) steaming decreased, but wet relaxation increased fabric thickness.

The thickness values as determined on the Instron confirmed this trend (see Table II).

TABLE II

Fabric thickness measured on the Instron tester at pressures of 5 and 70 g/cm²

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed							
5g/cm²		1.20	1.40	1.27	1.50	1.32	1.37
70g/cm²		0.92	0.97	0.99	1.07	1.01	1.16
Steamed							
5g/cm²		1.05	1.10	1.08	1.25	1.17	1.25
70g/cm²		0.86	0.92	0.94	1.04	0.99	1.05
Wet relaxed							
5g/cm²		1.35	1.44	1.40	1.70	1.54	1.65
70g/cm²		1.01	1.16	1.13	1.27	1.20	1.40

When, therefore, a thinner or thicker fabric is required, it is more advisable to choose another structure rather than to manipulate the ratio of yarn intake, provided this is commercially acceptable.

Resilience[35,36]

Smirfitt[2] found that an increase in thickness of a 1:1 rib fabric increases its resilience. This relation was confirmed by the results of the present investigation (See Table III) when each structure and each state of relaxation was considered *separately*:

Quality I was the thinnest and had the lowest resilience, quality VI was the thickest and had the highest resilience. The three French double piqué qualities which were thicker than the corresponding Swiss double piqué fabrics also had a higher resilience than the latter.

However, this rule was no longer valid when different states of relaxation were concerned: the steamed fabrics which were thinner than the dry relaxed fabrics, showed a higher resilience, while the wet relaxed fabrics, which were thicker than both, had a lower resilience than the steamed but a higher resilience than the dry relaxed fabrics.

TABLE III

Resilience values (%) obtained on the Shirley thickness tester

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed		90.7	91.7	92.9	93.2	93.0	94.3
Steamed		94.4	95.4	97.0	96.5	94.9	97.7
Wet relaxed		92.0	93.4	95.0	94.2	94.0	95.0

Hardness

TABLE IV

Hardness calculated from Instron fabric thickness measurements

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed		232	151	232	151	210	310
Steamed		342	361	464	310	361	325
Wet relaxed		191	232	240	151	191	260

From Tables II and IV it is clear that the smaller the difference between fabric thickness at 5 g/cm² and at 70 g/cm², the higher the hardness value (as defined under *Experimental*) and the leaner the fabric. The values in Table IV confirm that steaming decreased the fullness of the fabric.

Bending properties

Mean flexural rigidity

Peirce[20] found that the flexural rigidity of a woven fabric increases eightfold, when its thickness is doubled.

No such relationship was observed for the different ratios of yarn intake and the different states of relaxation of the knitted fabrics which were investigated. On the contrary, it was observed that

a) quality II, which was thicker than quality I, had a lower flexural rigidity (see Tables II and V);

b) all wet relaxed fabrics, which were thicker than the dry relaxed fabrics, had lower flexural rigidities;

c) all steamed fabrics, which were thinner than the wet relaxed fabrics, had higher flexural rigidities.

TABLE V

Mean flexural rigidity (mg-cm)

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed		176	128	214	196	123	196
Steamed		111	85	153	128	85	142
Wet relaxed		98	86	118	124	96	183

Relationship between coursewise and walewise flexural rigidity and tightness factor

In agreement with Smirfitt[2] it was found that flexural rigidity in the coursewise direction (Fig. 2) was related to the tightness factor, but this was not conclusively so for the flexural rigidity in the walewise direction (Fig. 3).

These deviations would probably have been smaller, had the qualities II, V and II, VI been knitted with the reduced average stitch lengths as indicated in Table I, but at the *median* ratio of yarn intake of 2.1 : 1 instead of 2.6 : 1 and 1.6 : 1 respectively.

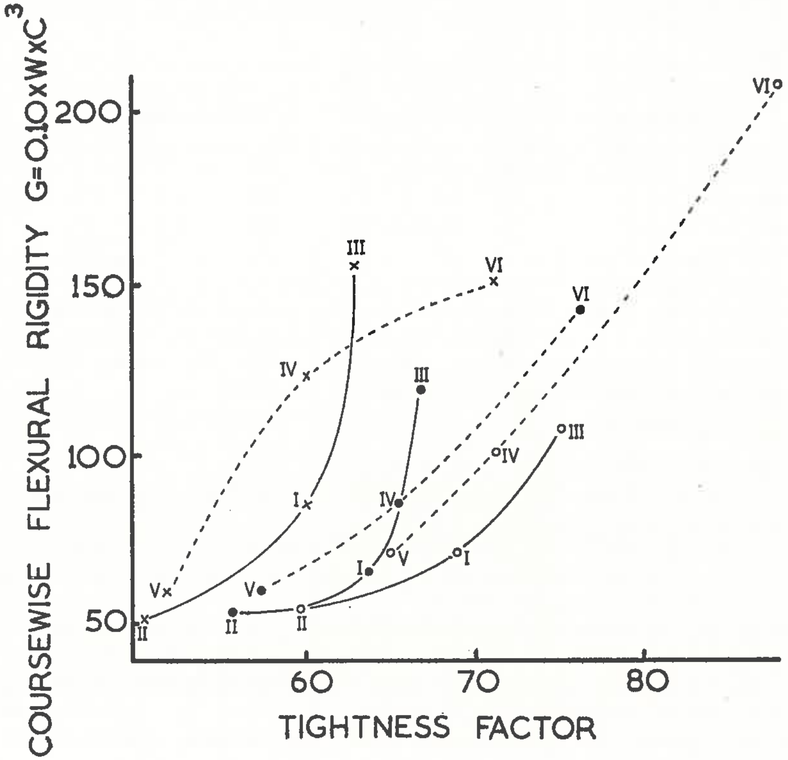

Fig. 2: Relationship between coursewise flexural rigidity and tightness factor.

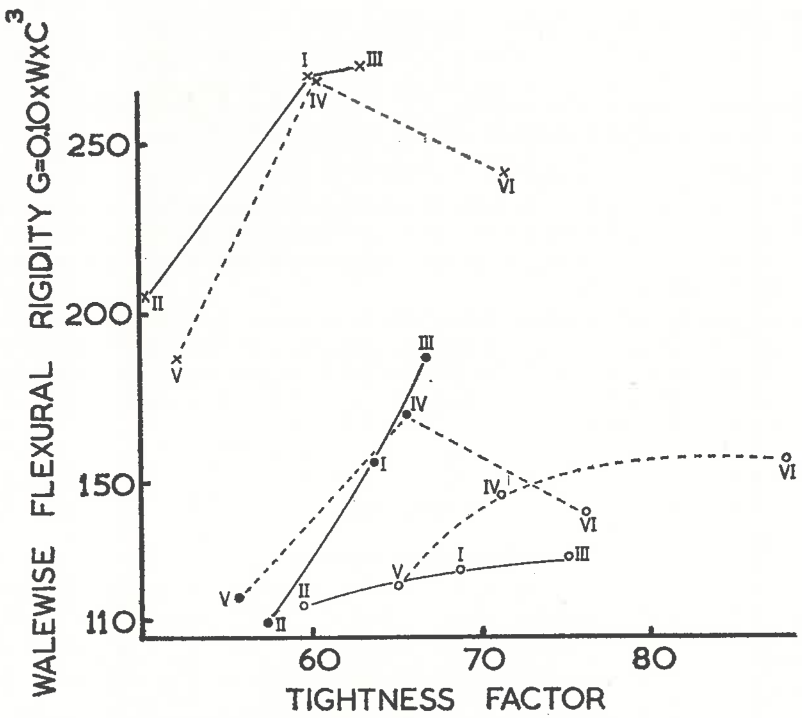

Fig. 3: Relationship between walewise flexural rigidity and tightness factor.

Ratio of coursewise to walewise flexural rigidity

Smirfitt[2] showed that rigidity along the ribs of 1 : 1 rib fabrics is more than three times that along the courses. Table VI shows that this relationship was not uniform for the double piqué fabrics investigated, but was dependent on the fabric structure, the ratio of yarn intake and the state of relaxation of the fabric.

TABLE VI

Walewise/coursewise flexural rigidity ratio

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed		3.20	4.00	1.76	2.20	3.20	1.62
Steamed		2.38	2.12	1.56	1.97	1.77	0.99
Wet relaxed		1.75	2.05	1.18	1.45	1.66	0.72

The values below 1.00 (quality VI) indicate that the coursewise flexural rigidity was even higher than the walewise flexural rigidity.

Elastic properties

Elastic recovery should be high if performance during wear is to be satisfactory[7]. In this respect, French double piqué shows some advantages, since its mean elastic recovery (Table VII) was higher than that of the corresponding Swiss double piqué qualities.

The findings of Smirfitt[2] have been confirmed that elastic recovery is related to the tightness factor and that, as with flexural rigidity, deviations from a linear relationship are due to the loop distortion which occurs when knitting at either low or high ratio of yarn intake. Again, the different states of relaxation had a disturbing influence.

TABLE VII

Mean elastic recovery

Fabric	Quality	I	II	III	IV	V	VI
Steamed		6.8	6.1	7.3	7.4	6.7	7.5
Wet relaxed		6.7	6.4	7.5	7.3	6.7	7.6

Widthwise and lengthwise extension

Smirfitt[2] showed that to extend a plain knit fabric in length requires more than twice the force than to extend it a similar amount in width. Fletcher[19] studied the elastic properties of lengthwise specimens which were extended 10% and of widthwise specimens which were extended 30% of their original dimensions. Since this method seems to be very close to the manual method of assessing the elastic behaviour of knitted fabrics, it has been adopted for these investigations.

TABLE VIII

Average extension force*

Fabric	Quality	I	II	III	IV	V	VI
Steamed		193	173	257	220	184	317
Wet relaxed		180	147	245	190	162	260

*

$$\text{Average extension force} = \frac{WF_{30} + LF_{10}}{2}$$

where WF_{30} = widthwise force at 30% extension

LF_{10} = lengthwise force at 10% extension

Table VIII shows that French double piqué exhibited a slightly higher average resistance to extension than Swiss double piqué.

However, Table IX shows that the resistance to 30% widthwise extension of French double piqué was much higher than its resistance to 10% lengthwise extension, while these values were fairly equal for Swiss double piqué.

TABLE IX

Fabric extension forces

Fabric	Quality	I	II	III	IV	V	VI
widthwise (30% extension)							
Steamed		195	185	280	270	195	485
Wet relaxed		180	150	290	230	190	400
lengthwise (10% extension)							
Fabric	Quality	I	II	III	IV	V	VI
Steamed		190	161	235	170	174	148
Wet relaxed		180	145	200	150	135	120

From the point of view of the maker-up, it is desirable that the widthwise extension equals the lengthwise extension. Swiss double piqué would therefore be preferable to French double piqué with the quality knitted at median ratio of yarn intake (quality I) showing the best behaviour.

Handle

Since an extremely harsh fabric will be as undesirable as a completely flabby one[21], the optimum value for handle will lie in the intermediate range.

This optimum value was found in the two qualities I and IV knitted at median ratio of yarn intake, whereas qualities II and V were decidedly too flabby and qualities III and VI were somewhat on the harsh side (see Table X).

TABLE X

Subjective ranking of handle

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed Steamed Wet relaxed	}	B	A	C	B	A	C

A = flabby; B = optimum value; C = too harsh

TABLE XI

Mean Handle-O-Meter readings (g)*

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed		19.5	18.0	26.8	24.8	20.5	29.9
Steamed		14.8	12.8	17.8	15.5	13.3	18.8
Wet relaxed		16.5	15.0	19.3	18.3	16.3	24.5

*Mean of four readings each.

The mean values found on the Handle-O-Meter gave the same ranking score as the subjective evaluation. However, this instrument showed the magnitude of differences in handle more clearly than the subjective method. The dry relaxed fabrics had the harshest handle; steaming softened the surface (which is in agreement with the "hardness"-values in Table IV), while wet relaxation slightly increased the reading on the Handle-O-Meter.

The readings on the Handle-O-Meter further show that French double piqué had a somewhat firmer handle than Swiss double piqué.

When comparing handle and flexural rigidity with the tightness factor (Fig. 4), it will be seen that both are directly related to this parameter.

Tailorability

In the opinion of the judges, the fabrics knitted at low ratio of yarn intake (qualities III and VI) were the most suitable for "styling" (see Table XII). This is in agreement with Lindberg[37] who showed that a garment must be able to bear reasonable loads in specific directions without appreciable extension.

When comparing handle with tailorability, it will be seen that fabrics which have the most acceptable handle will not necessarily have the best tailorability and *vice versa*.

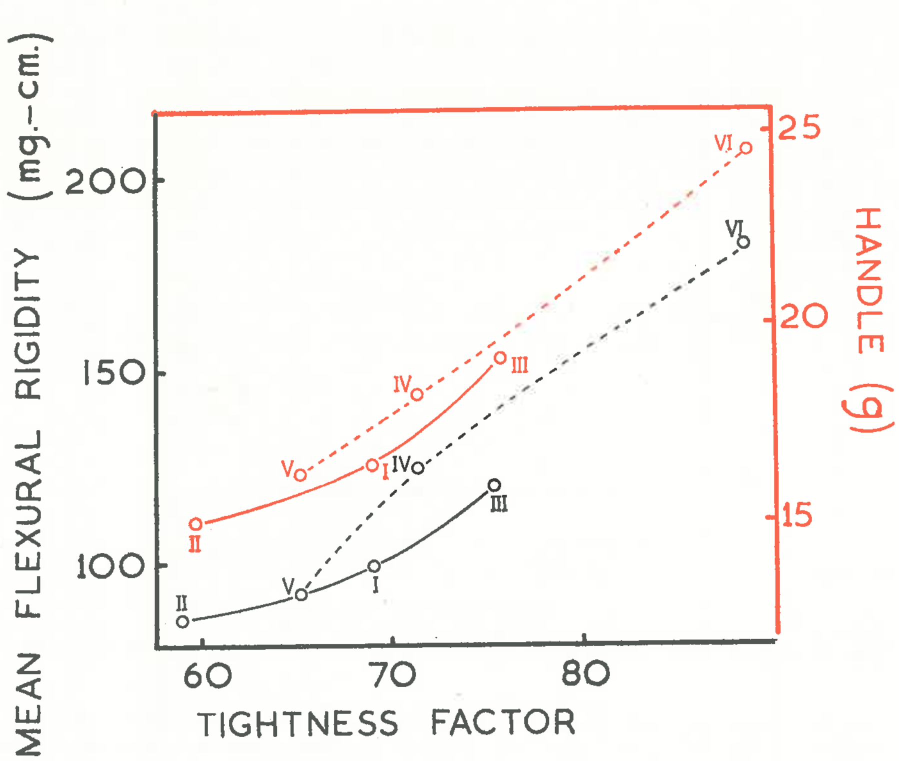

Fig. 4: Relationship between flexural rigidity, handle and tightness factor.

TABLE XII

Subjective ranking of tailorability

Fabric	Quality	I	II	III	IV	V	VI
Dry relaxed Steamed Wet relaxed	}	fair	poor	good	fair	poor	good

Air permeability

French double piqué showed a wider range of air permeability values for the different ratios of yarn intake than Swiss double piqué (Fig. 5). This indicates that a modification of the ratio of yarn intake had a greater influence on French than on Swiss double piqué.

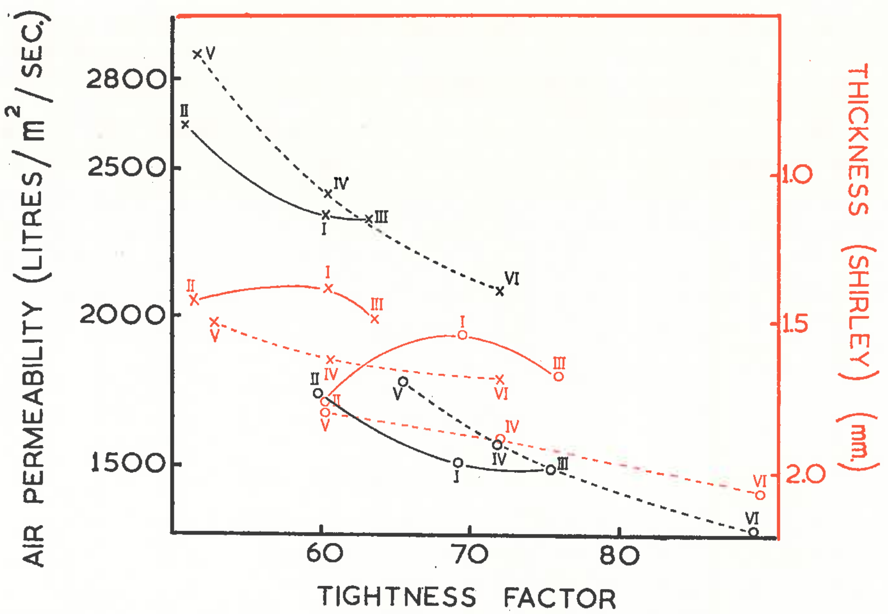

Fig. 5: Relationship between air permeability, thickness and tightness factor.

Wet relaxation reduced air permeability, because it increased fabric thickness. However, Fig. 5 shows that only French double piqué was related to air permeability, while there was no correlation to Swiss double piqué. This corroborates the findings of other workers who showed that air permeability does not depend on fabric thickness alone, but also on the structural characteristics[38–40] of the fabric.

Sagging

The fabrics which had, in the opinion of the judges, the highest sagging propensity, exhibited the lowest coursewise flexural rigidity.

When this physical parameter was used to evaluate the sagging propensity of the fabric, it appeared that

a) Swiss double piqué fabrics were more prone to sagging than French double piqué fabrics ;

b) sagging was at its highest for both structures when they were knitted at a high ratio of yarn intake (qualities II and V) ;

c) steaming and wet relaxation did not reduce the sagging propensity of the fabric.

Wrinkle recovery

The trend for the one-minute recovery values was confirmed and accentuated by the five minutes' recovery values.

It will be seen from Fig. 6 that wrinkle recovery of Swiss double piqué was related to the tightness factor. No such correlation existed for French double piqué, where quality IV, knitted at median ratio of yarn intake (medium tightness) had the lowest wrinkle recovery.

No relationship between wrinkle recovery and fabric thickness (Fig. 1) could be found which, again, may be due to the fact that knitting at high or low ratio of yarn intake created unpredictable loop distortions in the fabric.

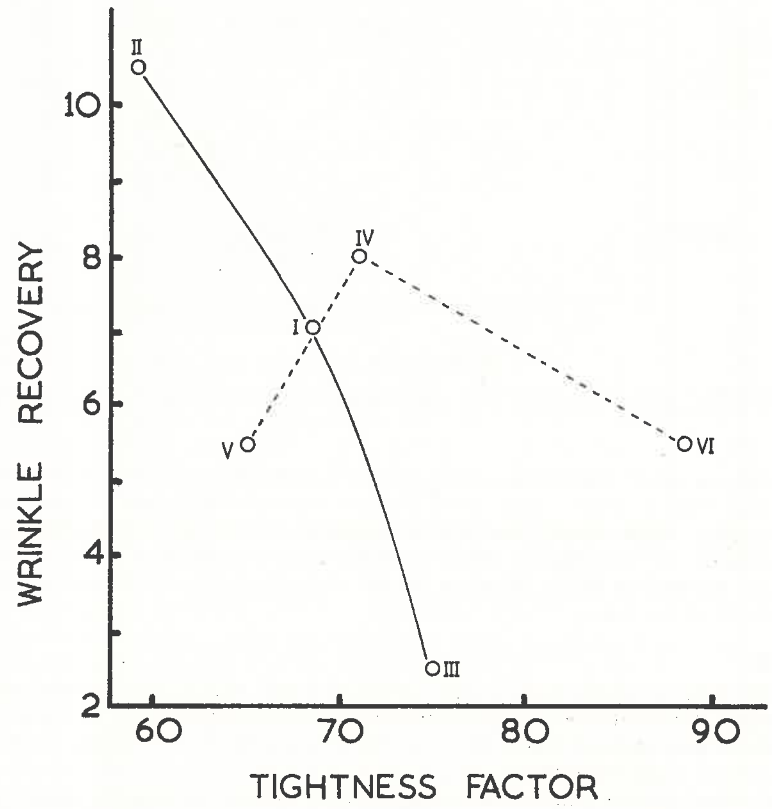

Fig. 6: Relationship between wrinkle recovery (after 5 min) and tightness factor. Rankings range from 2 (best) to 10 (worst).

Pilling propensity

The increase in pill formation, when a piece of warp knitted Nylon shirting was placed between the foam rubber and the test sample, may be explained by the generation of static electricity which caused the fine wool fibres to protrude more from the surface of the sample, thus increasing the pilling propensity[25].

Because a high percentage of ladies' underwear is currently made of hydrophobic synthetic fibres, this experimental procedure simulates actual wear conditions.

As was to be expected, the steamed test samples showed less pilling than the wet relaxed samples, because protruding fibres are pressed down into the fabric surface through steaming[41,42], but raised through wet relaxation[43].

In agreement with other authors[10,43] pilling was found to be linearly dependent on the tightness factor (see Fig. 7).

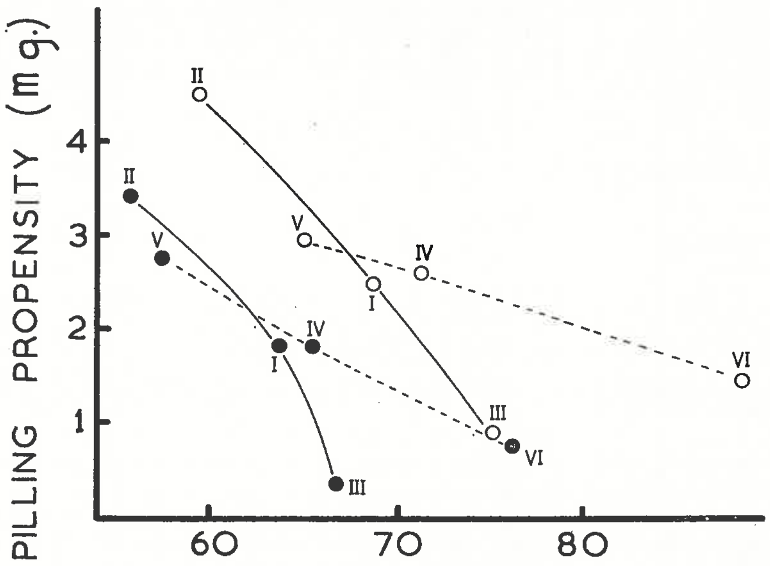

Fig. 7: Relationship between pilling propensity and tightness factor.

It was further observed that the mean pill weight decreased with decreasing stitch length (see Table XIII).

TABLE XIII

Mean pill weight (mg)

Fabric	Quality	I	II	III	IV	V	VI
Steamed		0.17	0.18	0.11	0.18	0.18	0.12
Wet relaxed		0.21	0.21	0.13	0.18	0.24	0.18

Finally, the pilling propensity of the two fabric sides was compared and it was found that the face side of quality II exhibited a considerably higher pilling propensity than the reverse side (Table XIV).

Whenever Swiss double piqué has to be knitted at high ratio of yarn intake, it is recommended to use as the face of the garment that side of the fabric which was knitted on the dial needles.

TABLE XIV

Pilling propensity (mg) on both fabric sides

Fabric	Quality	I	II	III	IV	V	VI
Steamed							
Face side		0.48	1.27	0.07	0.40	0.74	0.15
Reverse side		0.43	0.54	0.10	0.52	0.65	0.20
Wet relaxed							
Face side		0.45	1.63	0.24	0.51	0.80	0.30
Reverse side		0.79	0.73	0.24	0.77	0.69	0.43

Resistance to abrasion

In this project, only the surface abrasion of the wet relaxed test samples was examined. The amount of abrasion was measured in terms of the weight of the material removed by attrition[46]. The number of rubbing cycles was referred to a 6% loss of weight of the test sample, which corresponds to a "worn out appearance" of the garment[28].

The object of placing thin neoprene backing under the test sample was to keep the test piece in position[11]. In agreement with other authors[31] it was found that the fabric withstands a greater amount of rubbing when neoprene is placed under the test sample.

Standard worsted fabric was used as abrasive in preference to emery, because the latter showed the least discrimination between the test results[47] and because fibre damage was closer to actual wear when standard worsted fabric was used[48].

Fig. 8 shows that French double piqué has a higher total abrasion resistance than Swiss double piqué. This may be explained by the fact that French double piqué, having less of a "piqué effect" than Swiss double piqué, offers a greater area of contact[40] to the abradant. This is in agreement with other authors[49] who found that interlock fabrics have a higher abrasion resistance than rib fabrics. In this sense, French double piqué is much closer to interlock than is Swiss double piqué.

Fig. 8 further reveals that the tightly knitted quality VI had a lower abrasion resistance than the looser constructions (qualities IV, V).

This phenomenon has already been observed by others: Davis[11] demonstrated that service in wear is significantly reduced for fabrics in which courses per inch have been inserted in excess, because under the abrasion tester these

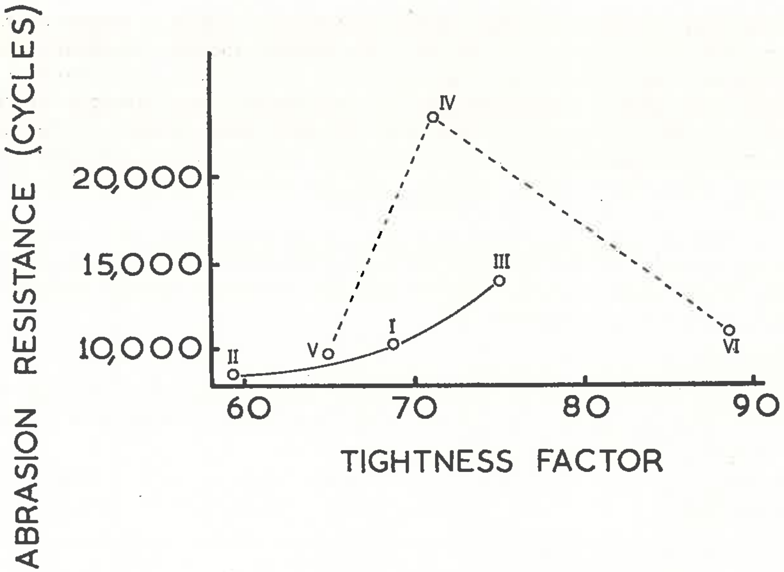

Fig. 8: Relationship between abrasion resistance and tightness factor.

tight textures receive the full force of the abradant and wear through quickly. Another possible explanation is that a higher stitch density brings less yarn crowns in contact with the abrasive surface[40]. The local load at a fibre point is therefore increased and the tight fabric wears through much quicker than a fabric of median tightness. Finally, internal wear and flexural stresses which also are motivating factors in fabric deterioration, increase with increasing stitch density[50,51].

This phenomenon is still further accentuated when the abrasion resistance of the face and of the reverse sides of the fabric are considered individually. From the results given in Table XV it is obvious that the abrasion resistance of the face side of Swiss double piqué increased with increasing tightness factor, whereas the reverse side of both Swiss and French double piqué did not show such a correlation.

TABLE XV

Abrasion resistance (cycles, wet relaxed fabrics)

Fabric	Quality	I	II	III	IV	V	VI
Face side		5162	3873	9767	16622	4350	6040
Reverse side		5148	4688	4155	7195	5420	4975

It has been shown that a tight fabric construction is likely to reduce pilling[44], but tight fabrics do not necessarily have the highest abrasion resistance. Pilling and abrasion, although tested on the same instrument, are therefore not necessarily correlated: pilling depends on the number and strength of fibres protruding from the fabric surface and, amongst other things, on the stitch length, whereas abrasion depends on the number and strength of the yarn crowns in contact with the abrasive surface, and on the over-all flexibility of the structure[52].

It is therefore not surprising that the fabric which had the lowest pilling propensity (quality III) did not have the highest abrasion resistance and, inversely, that the fabric which had the highest abrasion resistance (quality IV) did not have the lowest pilling propensity.

Felting shrinkage

The area felting shrinkage of plain knitted fabrics depends upon stitch tightness[53–57]. This compares with woven fabrics[32], where compactness correlates

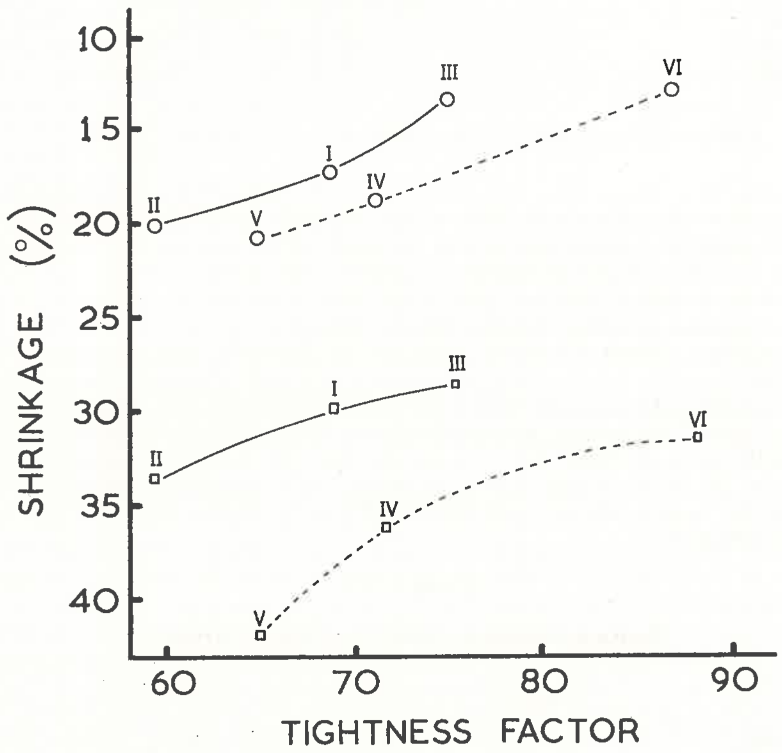

Fig. 9: Relationship between felting shrinkage (O), relaxation plus felting shrinkage (□) and tightness factor.

with shrinkage. However, it sometimes happens that relatively open weaves have a low, and rather compact fabrics, a high shrinkage. These exceptions to the general correlation indicate that factors other than compactness must be considered as controlling the shrinkage of more complicated structures.

Fig. 9 shows that felting shrinkage alone, as well as the sum of relaxation and felting shrinkage, are dependent on the tightness factor. The deviations from an exact linear relationship may again be due to the fact that the tighter and looser constructions were not knitted at median, but at either low or high ratios of yarn intake which created unpredictable loop distortions in the fabric.

Döttinger[58] found that tightly knitted double jersey fabrics show considerable width shrinkage and no length shrinkage, while looser constructions tend to shrink in length and have little or no width shrinkage.

TABLE XVI

Mean felting shrinkage after 120 min washing time

Fabric	Quality	I	II	III	IV	V	VI
% Width shrinkage		9.2	11.8	7.3	7.0	10.0	6.2
% Length shrinkage		9.4	9.6	6.8	12.9	12.3	10.2

Table XVI shows that this rule was not confirmed by the investigations reported here. French double piqué exhibited more shrinkage in length than in width, irrespective of the tightness of knitting. Swiss double piqué had approximately the same length shrinkage as width shrinkage when knitted at median ratio of yarn intake; however, when knitted at either high or low ratio of yarn intake, it had less shrinkage in length than in width.

Döttinger concluded that for the most favourable shrinkage behaviour it is necessary to knit a fabric of medium density and with length and width shrinkages approximately equal. These requirements would be met by Swiss double piqué knitted at median ratio of yarn intake.

SUMMARY

Some other physical properties of Swiss and French double piqué fabrics knitted at three different ratios of yarn intake were examined in this report, which continues Technical Report No. 95.

The results of measurements of thickness, flexural rigidity, elastic properties, handle, air permeability, wrinkle recovery, pilling propensity, abrasion resistance and felting shrinkage tests were plotted against a new *tightness factor* (Tf) which is based on a previously developed cover factor for double piqué fabrics. Into this cover factor was incorporated the k_s-factor for each quality in order to take into account the changes which occur in the geometry of the fabric during steaming and wet relaxation.

TABLE XVII

Relationship between fabric* properties and tightness factor

Fabric property	Almost linearly dependent on Tf	Partially proportional to Tf	No correlation with Tf
Thickness	Fr	—	Sw
Resilience	Fr	—	Sw
Hardness	—	—	Sw, Fr
Flexural rigidity	—	Sw, Fr	—
Sagging	—	Sw, Fr	—
Walewise flexural rigidity	—	Sw	Fr
Elastic recovery	—	Sw, Fr	—
Extension	Fr	Sw	—
Handle	Fr	—	Sw
Air permeability	Fr	Sw	—
Wrinkle recovery	Sw	—	Fr
Pilling propensity	Sw, Fr	—	—
Abrasion resistance	—	Sw	Fr
Felting shrinkage	Fr	Sw	—
Relaxation + felting shrinkage	—	Sw, Fr	—

*(Sw = Swiss double piqué ; Fr = French double piqué)

Some mechanical properties were shown (see Table XVII) to be almost linearly related to the tightness factor, others depended upon some more complex function of the variables involved, and still others showed no correlation with the tightness factor. The deviations from linearity may be due to the fact that for qualities II, III, V, VI not only the stitch length was altered but also the ratio of yarn intake, whereas in the tests performed by other workers on plain jersey and 1:1 rib fabrics, only the stitch length had been modified, because in fabrics where all courses are alike, the yarn intake of all courses is obviously the same.

It was further found that the compressive properties of the fabrics were more influenced by the type of structure than by the ratio of yarn intake, whereas it was the inverse for all the other mechanical properties.

Knitting at *high* ratio of yarn intake (qualities II and V) did not produce favourable properties in the fabrics investigated: the pilling and sagging propensities of Swiss double piqué were high, while the wrinkle recovery and abrasion resistance were low. French double piqué had a very high length shrinkage.

Knitting at *median* ratio of yarn intake (qualities I and IV) produced fabrics with a pleasant handle. In Swiss double piqué, the force required to effect a 30% widthwise extension equalled that for a 10% lengthwise extension; also, relaxation plus felting shrinkages in width and length were equal. French double piqué showed greater differences in widthwise and lengthwise extension forces and, therefore, requires greater skill in making-up; its relaxation plus felting shrinkage in length is much greater than in the widthwise direction. However, French double piqué had a somewhat higher wrinkle recovery and abrasion resistance and a firmer handle than the corresponding Swiss double piqué fabrics.

Knitting at *low* ratio of yarn intake (qualities III and VI) produced a fabric with perfect tailorability, reduced the pilling propensity and improved the wrinkle recovery. The width and length shrinkage of Swiss double piqué were lower than in the previous cases and remained approximately equal. Shrinkage of French double piqué was still high and length shrinkage much higher than width shrinkage. Cognisance should be taken of the fact that French double piqué was very difficult to knit at low ratio of yarn intake[1] (see Table I, stitch shape).

Subsequent steaming of the fabrics increased the resilience, reduced fabric thickness and stiffness, smoothed the fabric surface and reduced the pilling propensity. Wet relaxation reduced fabric stiffness even further and decreased the air permeability, whereas thickness and pilling propensity were increased.

Considering the above results, Swiss double piqué is preferred to French double piqué, the most favourable fabric being obtained at the median ratio of yarn intake. If tighter fabrics are required, it is not only the stitch length at the cylinder/dial feeds that should be reduced, but also the stitch length at the dial-only feeds. In this way, the median ratio of yarn intake is always maintained.

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