International Institute for Cotton
Technical Research Division
Manchester

Research Record No. 95

The Wet Relaxation Of Cotton Single Jersey
A Literature Survey

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January 1979

Key Words: Single Jersey, Wet Relaxation, Relaxed Structure, K-values, Spirality

Digital Version: May 2009

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Introduction

An investigation into the properties of cotton single jersey fabrics is to be undertaken at TRD during the next few years. An important objective of this work will be to establish the behaviour of such fabrics during relaxation treatments, as a function of knitting parameters (such as yarn count and stitch length) and finishing treatments (such as mercerising). This literature survey examines the published information on this subject, in an attempt to lay foundations for the projected study.

Doyle's Work On Dry-Relaxation

The early work on the relaxation of knitted fabric structures concentrated on wool. Much of it concerned dry relaxation, which apparently consisted of simply leaving the fabric for several days on a glass plate in a conditioned atmosphere. Doyle (1) was perhaps the first worker to make a serious study of the relaxation behaviour of knitted structures, and although he also limited his work to dry-relaxation effects, his conclusions represent an important landmark in knitting technology, as all subsequent investigators have built on them.

Doyle reported that, for all knitted fabrics in the equilibrium state:-

> *The surface density of unit cells, i.e. the total number of stitches per square inch of fabric, is a function dependent primarily on the length of yarn per unit cell and is independent of the yarn material, yarn structure and the system of knitting used to form the stitches. The total number of stitches per square inch can be expressed in terms of commonly measured factors, the number of courses and stitches (wales) per inch, and the whole statement expressed as follows.*
>
> $$N = C \cdot S$$
>
> *which is a function F(l) of the length of yarn per stitch (l), where N = surface density of stitches, C = courses per inch, S = stitches per inch.*

By plotting N against l for a large number of fabrics, Doyle found this relationship to be of the form:-

$$N = K / l^2$$

and he suggested a value for K of about 19.3.

A graph of Doyle's results is shown in *Figure 1*. Although he reported that a wide range of fabrics and materials were included in the investigation, he made no distinction as to fibre type, so it is not known whether or not any cotton fabrics were examined.

Wet-Relaxation And The Importance Of Agitation

Doyle had concluded that relaxation behaviour was independent of the yarn material, but in 1959, Munden (2), noted an important difference in dry-relaxation behaviour between wool and cotton fabrics. This was that,

> *whereas a plain fabric knitted from a worsted yarn will recover from a 60-80% extension in length to its natural length after 48 hours, if allowed to relax*

freely in the dry state, a fabric of similar construction knitted from a cotton yarn will retain permanently 10-20% of the extension in length.

In the dry state therefore, plain knit wool fabrics may be expected to return to their strain-free condition if allowed to relax freely. For cotton fabrics, the recovery will never be complete.

He further observed that,

Cotton fabrics which remain permanently distorted in the dry state recover completely from such strains when relaxed in water.

It is difficult, however, to see how his wet treatment could have resulted in complete relaxation, as it consisted simply of laying the fabric flat in water at 30°C for 12 hours, hydroextracting and drying, again flat, in an oven at 40-60°C

In fact, he admitted the deficiencies of this treatment later (3), saying,

It has been generally accepted that fabrics knitted from hydrophilic yarns are brought to their stable dimensions by the standard wet-relaxation treatment. Measurement of stitch length and courses and wales per inch on fabrics after wet-relaxation has revealed that this is often not the case, particularly for fabrics knitted to a tight construction from cotton and rayon yarns, where the forces of recovery to true stable dimensions are so small as often to be incapable of overcoming frictional restraints under static wet-relaxation conditions. In these cases, the fabric does not, at this stage, take up the true stable wet-relaxed shape as predicted by the fabric geometry relationships. Agitation, as produced by a standard washing treatment, is necessary to overcome the frictional retarding forces and allow the fabric to take up its true predicted wet-relaxation dimensions.

An example was then given to show that a highly distorted cotton fabric required 30 minutes agitation during washing to obtain the stable wet-relaxed state.

In work at the Centre de Recherches de la Bonneterie in Troyes (4), several wet-relaxation treatments for cotton were studied, including steam-injection tumbling and, later, Postle (5) reported results on a similar series of treatments, including one which he described as wet with gentle agitation at 100°C for up to 60 minutes, followed by hydroextraction and tumble drying at 80°C for 30 minutes. Of this treatment he said that measurements taken at different stages indicated that relaxation is very rapid and that any changes in dimensions after treatment for 15 minutes are very small. In addition, repetition of the treatment was accompanied by no further significant changes in fabric dimensions. He concluded that this treatment gave the completely relaxed plain knitted structure in its dimensionally stable state.

The Importance Of Repeated Washing In Achieving Full Relaxation

Postle claimed that a single wash and tumble dry cycle was enough to produce full relaxation in the knitted structure. This confirmed an earlier study by Suh (6), but the point has been contested by several other workers.

Knapton et al. (7) measured the dimensional changes of cotton single jersey fabrics over ten wash and tumble dry cycles (*Figure 2*) and concluded that residual shrinkage only becomes negligible after the fabric has been subjected to approximately five launderings. IIC work has reinforced this conclusion (8, 9).

On the other hand, Gowers and Hurt in a recent publication (10) have come out in favour of the single wash-cycle. In their study, the relaxation treatment was a 24-hour soak, followed by hydroextraction and tumble drying at 45°C for thirty minutes. Repetition of this process had little further effect; neither did a more severe washing-machine treatment. However, their work was carried out mainly on worsted and acrylic yarns (which are known to relax more readily in wet treatments) with only a minor study on cotton, and the detailed results on the cotton fabrics have not been published.

The Concept Of K-values

Doyle introduced the relationship

$$N = C \, . \, S = K / l^2$$

where C = courses per inch

S = stitches (wales) per inch

l = stitch length

and K is a constant for all single jersey fabrics.

This nomenclature has been revised in subsequent publications on the subject. Munden referred to the stitches per unit area as S, and the constant as K_1 so his relationships read:-

$$K_1 = S \, . \, l^2$$

Munden also introduced three other constants; he found that in all single jersey fabrics the courses per inch and the wales per inch each bore a constant relationship to the stitch length, so giving:-

$$K_2 = cpi \, . \, l$$

$$K_3 = wpi \, . \, l$$

and therefore $K_1 = K_2 \, . \, K_3$

and $K_4 = K_2 / K_3 = cpi / wpi$

K_1, K_2 and K_3 are now more generally referred to as k_s, k_c, and k_w respectively. A summary of reported values for these constants is given in *Table 1*. All except those of Postle, who unfortunately combined results obtained on cotton with others on viscose rayon fabrics, refer to data for wet-relaxed cotton single jersey fabrics.

If these are true constants, then it is clear that the relaxed fabric construction can be calculated from a knowledge of only two parameters; the count of yarn used, and the stitch length. Further, the relaxed width of the fabric is determined by the number of needles on the knitting machine. The inescapable inference is that the knitter alone controls the relaxed fabric structure, and that the finisher of the fabric can have no influence upon its final relaxed dimensions.

However, recent work is showing more and more clearly that these "k-values" are not quite as unvarying and invariable as was first thought. First, Knapton has shown that k_c in particular is dependent on fabric tightness (*Figure 3*) and, secondly, IIC work has shown that finishing processes can have a significant effect on the final relaxed structure.

Piece mercerisation in particular, can have a marked effect (11, 12, 13, 14, 15) but even the choice of dyeing machine may have some influence. That this is so for interlock and rib fabrics has already been established (16).

Crosslinking treatments are known to be effective in reducing fabric shrinkage (15, 17), and therefore must affect the relaxed fabric structure, but the precise details of the mechanisms involved in all these finishing processes have still to be established.

A summary of IIC test results in this area is given in *Table 2*.

Spirality

One difficulty which arises in the measurement of knitted fabric structure, particularly with unbalanced constructions such as single jersey, is the problem of how to deal with the occurrence of spirality. Earlier workers like Doyle and Munden ignored it (they could not have been unaware of its existence, as the effect was described as long ago as 1934 (18)); so have most of the more recent publications. Nevertheless, if reliable conclusions are to be drawn from any study of the relaxation of single jersey fabrics, spirality must be taken into consideration.

Spirality has been defined (19) as "*a distortion of a circular knitted fabric in which the wales follow a spiral path around the axis of the tube*". The entry goes on to attribute the cause to twist-liveliness in the yarn.

Nutting (20) lists the characteristics of a spiralled fabric:-

i. the angle between the line of wales and the line of courses is not a right angle,

ii. the line of courses remains perpendicular to the edge of the fabric,

iii. the wales appear to be bunched together to form a rib-like structure, caused by the lifting of one side of the knitted loop from the plane of the fabric.

In the same paper, a quantitative measure, the angle of spirality is defined as,

> *the angle between the line of wales and the perpendicular to the line of courses.*

Reference to Doyle's equation serves to illustrate the nature of the problem. In currently favoured nomenclature this would be written as:-

$$S = C \,.\, W = k_s / l^2$$

As S is stitches *per unit area*, C and W must be measured along directions at right angles to each other, otherwise the equation will be incorrect.

If, however, a fabric exhibits spirality, there is a distinct possibility that the course count (C) may be measured along a direction parallel to the wales, and the wale count (W) parallel to the courses; two directions not mutually at right angles. In such cases, the correct equation would be:-

$$S = C \,.\, W / \cos\alpha$$

where α is the angle of spirality.

The difficulty has been overcome, to some extent, in IIC laboratory practice, by making measurements of wale count in a direction perpendicular to the wales and course count in a direction parallel to the wales, thus cancelling any influence of spirality.

Clearly some sort of convention should be adopted generally; an equally good case could be prepared for making measurements relative to the course direction, which would give the same value for S but different figures for C and W.

Unfortunately, there appears to be no guidance in any of the standard test methods for knitted fabrics as to the directions in which course and wale counts should be measured; and none of the authors reviewed in this survey has considered it necessary to define the directions of course and wale measurements.

The pitfalls which spirality can produce are compounded when attempts are made to correlate shrinkage measurements with changes in courses and wales. The shrinkage of a fabric is measured along its length and width, two directions mutually at right angles; but where is the length and width in a spiralled fabric? And, equally important, do the length and width directions change if the spirality changes during the shrinking operation itself - as it is very likely to do?

A clue to the answers to these questions may be provided by Nutting -

> *the line of courses remains perpendicular to the edge of the fabric.*

If true, then the direction of the courses is always to be regarded as the width of the fabric, and it might then be sensible to adopt the perpendicular to the courses as both the length and the wale directions. But would this receive general agreement? In open-width finishing, for instance, the tubular cloth is slit along a wale line, which then becomes the edge of the fabric; if the fabric exhibits spirality then Nutting's statement clearly cannot be true.

Editor's note (May 2009):

> *In fact, with multi-feeder circular knitting machines, the line of courses is always spiralled (the so-called feeder skew), independently of any spirality to the wales caused by yarn twist-liveliness. This phenomenon, and the calculation of its magnitude are explained in the Starfish Workshop.*

It might perhaps be said that there is no need to consider spirality because if it is severe enough to affect calculations in this way, it will produce a fabric so visually unattractive as to be commercially unacceptable. This is probably true; the acceptable commercial limit for spirality is probably about 5° and $\cos(5°) = 0.9962$, so the error involved at this level is less than 0.4%. However, in research work, and especially in studies designed to find ways to reduce spirality, a firm convention is badly needed.

One of the few recent publications to acknowledge the existence of spirality is that of Lord et al. (21), who have looked at the effect of using open-end and twistless yarns. Part of the study included measurements of spirality on a range of open-end cotton yarns of varying twist factor. The yarns were treated before knitting either by waxing, steaming, or wetting-out and drying. The knitted fabrics were "fully-relaxed" by wetting out once at 80°C and tumble drying, also at 80°C, for two hours. This series was carried out using Pima cotton, combed.

In a second series, Lord looked at polyester-cotton blends, both ring-spun and open-end, and in this a different cotton, combed Memphis, was used with a twist factor of 3.5. All the yarns in the study were spun to a nominal count of Ne 18. Stitch length was not specified, but appears to have been about 0.17 inches. Some of the results are given in *Table 3*.

IIC work (9, 13, 14) has indicated that both piece mercerisation and cross- linking can have a beneficial effect on spirality, but further work needs to be done.

Yarn Diameter And Fabric Thickness

So far in this review, only two dimensions have been considered, but of course, a knitted fabric is a three-dimensional structure. However, it is even more difficult to define fabric thickness than to define length and width, due to the ease of compression. Knapton (7) measured fabric thickness under a constant pressure of 1 gf (9.81 mN) per loop, and found a relationship between thickness (*t*), stitch length (*l*) and tightness factor (*K*) of the form:-

$$t / l = 0.007K + 0.096$$

Gowers and Hurt (10) preferred to consider yarn diameter rather than fabric thickness as the third dimension. This was measured prior to knitting under a pressure of about 5 gf /cm^2 (490 N /m^2). They also preferred, in their consideration of fabric geometry, to use course and wale spacings, that is to say the length occupied in the fabric by one course or one wale, which they called *p* and *q* respectively. Munden's equation then became:-

$$q = k_q \,.\, l \quad \text{and}$$

$$p = k_p \,.\, l$$

By plotting *q* and *p* against *l* for a range of fabrics, they found intercepts b_l and b_2 respectively on the *q* and *p* axes which they concluded to be dependent on yarn diameter, producing the revised equations:-

$$q = a_1 \,.\, l + (0.73 \pm 0.17)d$$

$$p = a_2 \,.l - (0.47 \pm 0.14)d$$

where *d* is the yarn diameter, a_l and a_2 being new constants. These were derived from all the measurements which they made on worsted and acrylic fabrics as well as cotton. To show the trend for cotton, one of their graphs is reproduced as *Figure 4*.

Theoretical Models And Computers

Several theoretical models have been proposed for the shape of the fully relaxed knitted loop, but as these are in the main highly idealised structures, with little similarity to actual knitted cotton fabrics, it is not proposed to review them in detail. The following list of publications may, however, be useful.

G.A.V. Leaf: J. Text. Inst. 1960, 51, T49.

R. Postle and D.L. Munden: J. Text. Inst. 1967, 58, 329 and 352.

W.J. Shanahan and R. Postle: Text. Research J., 1970, 40, 656.

B. Hepworth and G.A.V. Leaf: J. Text. Inst. 1976, 67, 241.

The development of rules for the behaviour of real fabrics from calculations based on idealised mathematical models has been found to have many drawbacks. Assumptions have been made which have later proved to be false, and the difficulties which are only too readily apparent when an attempt is made to relate these calculations to such an unpredictable fibre as cotton make the theoretical approach appear somewhat unprofitable.

Recently, however, an alternative line of attack has been proposed (22, 23). This involves the use of computers to collect information on past experience with real fabrics, and evolve rules from this data for use in design and production control in the future. For cotton fabrics at least, this approach offers much more hope of success.

Objectives Of A Cotton Single Jersey Project

From this survey, it has become clear that there are many questions still unanswered concerning the behaviour of cotton single-jersey fabrics in wet-relaxation treatments. Almost all previous studies have concentrated on the wet-relaxation of fabrics straight from the knitting machine using, in most cases, untreated yarn.

A detailed study of the effects of dyeing and finishing processes is, therefore, long overdue and almost as important may be an examination of the results of yarn pretreatment.

It is desirable in such a project to consider the use of singles yarns, because of economics; this will inevitably introduce spirality effects, and analytical techniques will have to be clearly defined to take these into account.

Analysis must also take account of the third fabric dimension, be it yarn diameter or fabric thickness, which has been neglected by so many earlier workers. It may even be time to abandon the concept of k-values, which has been so beloved in the past, but which is now being shown to have serious deficiencies, and devise a fresh approach which will enable those engaged in knitted cotton design and production to predict with confidence the behaviour of their fabrics in processing and their performance in use.

References

1. P.J. Doyle: *Fundamental Aspects of the Design of Knitted Fabrics*, J. Text. Inst. 1953, 44, P561.
2. D.L. Munden: *The Geometry and Dimensional Properties of Plain Knit Fabrics*, J. Text. Inst. 1959, 50, T448.
3. D.L. Munden: *The Dimensional Stability of Plain Knit Fabrics*, J. Text. Inst. 1960, 51, P200.
4. Centre de Recherches de la Bonneterie: *Géométrie des Tricots Jersey. Etude comparative de méthodes de relaxation des tricots jersey laine et coton*, Bull. de l'I.T.F., 1964, *18*, 421.
5. R. Postle: *Dimensional Stability of Plain Knitted Fabrics*, J. Text. Inst. 1968, 59, 67.
6. Moon Won Suh: *Study of the Shrinkage of Plain Knitted Cotton Fabrics Based on the Structural Changes of the Loop Geometry due to Yarn Swelling and Deswelling*, Text. Research J. 1967, 37, 417.
7. J.J.F. Knapton, E.V. Truter and A.K.M.A. Aziz: *The Geometry, Dimensional Properties and Stabilization of the Cotton Plain Jersey Structure*, J. Text. Inst. 1975, 66, 413.
8. J.C. Stevens: *Shrinkage Testing of Greige State Single Jersey, Plain Knit Fabrics*, IIC Research Record 59, December 1976.
9. J.T. Eaton, "Single Jersey Fabrics made from Rotor Spun and Ring Spun Yarns", IIC Research Record 74, September 1977.
10. C.N. Gowers and F.N. Hurt: *The Wet Relaxed Dimensions of Plain-Knitted Fabrics*, J. Text. Inst. 1978, 69, 108.
11. R.D. Leah: *Resin Finishing of Piece-Mercerised Single Jersey Fabrics*, IIC Research Record 50, March 1976.

12. P.F. Greenwood: *Treatment of Cotton Knitgoods on the Benninger Mercerising Range*, IIC Research Record 53, June 1976.

13. S.A. Heap: *Pad-Roll Mercerising of Cotton Single Jersey*, IIC Research Record 82, May 1978.

14. P.F. Greenwood: *Treatment of Cotton Knitgoods on the Omez Tubular Mercerising Machine*, IIC Research Record 86, July 1978.

15. H.E. Bille, W. Thonig and G. Schmidt: *Comparing Chemical Finishing of Knit and Woven Goods*, Amer. Dyestuff Rep., 1972, 61 (10), 56.

16. IIC: *Central Project 1978*, in preparation.

17. T. Sϕrensen and P.F. Greenwood: *Der Einfluss der Vernetzung auf die Dimensionsstabilität einiger Baumwoll-Maschenwaren*, Wirk. u. Strick. Technik 1976, 26, 88.

18. W. Davis, C.H. Edwards and G.R. Stanbury: *Spirality in Knitted Fabrics*, J. Text. Inst. 1934, 25, T122.

19. The Textile Institute: *Textile Terms and Definitions*, 6th Edit. 1970.

20. T.S. Nutting: *Spirality in Weft Knitted Fabrics*, Hosiery Research Bulletin 1960, 4, 18.

21. P.R. Lord, N.H. Mohamed and D.B. Ajgaonkar: *The Performance of Open-End, Twistless and Ring Yarns in Weft Knitted Fabrics*, Text. Research J. 1974, 44., 405.

22. J.W.S. Hearle, M. Konopasek and A. Newton: *On Some General Features of a Computer Based System for Calculation of the Mechanics of Textile Structures*, Text. Research J., 1972, I?, 613.

23. M. Konopasek and K. Wustrow: *Computer Assisted Engineering Design and Control in Knit Fabric Production*, Knitting Times Yearbook, 1978, 63.

Table 1: Observed Values of k_s, k_c and k_w for Wet-relaxed Cotton Single Jersey Fabrics

Reference	k_s	k_c	k_w	k_c / k_w
2 (Munden)	22.6 ± 0.5	~	~	~
4 (CRB Troyes)	23.07	5.66	4.10	1.38
5 (Postle)*	24.3 ± 0.7	5.6 ± 0.2	4.3 ± 0.1	1.30
7 (Knapton et al)	23.49	5.73	4.10	1.40
8, 14 (IIC)	25.24	5.83	4.33	1.35
10 (Gowers & Hurt)	21.51	5.26	4.20	1.25

* mean values, including results on other fibres

Table 2: The Effects of Finishing Treatments on the Fully-relaxed Structure of Cotton Single Jersey

Treatment	Reference	Course to Wale Ratio	
		Before Treatment	After Treatment
Mercerise	12	1.37	1.29
	12	1.37	1.29
	12	1.31	1.21
	13	1.32	1.37
	13	1.43	1.44
	13	1.53	1.47
	13	1.25	1.17
	13	1.32	1.24
	13	1.39	1.36
	14	1.42	1.18
	14	1.39	1.20
Winch dye	14	1.42	1.24
Mercerise & winch dye	14	1.42	1.13
Dye & crosslink	14	1.42	1.08
Mercerise, dye & crosslink	14	1.42	1.03

Table 3: Spirality Angles (deg) of Single Jersey Fabrics Knitted from Ne 18 Open-end Yarns with Varying Twists (Lord et al)

Twist Factor	Yarn Pretreatment			
	None	Waxed	Steamed	Wetted & Dried
2.9	12	14	10	8.5
3.5	18.5	18	15	13
4.0	28.5	27	22	21
4.1	31.5	31	29.5	28.4

Figure 1: Stitch Density vs. Stitch Length (Doyle)

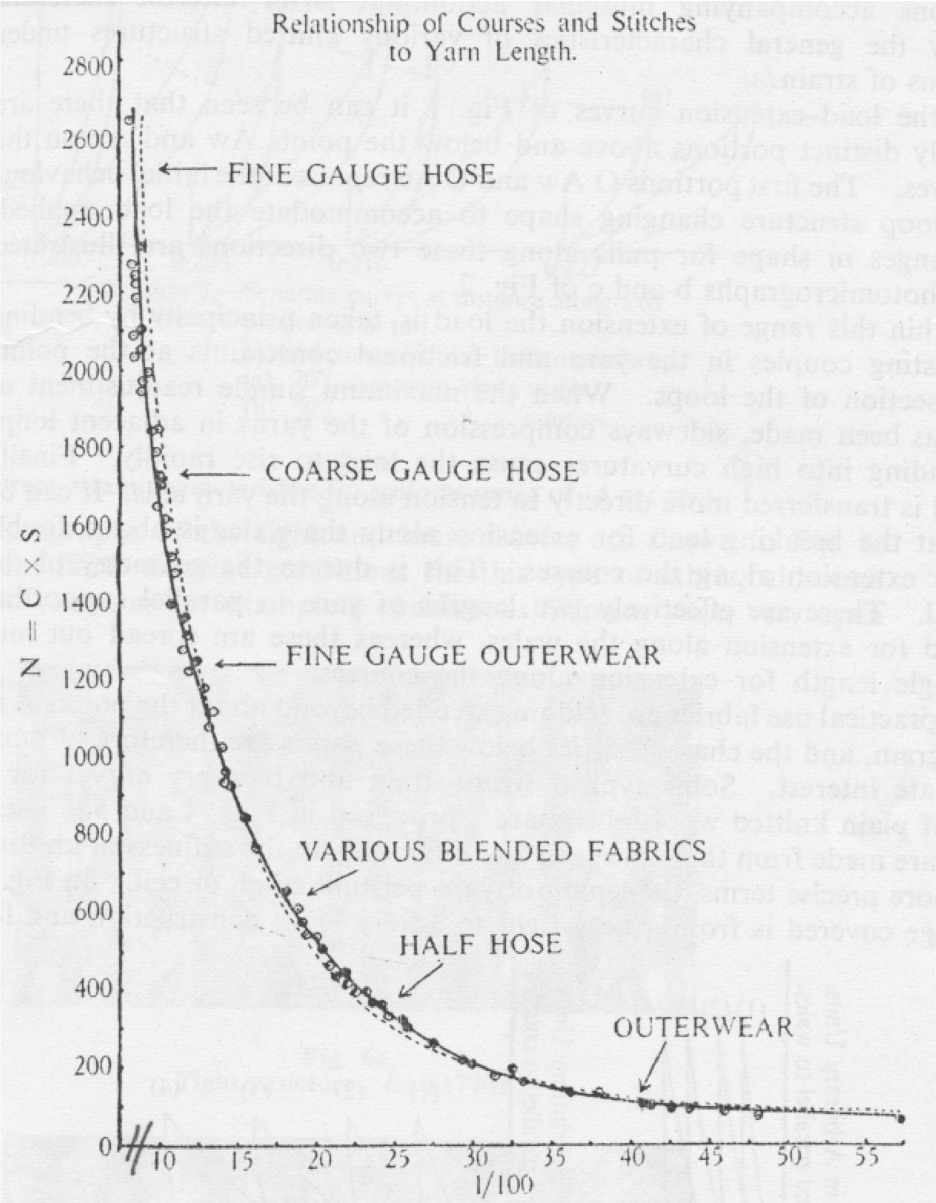

Fig. 3.
Graph of relationship N=C×S=F (*l*).
For plain fabrics in relaxed state.

Figure 2: Changes in k_s With Laundering (Knapton)

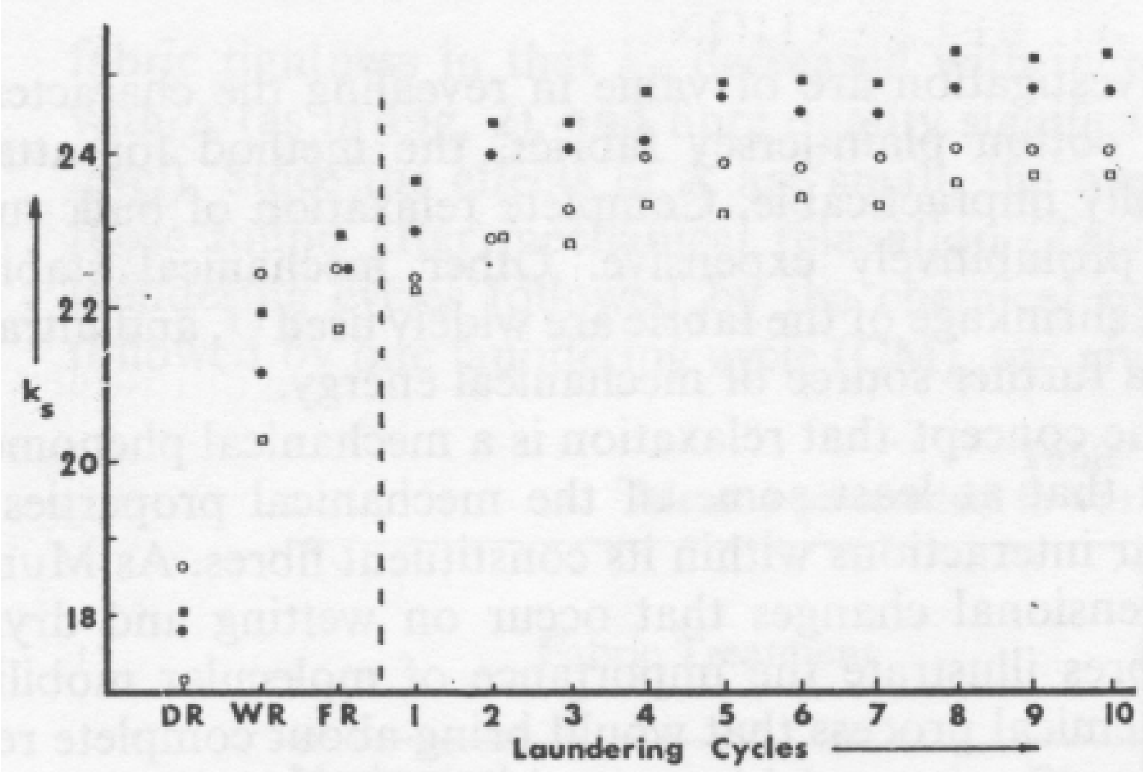

Fig. 1
Progressive change in k_s (DR = dry-relaxed; WR = wet-relaxed; FR = 'fully' relaxed)
○ Low twist, ● high twist, Izmir cotton
□ Low twist, ■ high twist, Montserrat cotton

Figure 3: Fully Relaxed k_c and k_w vs. Tightness Factor (Knapton)

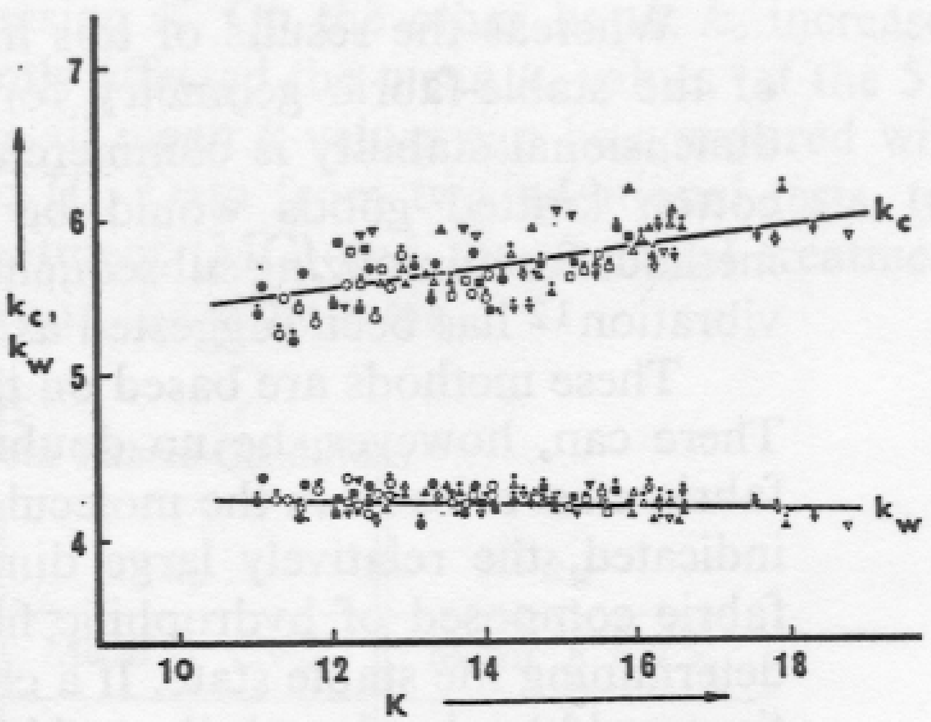

Fig. 2
Relation between the tightness factor, K, and k_c and k_w after the tenth laundering cycle
○ Low twist, ● high twist,
Izmir cotton 18·5 tex
$\dot{\circ}$ Low twist, $\dot{\bullet}$ high twist,
Montserrat cotton 18·5 tex
□ 18·5 tex × 2, Δ 29·5 tex, ∇ 29·5 tex × 2
(Solid symbols and dots over symbols have meanings given for 18·5-tex yarns)

Figure 4: Fully Relaxed Dimensions vs. Yarn Diameter
(Gowers & Hurt)

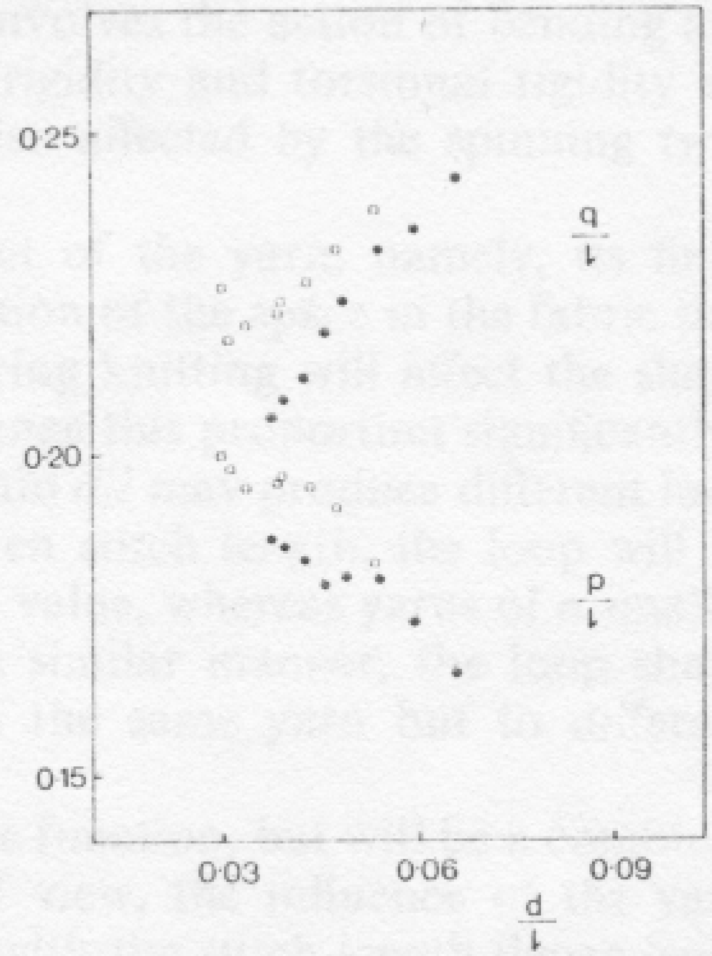

Fig. 9
Dependence of q/l and p/l on d/l for cotton fabrics
● R53.7 tex/2
□ R35.4 tex/2