FACTORS AFFECTING THE DEVELOPMENT OF SHRINKAGE IN COTTON KNITGOODS DURING DOMESTIC LAUNDERING AND TUMBLE DRYING

and

RECOMMENDATIONS FOR A PROGRAMME OF RESEARCH TO DEVELOP GUIDELINESS FOR THE OPTIMUM USE OF TUMBLE DRIERS IN THE HOUSEHOLD

A report prepared for

The National Institute for Consumer Research (SIFO)

and the

Norwegian Consumer Board

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EXECUTIVE SUMMARY

1. OBJECTIVES

The objectives of this report are,

1. To provide background data and information on the factors which can influence:-

   a) the accurate determination of shrinkage, and

   b) the development of shrinkage (relaxation), in cotton knitted fabrics and garments.

2. To provide recommendations to SIFO for the development of experimental protocols which may be used for:-

   a) the objective evaluation of domestic tumble drying machines with regard to their influence on the development of shrinkage in cotton knitted garments, and

   b) the development of information which may be used to provide guide-lines for the consumer on the optimum use of tumble drying equipment in home laundering procedures.

2. ORGANISATION AND LAYOUT

The report is prefaced by this executive summary which outlines the main points covered, the conclusions reached and the recommendations presented. Taken together, the conclusions and the recommendations comprise a blueprint for action.

The main body of the report has been prepared in two parts.

Part 1 is directed towards Objective 1. It provides a detailed summary of some of the experimental work carried out by the International Institute for Cotton on the subject of shrinkage in cotton knitgoods. It is subdivided into three sections, whose main themes are as follows:-

Section A:
Factors affecting the measurement of shrinkage.
Definition of a Reference State of Relaxation.

Section B:
Influence of fabric production and processing conditions on the dimensions of the Reference State.
Mechanism of shrinkage.

Section C:
Shrinkage in Garments.

Tables of data and diagrams are provided, where appropriate, within the body of the text, and additional figures illustrating certain aspects of the results described are provided at the end of **Part 1**.

Part 2 is directed towards Objective 2. It addresses the objectives of SIFO's planned evaluation of domestic tumble drying equipment and the development of consumer advice for the optimum use of tumble driers in home laundering. It is subdivided into three sections, whose main themes are as follows:-

Section A:
An evaluation of domestic tumble drying equipment.

Section B:
An evaluation of some of the potential effects of consumer practise.

Section C:
Guidelines for the selection of fabrics and testing procedures.

A list of literature references is provided at the end of **Part 2**. References to IIC internal research records are included for completeness, even though these may not be generally available.

Appendix A contains details of the fabrics used in the trials described in **Part 1**.

Appendix B contains the detailed IIC testing procedures for obtaining the Reference State of Relaxation and for measuring shrinkage in cotton knitted fabrics.

Appendix C is a reprint of Reference 40 "Low Shrink Cotton Knits". It contains a general description of the IIC Starfish quality control system for cotton knitgoods and shows what steps must be taken by the industry to develop low shrink cotton knits.

3. PRELIMINARY DISCUSSION

The objectives of the proposed studies by SIFO are :-

A. Evaluation of domestic tumble drying machines with regard to their effect on the development of shrinkage in garments made from knitted fabrics.

B. Development of consumer relevant information on the optimum use of tumble drying equipment in the home in order to minimise the development of shrinkage in garments during domestic laundering and tumble drying

One problem posed by these two objectives is that, in order to achieve them, the design of the experimental protocol must be such that it enables a reliable and objective evaluation of the machinery to be carried out whilst, at the same time, the procedures used must bear some relation to domestic laundering habits so that the results obtained are actually relevant to the consumer.

This in fact creates a dichotomy. In order to achieve A the testing regime must be highly formalised and standardised so as to be both reliable and consistent and yet, in order to achieve B, the fabrics and or garments and the laundering conditions assessed must be widely variable because consumers are unreliable and inconsistent, and can vary widely in their laundering habits.

In order to maintain a reasonable time and cost in any such investigations it is important to be able to reduce the number of variables in the experiments to the absolute minimum, consistent with the real world situation. For a rational choice of experimental conditions to be made, it is vital to know in advance which are the most important variables. This is the reason why such a large volume of information has been provided in some detail in **Part 1** of the main body of the report which summarises more than a decade of the IIC's investigations into the subject of shrinkage of cotton knitgoods.

The main objective of the IIC's research into the measurement and development of shrinkage in cotton knitgoods was to develop a reliable and reproducible testing procedure which would **enable** all (or most) of the potential shrinkage in a fabric to be developed so that:

all fabrics could be brought to an equivalent and stable state of relaxation for comparison, thus providing,

a secure point of reference which would enable the dimensions and properties of fabrics to be predicted, so that

manufacturers of cotton knitgoods could know in advance of manufacture at what dimensions a fabric should be finished, in order that

garments will have acceptable levels of shrinkage during domestic laundering and wear.

The main objective of SIFO's proposed studies is to develop information which will enable the consumer to **avoid** developing the full potential shrinkage in a garment.

These two objectives are not incompatible, they are simply addressing the same problem from opposite sides. If we know what conditions are necessary to ensure that the full potential shrinkage (reference state) of a fabric is developed (IIC objective), then we also know what conditions should be avoided in order to prevent the potential shrinkage in a fabric from being developed (SIFO objective).

4. SUMMARY OF EXPERIMENTAL RESULTS

The main conclusions to be drawn from the experimental work summarised in **Part 1** can be grouped under four main headings, as follows:-

4.1 The Starting Material.

The potential shrinkage in a garment when it is received by the consumer has already been fully determined by the type and construction of the fabric from which it is made, and the production and processing history of the fabric and the garments.

The potential shrinkage is defined as the difference between the dimensions of the fabric or garment as new and the dimensions which it will ultimately achieve after multiple cycles of washing followed by tumble drying. (e.g. by relaxation to the reference state). It is important to realise that the consumer can do nothing to alter the potential shrinkage of a given garment.

4.2 Consumer Behaviour and Equipment

The rate at which a particular fabric or garment will develop its full potential shrinkage is governed by the actual conditions of laundering and drying over the lifetime of the garment. Some of the more important factors in this development are:

- the washing temperature and cycle time and the direction of hanging if garments are line dried,
- the conditions of tumble drying, especially the residual moisture content in the garments at the end of the tumble drying cycle,
- the addition of a liquid softener in the washing/rinsing cycle, and
- pressing or ironing between cycles.
- In addition, the interaction between the size of the garment and the size of the wearer may be important for certain fabrics and garment types.

4.3 Remedial Measures

At any point during the lifetime of a given cotton garment some of the shrinkage (or extension) which has been developed during washing and drying is recoverable by changing the conditions of the next laundering and drying cycle. Thus,

- width extension in line drying can be partially recovered by tumble drying (although the length may shrink further),
- shrinkage developed in tumble drying can be partially recovered by rewetting, pulling out the garment by hand, and line drying, and/or reducing the thickness of the fabric by ironing or pressing.

4.4 Experimental Techniques

Measuring shrinkage and developing reliable information on the behaviour of knitted fabrics and especially garments can be influenced by many factors which need to be identified and taken into account if a misleading interpretation of the results is to be avoided. Some variation in the results is inevitable and therefore fabric and/or garment sampling procedures and testing techniques must be carefully controlled to ensure that the results are as consistent and reproducible as possible within practical limitations. Apart from the detail of the experimental procedures it is important to recognise that the only reliable indication of the current dimensions (i.e. degree of relaxation) of a given fabric is how far away it lies from the reference dimensions.

5. CONCLUSIONS

In arriving at a set of conclusions, it has been found useful to consider the following three hypotheses:-

Hypothesis 1

All garments made from knitted cotton fabrics have a certain level of potential shrinkage built into them by the manufacturer. There is nothing that the consumer can do to alter the ultimate level of shrinkage.

Hypothesis 2

All domestic tumble driers are equally capable of developing the ultimate level of potential shrinkage in cotton knitgoods.

Hypothesis 3

*All practically useful recommendations to consumers for slowing down the rate of development of shrinkage can already be deduced from the results of the IIC research, given in **Part 1**.*

If **Hypothesis 1** is held to be true, then the only effective measures which can be taken to aid the consumer lie in the hands of the industry.

Industry must be brought up to date in terms of the new technology and know how which has become available in recent years. This is exemplified by the Starfish quality control and prediction system, developed by the IIC, which is described in **Appendix C**.

In achieving this change in attitude by the industry, consumers and consumer pressure groups may have a role to play in demanding better performance from their purchases.

If **Hypothesis 2** is taken to be true, then there is little point in making comparative studies of different tumble drying machines unless it can be shown that the **rate** of development of the ultimate shrinkage can be influenced by the detailed design of the machine, and/or the way that it is operated.

Very little has been published about the effect of tumble drying machine design parameters upon the rate of development of shrinkage. The only factor which is known to be important is the final moisture content of the garments. Therefore, we can assume that it should be beneficial to include some kind of humidity or temperature sensor to determine the point at which the load has reached its "natural" moisture content so that overdrying can be prevented. There are a few tumble drying machines which do have such control equipment but their effectiveness has not been systematically studied.

Other machine design parameters which can be imagined to have an influence on the rate of development of shrinkage are the following:-

Temperature control mechanism (crude or fine)
Rate of energy supply (average temperature, rate of flow)
Absolute drum size and speed of rotation (impact energy)
Relative drum size (volume of drum to weight of load)

These variables are chosen on the assumption that the key factors will be the rate of drying, the uniformity of drying (from garment to garment), the amount of agitation, and the accuracy of control at the critical point when the moisture content of the garments is just above the natural level.

In **Part 2, Section A** more detailed consideration is given to the way that some of these variables might be investigated systematically.

If **Hypothesis 3** is considered to be true, then the following recommendations could be made to consumers:-

1. When purchasing garments made from knitted cotton fabric;

   - inspect the label to see if tumble drying is recommended or not specifically prohibited,
   - ask the shop assistant about shrinkage and tumble drying,
   - make sure that an appropriate size is selected.

2. When purchasing a tumble drier;

   - find a model with a humidity controller,
   - find out how it the controller works;
   - is it simply designed to conserve energy **after** the load is thoroughly dry, or
   - does it **preserve** the natural moisture content?

3. When laundering garments made from knitted cotton fabric;

   - use a liquid softener in the rinse,
   - never allow the load to overdry,
   - iron after laundering.

4. If shrinkage is excessive;

   - discontinue tumble drying for the remaining lifetime of the garment,
   - on the next laundering cycle attempt remedial action, by
   - line drying and pulling back to shape while damp,
   - complain to the vendor of the garment.

However, there are several aspects of consumer behaviour which have not been investigated systematically and which may have an influence on the rate of development of the ultimate shrinkage. Some questions which could be used to guide such an investigation are the following:-

Is it better to dry for a longer period of time at the low temperature setting, or the opposite?

Are the recommended loads (which are generally rather heavy) the best ones, or should the load be reduced to provide more rapid and uniform drying?

What is the consequence of overloading?

Is it advisable to make sure that the load contains garments with similar drying characteristics (i.e. lightweight versus heavyweight fabrics)?

What is the effect of overdosing the softener - either just once or regularly?

Does it make a difference whether the softener is applied as part of the detergent, as an addition to the rinse, or in the tumble drier itself?

Is there an interaction between softener and ironing?

If the tumble drier does not include a humidity control device, how does the consumer establish a simple routine to ensure that clothes are not overdried?

Does it matter if the drying load contains garments made from synthetic or regenerated cellulose fibres as well as cotton? Are the proportions by weight of pure cotton to non-cotton garments important?

Does it help if the first one or two times that a new garment is laundered, it is line dried (i.e. never tumble dry a new garment)?

In **Part 2, Section B**, detailed consideration is given to the way that some of these variables might be investigated systematically.

6. RECOMMENDATIONS

The following recommendations follow naturally from the conclusions arrived at in the previous section. If all of the recommendations were actually to be implemented, in full, then the problem of shrinkage in garments made from knitted cotton fabrics would disappear. However, they imply a very large level of expenditure both by industry and academic institutions so that it would be unrealistic to assume that all of the measures indicated can be taken in the short term. However, the list does provide a series of target objectives from which a selection can be made by appropriate organisations in order to achieve some progress in defined areas.

1. The cotton knitgoods and garment industry must be made aware that high levels of shrinkage are not inevitable. The appropriate basic research has been done and both the tools and the technology are available to help them to bring down the levels of shrinkage which they are building into their cotton garments.

2. The tumble drying machinery industry must be made aware of the effect of overdrying. It is surely not beyond their powers to design and build effective humidity monitors into their machines and to use them to interrupt the drying process when the moisture content of the garments has been reduced to just above the natural level.

3. Additional research may be needed into certain aspects of tumble drier machine design to see whether other features of this equipment can be improved with regard to slowing down the rate of development of shrinkage of cotton garments.

4. Consumers should be made aware of the fact that both the textile industry and the drying machine builders could serve them better if they chose to. Industry has a good record of responding to a clearly expressed consumer demand.

5. Consumers can be provided with a few simple guide-lines to help them ameliorate the rate of development of shrinkage in cotton knitted garments.

6. Some additional research into the effect of different laundering procedures upon the rate of development of shrinkage may be useful in arriving at a few further simple guide-lines for consumers.

PART 1

A SUMMARY OF SOME OF THE EXPERIMENTAL WORK CARRIED OUT BY THE IIC ON THE SUBJECT OF SHRINKAGE IN COTTON KNITGOODS

1. INTRODUCTION AND BACKGROUND

Systematic investigations into the factors which can affect the measurement and development of shrinkage in cotton knitgoods have been carried out by the IIC more or less continuously since 1976.

They can be grouped into three main areas of research:-

A. Establishing a reliable and reproducible testing procedure which can be used on a routine basis to bring all fabrics to an equivalent state of relaxation for comparison, (Reference State).

B. Evaluating the influence of fabric production and processing variables on the dimensions of the fabric in its Reference State (Reference Dimensions) so that the fundamental causes for differences in fabric dimensions and performance can be identified.

C. `Relating the information obtained regarding fabric shrinkage and the Reference State to the measurement and development of shrinkage in garments after standard laboratory laundering procedures and during domestic laundering and wear.

These investigations were undertaken as an integral and essential part of the Starfish knitgoods research project(1) the overriding objective of which is the elimination of shrinkage as a problem for manufacturers and consumers of cotton knitgoods.

1.1 Definition of Shrinkage (General)

The consumer's perception of shrinkage can be simply defined as the difference between the dimensions of a garment when new compared to the dimensions of the same garment after one or more cycles of domestic laundering and wear.

Unfortunately this simple definition is not sufficient to adequately explain why apparently similar fabrics or garments shrink by different amounts during domestic laundering and wear.

The amount by which a fabric or garment shrinks during laundering depends on its dimensions **before** laundering as well as after laundering. However, the dimensions of a fabric in its delivered or new state are relatively unstable, can be variable, and are affected by many things not least of which is handling by the consumer or testing technician. This can lead to problems in interpretation and makes the evaluation of the behaviour of different fabrics difficult if the only basis for comparison is the shrinkage result obtained.

In addition, depending on the construction and processing history of the fabric used in the construction of the garment, different laundering and or drying procedures can cause the fabric, and therefore the garment, to relax or shrink by different amounts and at different rates.

Therefore, in order to be able to understand why fabrics and garments shrink by different amounts in use it is necessary to define the relaxation shrinkage of a fabric or garment in terms of a standard relaxation procedure. This procedure must be not only reliable, consistent and reproducible but also capable of bringing all fabrics to an equivalent and stable state of relaxation by enabling all (or most) of the potential shrinkage in the fabric to be developed. The dimensions of a fabric in this "equivalent and stable state of relaxation" then provide a reference point for making comparisons between fabrics of different construction and processing history and, in addition, between the relative effects of different laundering conditions on the development of shrinkage.

Furthermore, if the "stable" or "reference" state dimensions of a fabric are known in advance of manufacture then it is relatively easy to calculate the dimensions at which that fabric should be delivered in order to avoid excessive or unacceptable levels of shrinkage in use.

1.2 Definition of a Reference State of Relaxation

The definition of a "stable" state of relaxation in which to make comparisons has occupied research workers in the field of fabric geometry for many years [2,3,4,5,6,7,8], and several "stable" states have been proposed.

e.g. Dry relaxed, wet relaxed, fully relaxed.

These "stable" states were, respectively, achieved by relaxation of the fabrics in air, in water, and by wetting and tumble drying.

Although all of these "stable" states provided some basis for making comparisons, in all cases further significant changes in fabric dimensions can be developed if the conditions of relaxation are changed, e.g. air relaxed or wet relaxed, or if multiple relaxation cycles are used. In addition, because the dimensions of fabrics can continue to change, can change by different amounts and at different rates, and can be influenced by handling, the variation in the results obtained even on specimens of the same fabric using these relaxation methods can be unacceptably high.

Thus, none of these so called "stable" states which had been proposed met our criteria for a standard procedure which would be consistent and reproducible and bring all fabrics to an equivalent reference state of relaxation for comparison.

In addition, at the time when the IIC began to make systematic investigations into the shrinkage of cotton knitgoods, most of the national and international standard testing procedures for assessing dimensional change (shrinkage) in fabrics were based on methods which had become standard for woven fabrics and used traditional relaxation or laundering procedures, e.g. wetting out or washing followed by flat drying. None were available, apparently, which had been designed specifically for the determination of shrinkage in cotton knitgoods. Furthermore, preliminary studies had soon made it clear that these recognised standard procedures were insufficient to develop an "equivalent and stable" state of relaxation or produce reliable and reproducible results from cotton knitgoods.

However, there was some evidence from published research data that a reliable "stable" state for cotton fabrics could be achieved if multiple cycles of thorough wetting followed by a drying procedure which provided heat and agitation were utilised. e.g. after several cycles of machine washing and tumble drying. For example, one piece of research, reported by Knapton, Truter and Aziz [9], although demonstrating that cotton knitgoods could continue to shrink during at least ten cycles of washing and tumble drying, indicated that in fact the changes in dimensions and shrinkage were very small after the completion of five cycles.

Therefore, initial research carried out by the IIC concentrated on the development of a standard, practical and reliable relaxation testing procedure, which could be used on a routine basis to bring all fabrics to an equivalent stable reference state of relaxation in order that realistic comparisons could be made between different fabrics produced under commercial conditions.

The main method of relaxation chosen for investigation was machine washing followed by tumble drying as this seemed to be the only method available which would enable all our criteria to be fulfilled. Aspects which were studied included the preparation of shrinkage specimens, (the effects of specimen size, methods of marking and measuring, number of replications), the conditions of washing, (influence of detergent, cycle time and temperature, fabric conditioner, number of cycles), the conditions of drying (time, temperature, moisture content, number of cycles), the influence of conditioning. In addition complementary studies were carried out using line drying for comparison and reference.

This then was the background to the development of the IIC Reference Relaxation Procedure for cotton knitgoods.

Once a satisfactory procedure had been established, fabrics which had been relaxed by it were defined as being in the Reference State of Relaxation.

1.3 Definition of Shrinkage (Specific)

Once a Reference State of relaxation has been established it is possible to define fabric or garment shrinkage in more specific terms. That is shrinkage can now be defined as the difference in fabric or garment dimensions as delivered or new compared to the dimensions of the same fabric or garment after relaxation to the Reference State.

In addition, once a Reference State of Relaxation has been defined then those factors which,

a) prevent the Reference State from being achieved, or

b) cause the Reference State of a fabric knitted to the same construction (yarn count and stitch length) to change,

can be identified and the potential shrinkage in a fabric or garment in any other condition or state of relaxation can be predicted.

The research into the factors which can affect the measurement and development of shrinkage in cotton knitted fabrics and garments which has been carried out so far has been neither exhaustive nor comprehensive in all its aspects. It does however provide a background of information and experience which can be utilised as a basis for the design of complementary studies directed specifically at the needs and requirements of the consumer.

The results obtained from the trials described in **Part 1** of this report are therefore included in order to provide a background for the recommendations given in **Part 2**. The importance for the accurate measurement and evaluation of shrinkage of the reproducibility and consistency of the testing procedure, the influence of differences in the construction and processing history of the fabrics, and the effect of differences in the laundering (washing and drying) conditions are addressed. In addition some of the extra difficulties associated with the evaluation of garments due to unavoidable differences in the dimensions of the fabrics from which they are manufactured are highlighted.

A. FACTORS WHICH CAN AFFECT THE MEASUREMENT OF SHRINKAGE AND THE DEFINITION OF A REFERENCE STATE OF RELAXATION

1. INTRODUCTION

The results obtained from any testing procedure are subject to a degree of uncertainty. Therefore, in order to obtain reliable and reproducible results those factors which can influence the level of variation both within a laboratory and between laboratories have to be eliminated or at least very well controlled.

Knitted fabrics are easily distorted and can be variable in their dimensions throughout a piece. It is therefore necessary, when testing knitted fabrics, to ensure that the normal spread of variations found within the fabric as a consequence of its manufacture are adequately represented, while at the same time removing those avoidable sources of variation which can influence the reliability of the results.

During the development and refinement of the Reference Relaxation Procedure many of the factors which can influence the reliability and reproducibility of the relaxation procedure, the definition of the Reference State, and the measurement of shrinkage have been investigated. Some of the most important of these are discussed in the following pages.

2. SAMPLE PREPARATION

2.1 Size of Test Specimen.

An early trial [10] looked at the reproducibility of shrinkage measurements compared to the size of the test specimen and test area, the number of test specimens (replications) per sample, and the effect of the number of washing and tumble drying cycles. Also considered was whether the specimens should be flat or tubular.

Two fabrics were used, both 24 gauge plain single jersey constructions of similar knitted stitch lengths and resultant yarn counts. The main difference between them was that one was knitted from singles yarn (Ref. CK 169) and the other was knitted from twofold yarn (Ref. CK 157). Both fabrics were in their greige or machine state (not finished).

From each fabric roll three sets of test specimens were prepared, as follows:-

Set 1 Five specimens 12 inches (30.5 cm) square.
Each specimen was marked with a 10 inch (25.4 cm) square test area by placing 3 measuring marks, using an indelible pen, on each side of the square. Total 5 replications.

Set 2 Five specimens 30 inches (76 cm) square.
Each specimen was marked with a 24 inch (61 cm) square test area by placing 3 measuring marks, using an indelible pen, on each side of the square. Total 5 replications.

Set 3 Three specimens, each 30 inches long and the full tubular width of the roll.
On each specimen two test areas were marked with a 24 inch (61 cm) square test area as above. One on either side of the fabric tube. Total 6 replications.

After preparation all the specimens were conditioned flat before remeasuring prior to laundering.

Laundering was carried out in a Hoover automatic domestic washing machine using a 60°C wash cycle. Tumble drying was carried out in a Hoover domestic tumble drying machine at the high temperature setting. The samples were tumble dried until dry.

Each set was washed and tumble dried a total of five times. At the end of each cycle the specimens were reconditioned and remeasured.

Average length and width percentage shrinkages were calculated for each specimen (replication) from the three measurements for length and width respectively and from these the average values plus 95% Confidence Limits were calculated for each sample and each set.

For each specimen size (set) the average levels of shrinkage measured per sample increased with the number of cycles of washing and tumble drying. In addition, the difference in length shrinkage between one and five cycles was greater than the difference in width shrinkage. This is illustrated in **Table 1** which gives the differences in length and width shrinkage between one and five cycles for the two fabric samples for each set of specimens.

Table 1

Difference in Shrinkage between One and Five Cycles of Washing and Tumble Drying

	CK169		CK157	
	Length %	Width %	Length %	Width %
Set 1	1.4	0.5	2.1	1.1
Set 2	2.9	1.6	2.2	1.5
Set 3	2.0	1.2	1.1	1.0

However, for a given specimen size the variability of the shrinkage results obtained for each sample set, as indicated by the 95% Confidence Limits, did not appear to change with the number of cycles. Similar values were recorded after each cycle. Therefore, to see if the reproducibility of the results was affected by the size of specimen/test area measured the 95% Confidence Limits were averaged over all five cycles for each sample set. These results are given in **Table 2.** N.B. The Confidence Limits for Set 3 were recalculated on the basis of five specimens (replications) in order to obtain a direct comparison with the other two sets.

Table 2

95% Confidence Limits for Five Replications averaged over Five Cycles of Washing and Tumble Drying

	CK169		CK157	
	Length	Width	Length	Width
Set 1	1.14	1.26	1.48	1.06
Set 2	0.68	0.46	0.76	0.48
Set 3	0.60	1.23	1.63	1.51

These results appeared to indicate that:-

a) the size of the test specimens/measured test area can affect the reproducibility of the shrinkage results. The results from Set 2 (24 inch test area) were less variable than the results from Set 1 (10 inch test area).

A simple explanation for this can perhaps be found if consideration is given to the potential additional source of variation due to measuring error.

For example, it is difficult to consistently measure knitted fabrics more accurately than to 0.1 of a cm. Therefore, for a 25 cm test length the potential error in measurement could be $\pm$ 0.2 cm or 0.8% in shrinkage, whereas for a 61 cm test length the same error is equivalent to only 0.3%

b) tubular specimens were on average less reproducible than flat samples.

An explanation for this could also be found by reference to the testing technicians who had reported that it had been much more difficult to accurately measure the tubular specimens than the flat specimens. This was probably due mainly to the relatively large size of the specimens and the tendency of the two sides of the tube to stick together making it difficult to lay the specimens flat without stretching. In particular, it was noted that the fabric made from singles yarns, which had spiralled badly during the laundering procedure, had been more difficult to measure than the fabric made from twofold yarns.

Thus it appeared that in order to achieve an accuracy of, at least, $\pm$ 1% in the measurement of shrinkage, the size of the specimen/measured test area, its shape (tubular or flat), and the number of replications all had to be considered.

In addition, although the number of cycles included in the test did not alter the reproducibility of the shrinkage results obtained, the fabrics continued to shrink over the five cycles of washing and tumble drying. This confirmed the results of other studies which had determined that in order to develop all of the potential shrinkage in a fabric several cycles of laundering and tumble drying are required.

On the other hand, the size of the specimen/measured test area did not appear to significantly influence the average levels of shrinkage recorded, similar values were recorded for each set of samples after the five cycles.

On the basis of these results a provisional testing procedure was established which specified five cycles of washing and tumble drying, using five replicate single thickness specimens per sample each with a measured test area of 24 inches (61 cm).

The size of specimen was later modified, following the adoption of metric measuring, to a 70 cm square containing a measured test area of 50 cm square. In addition, for occasions when insufficient fabric was available to carry out testing on the full size specimens an alternative specimen size of 45 cm square containing a test area of 25 cm square was also specified. This was allowed on the basis that specimen size did not appear to influence the average levels of shrinkage recorded, although it was recognised that the reproducibility of the results may not be as good.

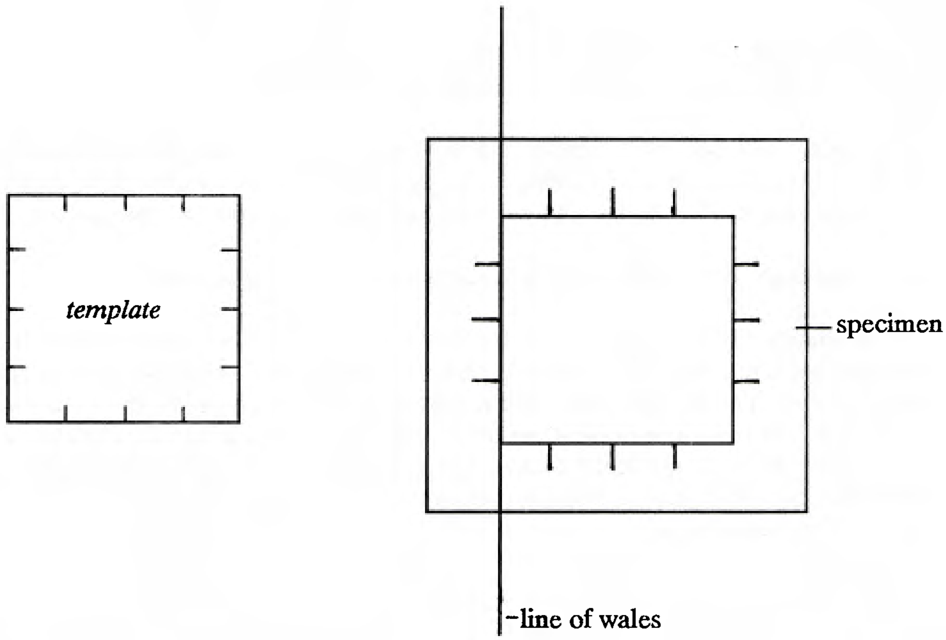
2.2 Marking of the Test Specimens

The method of marking specimens for shrinkage testing was also considered in an attempt to eliminate (control) variation in the results due to errors or inconsistencies in the marking and measuring procedure.

Originally measuring marks were placed on the specimen using a ruler. However, when using only a ruler it is difficult to ensure that the pairs of measuring marks are located perpendicular to each other or that the test area which is defined by them is a perfect square. It is also very easy to locate the three marks for width on different wales, especially when a fine gauge fabric with very small stitches is being prepared.

This potential source of variation becomes most evident if consideration is given to the tendency of single jersey fabrics produced from singles yarns to twist or spiral during laundering [11]. When this occurs the

Diagram 1



original square test area is distorted into a parallelogram. If the original test area is accurately located and is a perfect square then the effect of spirality on the shrinkage measurements can be calculated, and if required taken account of, by measuring the appropriate angle and applying the simple rules of geometry. (The angle of spirality was defined by Nutting [12] as the angle between the line of wales and the perpendicular to the line of courses). If on the other hand the original test area is not a perfect square and is not accurately lined up with the line of wales then this calculation cannot be made with any certainty. Similarly the accuracy and reproducibility of measurements within and between specimens may be affected because the relative orientation of the individual measuring marks may have changed by differing amounts on different specimens.

In addition, depending on the technician, the thickness of the measuring marks which are drawn on the samples can vary and different technicians can choose to take measurements from different sides of the mark.

In an attempt to exert stricter controls over these variables shrinkage templates were adopted to ensure that the measuring marks were located consistently by different operators on different occasions. The templates are made of clear perspex, and the three measuring positions are accurately located and etched onto each side of the square. Specimens are marked by placing one side of the square template aligned with a wale and drawing round the square. Measuring marks are located according to the positions indicated on the template by a line drawn perpendicular to the side of the template. The distance between the marks is then remeasured using a ruler from the inside of the line describing the square at the measuring positions. **Diagram 1.**

This marking and measuring procedure ensures the minimum of variation in technique between technicians and between the marking of individual specimens. Length shrinkage is calculated from the changes in length (along a wale), and width shrinkage is calculated from the changes in width between marks which were originally located perpendicular to wales.

2.3 Number of Replications per Sample

2.3.1 50 cm. square Test Area

The results of the early trial, reported in 2.1 above, indicated that at least five replications are required to ensure that measurements of shrinkage are reproducible to $\pm$ 1%. In a later and much more substantial trial [13,14] covering a wider range of fabric types (interlock, 1x1 rib, single jersey), constructions (yarn counts and stitch lengths), and finishes (grey, jet dyed, mercerised, cross-linked), this aspect of the testing procedure was examined further.

In this trial twenty different fabrics were subjected to 10 cycles of machine washing and tumble drying. Average length and width shrinkages per fabric sample were calculated after each of the ten laundering cycles on the five replicate specimens (50 cm square test area).

Similarly to the first trial, it was found that for a given fabric type the reproducibility of the shrinkage measurements as indicated by the 95% Confidence Limits are on average unaffected by the number of laundering cycles. They were more or less the same for each cycle.

On the other hand, the reproducibility of the results did seem to be influenced by the particular type of fabric under test. Some of the fabrics (particularly 1x1 rib) were more variable than others. In addition, width measurements were more variable on average than length measurements.

However, as the level of variation within a given fabric did not appear to be influenced significantly by the number of laundering cycles, the 95% Confidence Limits were averaged over all fabrics for the fifth cycle. These were calculated at 0.8% in length and 1.1% in width.

From these average results the effect on Confidence Limits of reducing the number of replications was calculated. These are given in **Table 3.**

Table 3

Effect on 95% Confidence Limits of Reducing the Number of Replications per Sample

Replications	95% Confidence Limits Length	Width
5	0.8	1.1
4	1.0	1.3
3	1.3	1.8
2	~2.0	~3.0

These results confirmed the earlier findings. In order to achieve the required level of reproducibility in shrinkage testing and maintain the average 95% Confidence Limits over all fabric types and finishes to within ± 1%, at least four and preferably five replications per sample are required.

2.3.2 25 cm. square Test Area

In the first trial, the size of the specimen/measured test area had also been shown to have an effect on the reproducibility of shrinkage measurements although not on the average levels of shrinkage measured. This point has also been confirmed.

An analysis of many hundreds of shrinkage results obtained by the IIC laboratory over a number of years on samples of 25 cm test area compared to the 50 cm test area, confirmed that:-

1. on average there is no significant difference between the levels of shrinkage obtained after five cycles of laundering and tumble drying from the two specimen sizes/measured test areas, and

2. the reproducibility of the results obtained from 5 replicate specimens of 50 cm square test area are on average better than can be obtained using 5 replicate specimens of 25 cm square test area.

   From the results it was calculated that in order to achieve the same level of reproducibility (95% Confidence Limits) when the 25 cm square test area is used, the number of replications should be increased to six.

3. LAUNDERING PROCEDURE

The importance of the detail of the laundering procedure depends to a very large extent on the method of drying to be used. If tumble drying follows washing there appears to be little if any significant influence of, for example, time (length of cycle), temperature, or type of detergent.

3.1 Effect of Substituting Rinse Cycles for Washing Cycles

As part of the same study mentioned in 2.3 above [13,14], shrinkage measurements were made on duplicate sets of specimens prepared from the same fabrics after 1 cycle of machine washing and tumble drying followed by 4 cycles using the rinse only cycle followed by tumble drying.

For both sets of specimens washing and/or rinsing was carried out in a Hoover automatic domestic washing machine. Tumble drying was carried out in a Hoover domestic tumble drier at the hottest temperature setting until the specimens were dry.

Table 4
Shrinkage Results Averaged Over Cycles

Fabric Reference		Length Shrinkage % Set 1	Set 2	Width Shrinkage % Set 1	Set 2
1	IJDH	17.4	17.4	6.3	7.3
2	IMJDH	16.4	18.1	5.6	5.6
3	RJDH	18.5	17.5	5.3	9.2
4	RMJDH	20.2	21.2	3.6	3.7
5	SJ2G	20.5	20.7	16.1	15.5
6	SJ1G	22.5	23.2	16.5	14.1
7	IntG	24.2	23.6	11.1	12.4
8	RibG	16.9	16.2	19.9	21.4
9	IMJDX	9.8	9.7	10.1	9.3
10	IJDX	15.1	14.6	9.4	9.0
11	RMJDX	11.1	11.1	10.1	10.9
12	IJDX	12.3	10.9	7.0	8.2
13	IMJDH	16.7	17.2	4.3	4.4
14	IJDH	13.8	12.7	7.5	8.3
15	RJDH	11.1	7.9	5.6	10.1
16	RMJDH	11.5	12.3	5.0	5.1
17	SJ1BRAZ	13.4	13.6	10.9	11.1
18	SJ2BRAZ	10.7	11.0	11.5	13.1
19	SJ2MBRAZ	6.1	6.3	21.1	21.2
20	SJ1MBRAZ	14.6	15.9	16.7	16.2
	mean	15.1	15.1	10.2	10.8
	sd	4.6	4.9	5.3	5.0

The full washing cycle for this machine takes approximately 52 minutes and includes washing at 60°C with detergent, five rinse cycles and two spin cycles of 2 and 4 minutes respectively. The rinse cycle utilised was the last part of the full 60°C washing cycle, i.e. two cold water rinses (no detergent) followed by a four minute spin, and is considerably shorter in duration.

The results obtained from the two sets of specimens, Set 1: five full cycles of washing and tumble drying, and Set 2: one full cycle of washing and tumble drying followed by four reduced cycles of cold water rinsing followed by tumble drying, were compared.

Figure 1 compares the average shrinkage results obtained for each set after the first cycle (full washing for both sets).

For the first cycle, in which the washing procedure was identical for both sets, linear regression analysis yielded a slope not significantly different from 1.0 with a correlation coefficient of $r = 0.96$ and a mean deviation of about 1% of shrinkage. The bulk of the data lay between ± 2% of equality.

If the two methods are returning the same results over all 10 cycles then comparisons of the results obtained from the two sets for cycles 2 to 10 should conform to about the same level of agreement as was found for the first cycle. The correlation coefficients were in fact found to be between 0.96 and 0.97 with mean deviations in the range 0.8 to 1.2. There were no particular trends apparent as the number of cycles increased.

Figure 2 shows the plot of all the shrinkage results comparing the two methods. By far the greatest proportion of these data lie within plus or minus 2% of the equality line.

Finally, the results obtained from all the fabrics within a set were averaged over all ten laundering cycles. These data are given in **Table 4.**

With two exceptions, fabrics 3 and 15 (both 1x1 rib fabrics), the two methods seem to be returning results which, on average, are not significantly different.

Thus it was deduced that the substitution of a cold water rinse for the full wash cycle after the first cycle did not significantly affect either the absolute levels of shrinkage obtained or the reproducibility of the results. However, the testing time was significantly reduced, which is a clear advantage.

3.2 Effect of Temperature and the Length of the Washing Cycle

Another trial investigated the potential influence on the development of shrinkage of differences in the time and temperature when full washing cycles are utilised [15].

This was done by comparing the dimensions of fabrics which had been subjected to 1) the "Minimum Iron" washing cycle compared to those obtained on fabrics which had been washed using 2) the "Fast Coloured" cycle.

Both sets of specimens were tumble dried until dry, after each washing cycle, in a Hoover domestic tumble drying machine set at the hottest temperature setting.

Ten different fabrics were used in the trial. These included samples of 1x1 rib, interlock and single jersey constructions, and examples of grey, bleached, dyed, and mercerised and dyed fabric.

The "Fast Coloured" (FC) programme includes a wash at 60°C, three rinse cycles followed by a 2 minute spin, and two rinse cycles followed by a 4 minute spin. The total cycle time is approximately 52 minutes.

The "Minimum Iron" (MI) programme includes a wash at 50°C followed by three rinse cycles. At the end of the final rinse the machine waits until instructed to carry out the final spin. This lasts for approximately 2 minutes. Total cycle time is approximately 36 minutes.

Table 5

Shrinkage Measurements after One Cycle of Washing and Tumble Drying for Ten Different Fabric Samples

Fabric Reference		Length Shrinkage % FC	MI	Diff.	Width Shrinkage % FC	MI	Diff.
1	SJ2MBRAZ	7.0	8.2	+1.2	20.0	19.0	-0.1
2	SJ1MD	13.0	13.6	+0.6	15.5	15.9	+0.4
3	RWB	6.0	5.8	-0.2	9.5	9.5	0
4	IWD	17.9	16.8	-1.1	11.4	10.8	-0.6
5	IWB	10.0	9.6	-0.4	3.8	4.2	+0.4
6	IWD	13.8	14.0	+0.2	13.0	13.3	+0.3
7	REJD	18.0	16.9	-1.1	15.6	14.0	-1.6
8	SJ1RS	6.8	6.7	-0.1	11.6	11.4	-0.2
9	SJ1BRAZ	9.7	9.6	-0.1	7.8	8.0	+0.2
10	RMJD	14.7	14.9	+0.2	15.9	15.6	-0.3
	mean	11.7	11.6	-0.1	12.4	12.2	-0.1
	sd	4.5	4.1	0.7	4.7	4.3	0.8

Table 6

Shrinkage Measurements after Five Cycles of Washing and Tumble Drying for Ten Different Fabric Samples

Fabric Reference		Length Shrinkage % FC	MI	Diff.	Width Shrinkage % FC	MI	Diff.
1	SJ2MBRAZ	9.2	10.3	+1.1	19.7	18.8	-1.1
2	SJ1MD	17.3	19.0	+1.7	14.9	13.9	-1.0
3	RWB	7.7	8.1	+0.4	8.7	8.8	+0.1
4	IWD	21.9	21.7	-0.2	10.1	9.4	-0.7
5	IWB	12.4	13.5	+1.1	3.5	3.7	+0.2
6	IWD	17.0	18.1	+1.1	13.4	13.0	-0.4
7	REJD	21.6	21.5	-0.1	8.3	6.6	-1.7
8	SJ1RS	7.7	8.2	+0.5	12.7	12.2	-0.5
9	SJ1BRAZ	11.1	11.5	+0.4	7.9	8.6	+0.7
10	RMJD	17.2	18.3	+1.1	14.1	14.4	+0.3
	mean	14.3	15.0	+0.7	11.3	10.9	-0.4
	sd	5.4	5.3	0.6	4.6	4.4	0.7

Shrinkage measurements were made after one and five cycles of washing and tumble drying. The results are given in **Tables 5 and 6.**

Although there is a suggestion that the "Minimum Iron" washing cycle may be returning slightly higher length shrinkage results after five cycles of washing and tumble drying, the difference is not statistically significant. Thus, on the average, the two washing cycles are returning essentially the same results over a wide range of fabrics, finishes and levels of shrinkage. These results therefore appeared to confirm that the washing temperature and particularly the length of the washing cycle, do not have a significant influence on the level of shrinkage developed when washing is followed by tumble drying.

3.3 Effect of Detergent

A small trial [16] was carried out to evaluate whether the type of detergent used in the washing cycle could influence the reference state dimensions of cotton knitted fabrics. The comparison was made between a standard domestic detergent (Persil Automatic) and the EEC standard detergent as specified in ISO 6330 : 1984.

Ten replicate specimens were prepared from ten different fabric qualities including interlock, 1x1 rib, and single jersey. Mercerised, dyed and finished samples were included as well as "standard" dyed and finished samples.

Half the specimens were washed using Persil, the other half were washed using the standard EEC detergent. In all other respects, washing machine, washing and rinsing cycles, tumble drying procedure etc., the two sets of fabrics were treated in identical manner.

The average dimensions, courses per 3 cm, wales per 3 cm, weight gsm, yarn count and stitch length, were measured after completion of the two trials.

A statistical analysis of the two sets of data using the Student's t-Test showed no significant difference in the values returned for courses, wales, weight and tex at the 5% level. The results for stitch length were significant at the 5% level but not at the 1% level. **Table 7.**

Table 7

Comparison of Persil and EEC standard detergent

	t
Courses/3cm	1.39
Wales/3cm	1.93
Weight gsm	1.53
Tex	0.93
Stitch Length mm	2.90 (significant at 5% but not at 1%)

As no significant differences were found in the Reference State measurements of courses and wales it can therefore be assumed that the choice of detergent is unlikely to influence the development of shrinkage.

So far, no detailed studies have been carried out to investigate whether, e.g. the size of load, proportion of test specimens in the load, composition of make-weights etc. in the washing cycle have a significant effect on the measurement of shrinkage or the dimensions of the reference state. However, it appears from the investigations into washing conditions which have been made that, for cotton knitgoods in particular, it is the multiplicity of wetting out and tumble drying which has the overriding influence on the ultimate relaxation shrinkage of a fabric. This of course is not necessarily the case for fabrics or garments made from other fibres, and in addition depends on the conditions of tumble drying being carefully controlled. This particular aspect of the laundering procedure will be dealt with in a later section.

Table 8

Effect of Adding Softener to the Final Rinse of the Washing Cycle on Fabric Shrinkage after Five Full Cycles of Washing and Tumble Drying

Fabric Reference		Length Shrinkage % Set 1	Set 2	Diff.	Width Shrinkage % Set 1	Set 2	Diff.
1	SJ Tight	14.1	13.7	-0.4	11.5	11.5	0
2	SJ Slack	15.5	14.2	-1.3	8.2	9.6	+1.4
3	Rib Tight	11.6	10.1	-1.5	5.8	8.2	+2.4
4	Rib Slack	21.5	19.4	-2.1	0.9	4.8	+3.9
5	Int Tight	17.7	15.5	-2.2	7.7	10.3	+2.6
6	Int Slack	22.3	20.5	-1.8	10.0	12.0	+2.0
	mean	17.1	15.6	-1.6	7.4	9.4	+2.1
	sd	4.2	3.9	0.7	3.7	2.6	1.3

Table 9

Effect of Adding Softener to the Final Rinse of the Washing Cycle on Fabric Shrinkage after Ten Full Cycles of Washing and Tumble Drying

Fabric Reference		Length Shrinkage % Set 1	Set 2	Diff.	Width Shrinkage % Set 1	Set 2	Diff.
1	SJ Tight	14.1	14.1	0	11.4	10.8	-0.6
2	SJ Slack	15.6	14.5	-1.1	7.3	9.6	+2.3
3	Rib Tight	12.1	10.7	-1.4	4.0	6.6	+2.6
4	Rib Slack	21.9	20.0	-1.9	-4.6	1.4	+6.0
5	Int Tight	18.6	16.0	-2.6	5.1	9.3	+4.2
6	Int Slack	22.5	20.7	-1.8	6.0	10.6	+4.6
	mean	17.5	16.0	-1.5	4.9	8.1	+3.2
	sd	4.2	3.8	0.9	5.3	3.6	2.3

These comments notwithstanding, normal IIC laboratory testing procedures ensure that when testing fabrics or garments for shrinkage the loading of the washing machine is always maintained at the standard dry weight recommended by the machinery manufacturer, and make-weights when required are made up of 100% cotton knitted fabrics of similar size, weight, construction and finish to the specimens undergoing test.

3.4 Effect of Softener

Although generally the detailed conditions of the laundering procedure do not appear to have a significant effect on shrinkage when washing is followed by tumble drying, it was suggested that this may not necessarily be true if a fabric softener is included in the rinse cycle.

In the UK, it is not uncommon for consumers to include a fabric conditioner or softener in the final rinse cycle of the washing procedure. This is supposed to add a pleasant smell to the washing, and give the fabrics a softer and bulkier hand after washing and drying. Therefore it was important to establish if this could have an effect.

Consequently a trial was carried out to investigate whether the addition of a domestic, fabric softener in the washing cycle would have a significant influence on the development of shrinkage and the dimensions of the reference state [17].

Three fabric types, single jersey, 1x1 rib and interlock, each in two fabric qualities one tight the other slack were included in this investigation. All the samples were dyed and fully finished.

Two replicate sets of shrinkage specimens were prepared from each fabric. Shrinkage measurements were obtained on each set after each of ten full washing and tumble drying cycles. Both sets were washed and tumble dried under identical conditions with the exception that the Set 1 specimens were washed using only the standard detergent (Persil), while the Set 2 specimens had the recommended quantity of "Comfort" fabric softener added to the last rinse of each washing cycle.

The average shrinkage measurements obtained from both sets of specimens for the two laundering methods after the completion of five and ten full cycles of washing and tumble drying are given in **Table 8** and **Table 9** respectively.

These results clearly showed that the addition of a fabric softener to the final rinse of the washing cycle can influence the amount of shrinkage which is developed in a fabric. In addition, it appears that the amount by which shrinkage is affected not only depends on fabric type but also on fabric tightness. On average the tighter fabrics show smaller differences than the slack fabrics, although for interlock fabrics the reverse may be true.

In general length shrinkage is reduced and width shrinkage is increased by the addition of softener. For width shrinkage, and for interlock and rib fabrics in particular, the effects appear to increase with number of cycles. For both sets of fabrics width shrinkage is less after ten cycles than after five. There was virtually no change in the average length shrinkage results between five and ten cycles.

As in previous trials there was no particular trend in the 95% Confidence Limits with number of cycles therefore the averages were calculated over all cycles and all fabrics for the two washing conditions. For the fabrics washed without softener (Set 1) the average 95% Confidence Limits were 0.7% for length, and 1.2% for width, which are similar to the results obtained from previous trials. The average 95% Confidence Limits calculated for the fabrics washed and rinsed in softener (Set 2) were 1.0% for length and 1.3% for width, suggesting a slight reduction in the level of reproducibility or an increase in variation in the average results when softener is added.

Therefore for a standard reference shrinkage test it is probably not a good idea to include a fabric softener in the washing procedure. (Detergents used in standard shrinkage testing carried out by the IIC do not contain softener). However, this aspect should be kept in mind when relating laboratory shrinkage testing to normal consumer laundering habits.

Table 10

Effect of Washing Conditions (temperature and cycle time) on Fabric Shrinkage after One and Five Cycles of Washing and Line Drying (samples hung with wales vertical)

Fabric Reference		Temp.	Length Shrinkage % One	Length Shrinkage % Five	Length Shrinkage % Diff.	Width Shrinkage % One	Width Shrinkage % Five	Width Shrinkage % Diff.
1	IWB	cold	11.3	15.2	+3.9	5.1	1.8	-3.3
		40°C	12.6	16.3	+3.7	5.8	3.2	-2.6
		60°C	13.6	16.9	+3.3	4.8	1.6	-3.2
		90°C	14.6	17.9	+3.3	3.9	-0.9	-4.8
2	SJ2MD	cold	-2.1	-2.8	-0.7	14.1	15.6	+1.5
		40°C	-2.7	-2.5	+0.2	15.1	16.3	+1.2
		60°C	-2.0	-2.0	0	15.1	16.1	+1.0
		90°C	-1.9	-1.2	+0.7	15.3	15.7	+0.4
3	RWB	cold	2.9	4.0	+1.1	4.2	3.3	-0.9
		40°C	2.8	3.9	+1.1	5.0	4.3	-0.7
		60°C	3.0	4.2	+1.2	4.6	3.7	-0.9
		90°C	3.5	5.1	+1.6	4.8	2.5	-2.3
4	SJ2MD	cold	11.1	12.8	+1.7	7.9	6.9	-1.0
		40°C	11.8	14.0	+2.2	6.9	5.0	-1.9
		60°C	12.8	14.7	+1.9	6.8	4.9	-1.9
		90°C	12.7	14.7	+2.0	6.8	4.7	-2.1
5	RibG	cold	11.5	15.1	+2.6	3.1	0.8	-2.3
		40°C	13.2	15.2	+2.0	3.5	1.0	-2.5
		60°C	14.5	15.7	+1.2	3.0	0.5	-2.5
		90°C	14.0	15.3	+1.3	2.7	-1.1	-3.8
6	REJD	cold	10.1	13.5	+3.4	8.7	2.5	-6.2
		40°C	11.3	14.7	+3.4	4.8	-2.6	-7.4
		60°C	11.6	14.7	+3.1	2.5	-3.0	-5.5
		90°C	12.6	15.5	+2.9	3.2	-4.2	-7.4

N.B. A minus sign indicates an extension or growth

Table 11

Differences in Shrinkage between One and Five Cycles grouped according to Temperature

Fabric Reference		Length Shrinkage % cold	Length Shrinkage % 40°C	Length Shrinkage % 60°C	Length Shrinkage % 90°C	Width Shrinkage % cold	Width Shrinkage % 40°C	Width Shrinkage % 60°C	Width Shrinkage % 90°C
1	IWB	+3.9	+3.7	+3.3	+3.3	-3.3	-2.6	-3.2	-4.8
2	SJ2MD	-0.7	+0.2	0	+0.7	+1.5	+1.2	+1.0	+0.4
3	RWB	+1.1	+1.1	+1.2	+1.6	-0.9	-0.7	-0.9	-2.3
4	SJ2MD	+1.7	+2.2	+1.9	+2.0	-1.0	-1.9	-1.9	-2.1
5	RibG	+2.6	+2.0	+1.2	+1.3	-2.3	-2.5	-2.5	-3.8
6	REJD	+3.4	+3.4	+3.1	+2.9	-6.2	-7.4	-5.5	-7.4
	mean	+2.0	+2.1	+1.8	+2.0	-2.0	-2.2	-2.2	-3.3
	sd	1.7	1.3	1.3	1.0	2.6	2.6	2.2	2.7

N.B. A minus sign indicates an extension or growth

3.5 Effect of Laundering Conditions when Washing is followed by Line Drying

Although, with the exception of fabric softener, the details of the washing procedure do not appear to have a significant effect on shrinkage if washing is followed by tumble drying, this is not the case if other drying procedures e.g. line drying are used.

When other drying procedures are used the conditions of washing, e.g. time, temperature, duration of the washing cycle as well as the addition of softener can all influence the levels of shrinkage developed and the reproducibility of the results. This then can be another source of variation when trying to relate the results obtained in a laboratory to the domestic laundering situation.

3.5.1 Effect of Temperature and the Length of the Washing Cycle

Similarly to tumble drying, shrinkage in line drying is usually progressive with the number of cycles, although the rate may be slower and the absolute levels measured may be less than when similar samples are tumble dried. In line drying however the conditions of the washing procedure (the temperature and the length of the washing cycle) as well as the number of washing cycles can influence the development of shrinkage in fabrics which are line dried in a standard manner.

Both these points are illustrated by the results obtained from another series of trials [18].

Six fabric samples including single jersey, 1x1 rib and interlock constructions, both grey and finished, were used to prepare four identical sets of shrinkage specimens, (5 x 25 cm square test area). Each set was washed in a Hoover automatic domestic washing machine using one of four different washing conditions. Each set of specimens was washed and dried five times. After each cycle of washing the specimens were hung on a line with the wales running vertically. Shrinkage was measured after the first and fifth cycles. The complete exercise was repeated using replicate sets of specimens taken from the same fabric pieces.

The four washing procedures evaluated were:-

1. "rinse only", cold water, no detergent.
2. "non-fast coloured" cycle, 40°C wash, approximate duration 37 minutes.
3. "fast coloured" cycle, 60°C wash, approximate duration 52 minutes.
4. "whites" cycle, 90°C wash, approximate duration 70 minutes.

N.B. Times are approximate and according to the manufacturers details given in the handbook.

The length and width shrinkage results, averaged across the two replications for each fabric and washing cycle are given in **Table 10**.

These results confirmed that there is a significant effect of the temperature and the length of the washing cycle on the development of shrinkage when line drying follows the washing procedure.

Generally length shrinkage tends to increase with an increase in the washing temperature and cycle time. Width shrinkage on the average decreases. This suggests that an increase in temperature and cycle time is causing fabrics which are line dried to relax more fully. Relaxation is greater after a 90° C wash than after a cold rinse. In addition there is also an indication that the rate of relaxation may be affected by temperature and cycle time.

This is illustrated in **Table 11**, which shows the differences in recorded shrinkage, for each fabric, between one and five cycles grouped according to temperature.

For length shrinkage there is no consistent effect, across all fabric types, of the washing temperature and cycle time, on the rate of relaxation as indicated by the differences between one and five cycles. On the average all the fabrics are shrinking by approximately 2% more after five cycles than after one cycle.

Table 12

Effect of Adding Softener to the Final Rinse of the Washing Cycle on Fabric Shrinkage after Five Full Cycles of Washing and Line Drying

Fabric Reference		Length Shrinkage %			Width Shrinkage %		
		Set 3	Set 4	Diff.	Set 3	Set 4	Diff.
1	SJ Tight	10.0	10.1	+0.1	7.9	9.1	+1.2
2	SJ Slack	12.1	11.9	-0.2	5.1	6.5	+1.4
3	Rib Tight	10.0	10.0	+0.8	1.5	2.5	+1.0
4	Rib Slack	18.8	18.2	-0.6	-15.4	-11.1	+4.3
5	Int Tight	13.3	14.2	+0.9	2.3	3.6	+1.3
6	Int Slack	19.9	18.5	-1.4	-6.3	-1.2	+5.1
	mean	14.0	13.8	-0.1	-0.8	1.6	+2.4
	sd	4.3	3.8	0.9	8.6	7.1	1.8

N.B. A minus sign indicates an extension or growth

Table 13

Effect of Adding Softener to the Final Rinse of the Washing Cycle on Fabric Shrinkage after Ten Full Cycles of Washing and Line Drying

Fabric Reference		Length Shrinkage %			Width Shrinkage %		
		Set 3	Set 4	Diff.	Set 3	Set 4	Diff.
1	SJ Tight	10.0	10.4	+0.4	8.0	7.8	-0.2
2	SJ Slack	12.2	12.5	+0.3	4.7	5.1	+0.4
3	Rib Tight	10.2	11.5	+1.3	0.9	0.3	-0.6
4	Rib Slack	19.3	20.0	+0.7	-23.1	-23.2	-0.1
5	Int Tight	14.6	18.6	+4.0	0.1	-0.4	-0.5
6	Int Slack	19.2	19.6	+0.4	-9.8	-9.7	+0.1
	mean	14.3	15.4	1.2	-3.2	-3.4	-0.2
	sd	4.2	4.4	1.4	11.4	11.4	0.4

N.B. A minus sign indicates an extension or growth

For the width, however, there is apparently a gradual increase in the average size of the differences over washing temperature and cycle time. That is, the absolute differences between one and five cycles are increasing. Since the values are negative this suggests that the rate at which the fabrics are relaxing in the width direction (width expansion) is being accelerated by the increase in washing temperature and cycle time.

3.5.2 Effect of Softener

The addition of fabric softener "Comfort" to the final rinse of the washing cycle has already been shown to affect the shrinkage of fabrics after tumble drying. This is also true for fabrics which are line dried.

As part of the same trial reported in 3.4 (17) two additional replicate sets were prepared from the same fabrics. Set 3 was washed at 60°C, in a Hoover automatic domestic washing machine with standard detergent. Set 4 was washed in the same machine at the same temperature but "Comfort" fabric softener was added to the final rinse of each washing cycle. After washing both sets of specimens were hung on a line to dry (wales vertical). After drying the specimens were measured for shrinkage. Ten full cycles of washing and line drying were carried out on both sets.

The average length and width shrinkage results for each fabric and each washing condition after the fifth and tenth cycles are given in **Table 12** and **Table 13** respectively.

On average there is no effect on length shrinkage from the addition of softener after five cycles although there is a small increase in shrinkage in the tight fabrics and a slight decrease in shrinkage in the slack fabrics. After ten cycles however there is on average a small increase in length shrinkage due to the addition of softener. The size of the effect is dependent on the fabric type and construction.

On the other hand, the effect on the width direction of adding softener is greater after five cycles than after ten. On average width shrinkage is increased (extension is reduced) after five cycles but there is almost no difference between the sets after ten cycles. Similarly to length shrinkage the size of the effect depends on the type and construction of the fabric.

Length shrinkage on average tends to increase with number of cycles, width shrinkage tends to decrease. Where a width extension or growth is developed this increases (the fabric continues to grow) with the number of cycles.

The effect of adding softener on the reproducibility of the shrinkage results can again be assessed by reference to the 95% Confidence Limits. The average 95% Confidence Limits calculated over all cycles and all fabrics for the specimens washed without softener (Set 3) were 1.7% in length, and 2.9% in width. The equivalent values for the specimens washed and rinsed in softener (Set 4) were 1.2% and 2.0% respectively. This suggests that the addition of fabric softener is helping to reduce the variation in measurement. However for both washing conditions the variability in the width measurements, especially for the interlock and rib samples, was much higher than for the length measurements.

4. DRYING PROCEDURE

It has already been shown that the conditions of laundering can influence the shrinkage results if washing is followed by line drying, and also that the addition of fabric softener will affect the results whether washing is followed by line drying or tumble drying.

In addition, however, even when a standardised laundering procedure is maintained the method and conditions of drying can also influence both the absolute levels of shrinkage developed and the variability of the results.

Table 14

Influence of the Direction of Hanging after One Cycle of Washing and Line Drying

Fabric Reference		Length Shrinkage % Vert. Wales	Horiz Wales	Diff.	Width Shrinkage % Vert. Wales	Horiz. Wales	Diff.
1	SJ1D	7.4	7.9	+0.5	6.0	4.8	-1.2
2	SJ1D	7.7	8.1	+0.4	11.6	11.6	0
3	RWB	3.4	4.2	+1.2	2.2	-1.0	-3.2
4	SJ1G	12.7	12.9	+0.2	18.7	18.5	-0.2
5	IWD	13.4	14.8	+1.4	5.2	2.1	-3.1
6	IWB	6.2	5.8	-0.4	0.2	-2.8	-3.0
7	SJ2MD	-2.5	-1.0	+1.5	16.7	15.3	-1.4
8	SJ2MD	-0.5	0	+0.5	19.6	19.7	+0.1
9	SJ2D	8.6	8.6	0	10.1	10.1	0
10	SJ2MD	4.4	5.2	+0.8	7.8	6.4	-1.4
	mean	6.1	6.7	+0.6	9.8	8.5	-1.3
	sd	5.1	5.0	0.6	6.8	7.9	1.3

N.B. A minus sign indicates an extension or growth

Table 15

Influence of the Direction of Hanging after Five Cycles of Washing and Line Drying

Fabric Reference		Length Shrinkage % Vert. Wales	Horiz. Wales	Diff.	Width Shrinkage % Vert. Wales	Horiz. Wales	Diff.
1	SJ1D	8.2	8.9	+0.7	5.7	4.2	-1.5
2	SJ1D	8.8	8.9	+0.1	12.5	12.3	-0.2
3	RWB	4.1	5.9	+1.8	1.9	-2.6	-4.5
4	SJ1G	12.8	14.3	+1.5	19.6	19.1	-0.5
5	IWD	16.8	17.7	+0.9	3.5	-0.6	-4.1
6	IWB	8.2	8.7	+0.5	-1.1	-6.0	-4.9
7	SJ2MD	-2.9	-1.8	+1.1	17.4	16.4	-1.0
8	SJ2MD	-0.9	0.3	+1.2	21.4	20.6	-0.8
9	SJ2D	8.5	9.1	+0.6	10.7	10.4	-0.3
10	SJ2MD	5.9	6.9	+1.0	7.8	5.6	-2.2
	mean	7.0	7.9	+0.9	9.9	7.9	-2.0
	sd	5.9	5.8	0.5	7.7	9.3	1.8

N.B. A minus sign indicates an extension or growth

4.1 Line Drying

4.1.1 The Effect of the Direction of Hanging

Most of the time, garments to be line dried are hung on the washing line with the wales running in a vertical direction down the length on the garment. This is because traditionally garments were constructed from one type or construction of fabric and the laying and cutting of the garment blanks was so arranged that the wales ran down the length of the garment.

Increasingly these days garments are constructed from more than one fabric type and construction (woven as well as knits being included in the same garment), and for design effects the direction of the fabric is often rotated such that the wales run horizontally.

The consumer, however, is unlikely to change her method of pegging these garments on the line. Therefore, there may be occasions when although the garment is hung with the length direction vertical this may not in fact be the length direction of the fabric.

It seems logical to expect that when hanging a wet garment on a line the weight of the wet fabric and the effect of gravity should work to reduce potential length shrinkage. Conversely if the length of the garment is in fact the width of the fabric then the effect of weight and gravity would be to reduce the width shrinkage in the fabric (length in the garment).

In order to discover whether or not there is a measurable influence on fabric shrinkage in line drying dependent on the direction of hanging a small trial was carried out [(19)].

Samples of ten different fabrics (types, constructions, and finishes) were selected and two replicate sets each of five specimens for each sample were prepared. In this trial 25 cm square test areas were used.

Both sets were washed in a Hoover automatic domestic washing machine at 60°C. ("Fast Coloured" wash cycle).

One set was hung on the line to dry with the wales running vertically down the length of the specimens. The other was hung with the wales running horizontally. The washing and drying procedure was repeated a further four times making five cycles in all.

Shrinkage measurements were recorded after the first and fifth cycles. The average length and width shrinkage results obtained for these cycles from both sets are given in **Table 14** and **Table 15** respectively.

From the results of this trial it appears that there is a small (less than 1%) but consistent effect on length shrinkage from the direction of hanging. The samples hung with the wales running vertically having slightly lower length shrinkages than those hung with the wales in a horizontal direction.

In addition, there is also an effect on width shrinkage which is larger than in the length direction. Samples hung with wales running vertically have higher width shrinkages than those with wales running horizontally. The biggest differences are seen in the interlock and 1x1 rib samples where very small width shrinkage/extension results have developed into much larger width extensions. The effect is greatest for the samples with low width shrinkage. For fabrics with high width shrinkage the effects are small.

For both the length and width shrinkage results the size of the differences found between the two sets of specimens varies depending on the fabric type and finish. In the width direction, in particular, the direction of hanging causes the biggest difference in the results from the interlock and rib fabrics.

Thus, although in the main the differences are small, the orientation of a fabric within a garment can influence the shrinkage results obtained and can be another source of variation in shrinkage results obtained using line drying.

For the consumer this effect could increase the potential problem of extension or growth in garments made from susceptible fabrics.

In addition, because the size of the test specimens used in this trial was only 25 cm square, one can speculate that with larger test samples (where the total weight of the fabric plus moisture is greater) or in a garment, the influence of the direction of hanging could be larger.

4.1.2 Reproducibility

The level of reproducibility of shrinkage measurements found in a shrinkage test which includes line drying tends to be worse than for a test which includes tumble drying. i.e. line drying is more variable than tumble drying. This is illustrated if the average results obtained from the standard (i.e. without softener) wash and line dry and wash and tumble dry samples described in the previous sections are compared. **Table 16.**

Table 16

Reproducibility of Shrinkage Results Obtained after a Standard Wash and Line Dry Test Compared to a Standard Wash and Tumble Dry Test. (5 replications over 10 cycles, various fabrics and finishes)

	Average 95% Confidence Limits	
	Line Dry	Tumble Dry
Length	1.7	0.7
Width	2.9	1.2

4.2 Tumble Drying

Although tumble drying may apparently give more consistent results than line drying and in addition be most likely to develop the maximum potential shrinkage in a fabric, the conditions of tumble drying can also have a significant influence both on the absolute shrinkage values measured and the variability of the results obtained. In a shrinkage test which includes tumble drying therefore it is the conditions of the tumble drying stage that are much more important than the conditions of washing, with the notable exception of the addition of a fabric softener. If the conditions of tumble drying are not accurately monitored and controlled, they can be the prime source of variation in fabric shrinkage results both within and between laboratories. This fact can also cause problems when trying to relate laboratory shrinkage results to consumer practice since the consumer will rarely be consistent in controlling the conditions of tumble drying in the home.

Within the IIC laboratory tumble drying conditions have always been carefully monitored so that specimens under test are completely dry when removed from the tumble drier. When carrying out interlaboratory comparisons however, shrinkage results were often found to be less reproducible even after a five cycle machine washing and tumble drying procedure than could be explained by normal variation in the fabrics or testing techniques. Early work had indicated that the moisture content of the samples, the temperature of the tumble drier and the length of the tumble drying cycle could all influence the development of shrinkage in fabrics and therefore this was suggested as the potential source for the variation found between laboratories. Consequently, in order to thoroughly investigate the influence of the conditions of tumble drying on the development of shrinkage and the reproducibility of measurement, a series of trials were undertaken. These looked at the length of time in the tumble drier, the moisture content of the samples, the temperature of the exhaust and the effect of conditioning [20, 21, 22, 23, 24, 25].

Table 17

Change in Moisture Content, Length and Width Shrinkage over Time (minutes) in Tumble Drying. Average 5 replications, Winch Dyed Interlock

Cycle	Time	MC %	sd	LS %	sd	WS %	sd
1st Cycle	30	30.4	5.1	12.3	1.5	2.5	0.9
	40	24.3	6.4	13.7	1.1	3.2	0.8
	50	12.7	6.2	14.5	1.3	5.7	3.0
	60	2.5	0.6	17.7	0.6	10.3	1.4
	70	0.8	0.1	18.4	0.5	10.4	1.0
	80	0.8	0.1	18.3	0.8	10.3	1.2
2nd Cycle	30	28.8	4.1	14.8	0.2	3.9	0.7
	40	17.7	5.2	16.5	0.9	4.2	4.1
	50	4.4	1.8	19.3	0.9	9.3	1.8
	60	0.9	0.2	20.4	0.5	10.4	1.2
	70	0.7	0.2	20.5	0.5	10.4	1.1
3rd Cycle	30	26.4	3.7	17.6	0.9	1.4	1.6
	40	15.0	2.4	17.7	0.6	5.0	1.1
	50	4.0	0.4	20.1	0.6	10.4	0.7
	60	0.8	0.2	21.3	0.6	10.5	1.1
	70	0.8	0.2	21.3	0.6	10.2	1.0
4th Cycle	30	27.6	4.0	18.4	0.7	-0.2	0.9
	40	15.1	5.4	18.7	0.6	4.6	3.3
	50	3.9	2.3	21.1	0.7	9.1	2.0
	60	0.5	0.4	22.0	0.3	10.2	0.9
	70	0.5	0.1	21.8	0.5	10.3	1.2
5th Cycle	30	26.0	5.9	19.3	0.4	0	3.4
	40	17.8	6.7	19.1	1.2	2.7	3.5
	50	4.2	1.9	21.0	1.1	9.7	1.5
	60	0.4	0.3	22.5	0.6	10.6	0.9
	70	0.7	0.2	22.4	0.5	9.8	1.1

4.2.1 Preliminary Trial

As a first step a preliminary trial [20] was devised with the objective of monitoring the development of shrinkage and the rate of reduction of moisture content in a fabric during tumble drying. This was carried out by making measurements at regular time intervals during a standard 5 cycle relaxation procedure.

Five standard shrinkage specimens (50 cm square template) were prepared from a roll of 20 gauge winch dyed interlock fabric. Each specimen was conditioned in the laboratory, marked measured and weighed prior to laundering. A standard load of 2.75 kg was assembled from the test specimens and make-weight fabric of a similar construction. Initial moisture content and % regain were determined for the fabric based on the oven dried and reconditioned weight of a separate specimen taken from the same roll.

The specimens were washed with detergent at 60°C in a Hoover automatic domestic washing machine. On completion of the washing cycle the load was transferred to a Hoover single direction tumble drier and tumble dried on the hottest temperature setting for 30 minutes.

At the end of 30 minutes the load was removed from the tumble drier, the shrinkage specimens were weighed and measured and then the whole load was returned to the tumble drier.

Weighing and measuring of the shrinkage specimens was repeated at 10 minute intervals until the average weight of the specimens remained constant. This was achieved at 80 minutes, i.e. the average weight of the specimens remained constant between 70 and 80 minutes. The drying time for the load was therefore established at 70 minutes and tumble drying after all subsequent cycles was stopped at 70 minutes.

The load was then returned to the washing machine and re-wet using the rinse cycle. On completion of the rinse cycle the load was transferred to the tumble drier and dried at the hottest temperature setting for 30 minutes. The whole load was removed, the shrinkage specimens weighed and measured, and the whole load returned to the tumble drier. Measurements were taken as for the first cycle at 10 minute intervals until 70 minutes, the drying time established from the first cycle.

The rinse/tumble drying cycles were repeated a further 3 times, with measurements and weights being recorded every 10 minutes from 30 to 70 minutes during the tumble drying stage.

All measurements were made on the specimens directly from the tumble drier without conditioning. During the time that it took to measure and weigh the shrinkage specimens the tumble drier was left running at the hottest temperature setting to maintain the temperature in the drum.

For each specimen the moisture content at the different time intervals over the five cycles was calculated using the formula:

$$\% \text{ M.C.} = \frac{\text{Specimen Weight - Calculated Oven Dry Weight}}{\text{Specimen Weight}} \times 100$$

(Oven dry weights were calculated from the original conditioned weights using the average moisture content established on a separate specimen of the same fabric).

The average results and standard deviations obtained for the five replications for moisture content, length and width shrinkage for each cycle are given in **Table 17**. The results for length shrinkage and moisture content and width shrinkage and moisture content are illustrated in **Figure 3** and **Figure 4**, respectively.

From the results obtained from this trial the following observations can be made:

a) Length Shrinkage

Length shrinkage recorded on the test specimens increased progressively both with time in the tumble drier (reducing moisture content) and over the number of cycles.

Variation in the measurements as described by the standard deviations do not however indicate a significant reduction in variability, after the first cycle, as residual moisture content decreased. On average the standard deviations were found to be in the region of 0.6% at the end of the drying time.

It is clear however that the maximum length shrinkage obtained in these specimens in any one cycle was only developed after the average residual moisture content fell below the original air-dry moisture content, and levelled out as the residual moisture content approached zero.

b) Width Shrinkage

Width shrinkage increased with time in the tumble drier (reducing moisture content) but was not progressive over cycles.

Variation in the measurements between the specimens did however generally improve as moisture content decreased, although on average they are higher than those recorded for the length shrinkage results. Final standard deviations were on average 1.1% at the end of the drying time.

Similarly to that found for the length shrinkage, maximum width shrinkage was only developed after the average residual moisture content in the specimens fell below the original air-dry moisture content, and levelled out as the residual moisture content approached zero.

c) Moisture Content

The residual moisture content in the specimens decreased with time in the tumble drier. In addition, the moisture content in the specimens at the start of each cycle of tumble drying had also apparently decreased. This may have been due to a decreased pick up in the cold rinse cycles with no detergent present, as compared to the full hot washing procedure with detergent in the 1st cycle. It may also be associated with a gradual weight loss in the specimens over cycles.

Variation in moisture content between the test specimens was high during the earlier stages of drying but decreased to very low levels, approximately 0.2% standard deviation, by the end of the drying cycle. This is to be expected as at high moisture content, evaporation will continue during handling and weighing.

4.2.2 Second Trial

The results of the preliminary trial had indicated that the maximum potential shrinkage which will develop in a fabric in any one cycle is only achieved once the residual moisture content falls below normal regain. They had also shown that the reproducibility of the shrinkage measurements, especially in width, was improved at low moisture contents.

This trial did have certain limitations however. For example, the shrinkage behaviour of the fabrics may have been impaired because the tumble drying cycles were interrupted every ten minutes. Also the normal practise of allowing a ten minute cool down period at the end of the drying cycle had not been followed and measurements had been taken without reconditioning of the specimens. Therefore, a second trial was carried out [21] to see if similar trends in shrinkage behaviour would follow when specimens were allowed to tumble dry without disturbance for different lengths of time with the inclusion of a cool down period at the end of each cycle. In addition, measurements were taken both immediately on completion of the drying cycle and also after the specimens had been allowed to properly recondition in the standard atmosphere to discover how conditioning would influence the results. For comparison an extra set of specimens was prepared, washed under the same conditions and allowed to line dry in the standard atmosphere (wales vertical).

Six identical sets of shrinkage specimens (50 cm square test area, 5 replications for each set) were prepared from a different roll of the same fabric quality as was used in the preliminary trial. i.e. Winch dyed interlock (Ne 1/38, Stitch Length 3.38 mm).

Each specimen was conditioned in the laboratory, marked, measured and weighed prior to laundering. Six standard loads of 2.75 kg were assembled from the test specimens and make-weights of a similar construction.

Initial moisture content and % regain were determined from four separate specimens taken from the same roll.

Each set of shrinkage specimens was washed in a Hoover automatic domestic washing machine at 60°C.

a) Tumble Dried Sets

On completion of the washing cycle the test specimens were weighed and then the full load was transferred to a Hoover domestic single direction tumble drier and tumble dried at the hottest temperature setting for a specified length of time. Tumbling was then continued for a further 10 minutes with the heat turned off, by using the cool down setting on the tumble drier.

Set 1 40 minutes Hot tumble + 10 minute Cool down.
Total time in tumble drier 50 minutes.

Set 2 50 minutes Hot tumble + 10 minutes Cool down.
Total time in tumble drier 60 minutes.

Set 3 60 minutes Hot tumble + 10 minutes Cool down.
Total time in tumble drier 70 minutes.

Set 4 80 minutes Hot tumble + 10 minutes Cool down.
Total time in tumble drier 90 minutes.

Set 5 100 minutes Hot tumble + 10 minutes Cool down.
Total time in tumble drier 110 minutes.

On completion of the specified drying time the test specimens were weighed and measured and then transferred to the laboratory for reconditioning in the standard atmosphere. (65$\pm$2% RH, 20$\pm$2°C). Each specimen was allowed to condition over night (minimum 12 hours). After conditioning the specimens were re-weighed and remeasured and then the complete load was re-wet in the washing machine using the rinse cycle. On completion of the rinse cycle the specimens were weighed and the load transferred to the tumble drier and dried for the appropriate length of time. On completion of the specified drying time, the specimens were weighed and measured and then transferred to the laboratory for reconditioning, re-weighing and remeasuring.

The rinse/tumble drying cycles were repeated a further 3 times for each set, making five cycles in all. Measurements were taken directly from the tumble drier and after reconditioning in the laboratory.

b) Line Dried Set

The line dried set (Set 6) was washed in the same way as the tumble dried sets using the Hoover automatic, domestic washing machine at 60°C.

Table 18

Shrinkage in Tumble Drying; Specimens Measured Immediately

Cycle/Set	LS %	sd	WS %	sd	MC %	sd
Set 1: Tumble Dry 40 + 10 minutes						
1	10.9	0.9	10.4	1.4	16	4.7
2	12.7	0.8	10.0	1.2	12.5	1.8
3	11.7	2.5	11.7	2.2	13.8	2.7
4	13.4	1.2	9.6	1.1	14.2	2.6
5	15.2	0.8	11.6	0.5	9.1	1.3
mean	**12.8**	**1.3**	**10.7**	**1.3**	**13.1**	**2.6**
sd	**1.6**	**0.7**	**0.9**	**0.6**	**2.6**	**1.3**
Set 2: Tumble Dry 50 + 10 minutes						
1	16.2	1.0	11.2	0.5	5.7	0.5
2	18.3	0.4	11.4	0.3	3.5	0.2
3	18.5	0.5	11.7	0.3	4.8	0.7
4	18.0	0.6	11.4	0.3	6.2	0.5
5	20.3	0.5	11.9	0.6	3.6	0.3
mean	**18.3**	**0.6**	**11.5**	**0.4**	**4.8**	**0.4**
sd	**1.5**	**0.2**	**0.3**	**0.2**	**1.2**	**0.2**
Set 3: Tumble Dry 60 + 10 minutes						
1	17.3	0.6	12.2	0.7	1.8	0.6
2	19.3	0.8	11.6	0.6	1.3	0.1
3	20.2	0.3	11.3	1.0	1.3	0.2
4	20.3	0.4	12.2	0.8	3.1	0.6
5	20.9	0.4	12.0	0.5	1.4	0.1
mean	**19.6**	**0.5**	**11.9**	**0.7**	**1.8**	**0.3**
sd	**1.4**	**0.2**	**0.4**	**0.2**	**0.8**	**0.3**
Set 4: Tumble Dry 80 + 10 minutes						
1	17.2	0.4	12.5	0.4	1.1	0.1
2	19.3	0.4	12.0	0.5	0.6	0.3
3	20.5	0.4	12.0	0.4	1.2	0.1
4	21.1	0.5	11.2	1.3	0.2	0.2
5	21.3	0.6	11.7	1.0	0.4	0.2
mean	**19.9**	**0.5**	**11.9**	**0.7**	**0.7**	**0.2**
sd	**1.7**	**0.1**	**0.5**	**0.4**	**0.4**	**0.1**
Set 5: Tumble Dry 100 + 10 minutes						
1	17.2	0.5	11.3	1.2	1.7	0.1
2	18.8	0.3	11.4	0.6	1.6	0.1
3	19.7	0.5	11.4	0.7	1.6	0.1
4	20.5	0.6	11.4	0.7	1.8	0.1
5	20.9	0.4	11.1	0.9	1.4	0.3
mean	**19.4**	**0.4**	**11.3**	**0.8**	**1.6**	**0.2**
sd	**1.5**	**0.1**	**0.1**	**0.2**	**0.1**	**0.1**
Set 6: Line Dry 24 hours Standard atmosphere						
1	13	1.1	7.4	1.5	7.3	0.1
2	13.5	0.8	6.5	1.3	7.6	0.1
3	14.2	0.2	6.2	1.3	7.4	0.1
4	13.8	1.7	5.8	2.0	7.4	0.1
5	14.2	0.8	6.5	1.4	7.4	0.1
mean	**13.7**	**0.9**	**6.5**	**1.4**	**7.4**	**0.1**
sd	**0.5**	**0.6**	**0.6**	**0.5**	**0.1**	**0**

On completion of the washing cycle the test specimens were weighed and then hung on a line (wales vertical) in the laboratory in the standard atmosphere and left to dry for 24 hours. After 24 hours the specimens were weighed and measured before being returned to the washing machine with the make-weights for re-wetting using the rinse cycle.

On completion of the rinse cycle the specimens were re-weighed and hung on a line in the laboratory for 24 hours before remeasuring and re-weighing.

The rinse/line drying cycles were repeated a further 3 times making five cycles in all.

At the end of the fifth cycle the specimens were left for a further 24 hours and then re-weighed and remeasured. At the end of this period each specimen was oven dried and re-weighed.

The average results for shrinkage and moisture content (over the five replications) and the standard deviations obtained for each cycle and each set before and after conditioning are included in **Table 18** and **Table 19** respectively. The results for length shrinkage and moisture content before and after conditioning and for width shrinkage and moisture content before and after conditioning are illustrated in **Figures 5, 6, 7 and 8** respectively.

These results confirmed those obtained from the earlier trial with respect to the development of shrinkage in relation to the residual moisture content in the samples after tumble drying.

4.2.2.1 Effect of Tumble Drying Conditions

a) Length Shrinkage (Figure 5)

In each of the tumble dried sets length shrinkage increased progressively with the number of cycles. Generally also length shrinkage increased with the length of time in the tumble drier. In particular the specimens in Sets 1 and 2 did not develop the same amount of shrinkage as found in the other three sets. The differences in shrinkage found between Sets 3, 4 and 5 were however negligible. This suggests that the maximum potential shrinkage which can be developed in a fabric during any one cycle can only be achieved when the average residual moisture content in the specimens falls below approximately 2%. Once the specimens are uniformly dry (< 2%) tumbling for additional lengths of time does not appear to significantly change the level of length shrinkage developed.

The shrinkage results recorded for Set 1 were similar to those obtained from the line dried set, which also showed progressive shrinkage with number of cycles.

With the exception of Set 1 the shrinkage recorded after tumble drying was always significantly higher than that developed after line drying.

Variation between the specimens within a set on average improved as tumble drying times increased.

The variation in the line dried results (Set 6) was on average slightly better than Set 1 and slightly worse than Set 2.

b) Width Shrinkage (Figure 7)

Width shrinkage, for this particular fabric quality, did not appear to be progressive with the number of cycles, but increased slightly with length of time in the tumble drier (reducing moisture content). In particular the average width shrinkage results recorded on the Set 1 specimens were lower than those obtained from the other sets.

Similarly to length shrinkage, maximum width shrinkage was only achieved with low levels of residual moisture (< 2%).

Table 19

Shrinkage in Tumble Drying; Specimens Measured After Conditioning

Cycle/Set	LS %	sd	WS %	sd	MC %	sd
Set 1: Tumble Dry 40 + 10 minutes						
1	12.5	1.1	9.1	2.3	7.8	0.1
2	13.2	0.6	10.7	0.5	7.6	0.1
3	13.9	0.3	10.1	1.1	7.9	0.1
4	14.4	0.8	9.7	0.7	7.6	0.2
5	15.1	0.4	11.2	1.0	7.6	0.2
mean	**13.8**	**0.6**	**10.2**	**1.1**	**7.7**	**0.1**
sd	**1.0**	**0.4**	**0.8**	**0.7**	**0.1**	**0.1**
Set 2: Tumble Dry 50 + 10 minutes						
1	15.2	0.4	11.0	0.7	7.2	0.2
2	16.9	0.5	11.5	0.3	6.6	0.1
3	17.0	0.7	11.5	0.6	6.7	0.2
4	17.3	0.6	11.6	0.7	7.1	0.2
5	18.3	0.5	11.4	0.6	6.8	0.2
mean	**17.0**	**0.6**	**11.4**	**0.6**	**6.8**	**0.2**
sd	**1.1**	**0.1**	**0.2**	**0.2**	**0.3**	**0.1**
Set 3: Tumble Dry 60 + 10 minutes						
1	15.8	0.4	12.0	0.7	6	0.5
2	17.4	0.6	12.0	0.7	6.2	0
3	18.7	0.5	11.8	0.3	6.1	0.1
4	18.5	0.5	12.1	0.6	6.4	0.1
5	19.1	0.4	12.3	0.9	6.3	0.1
mean	**17.9**	**0.5**	**12.1**	**0.6**	**6.2**	**0.2**
sd	**1.3**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**
Set 4: Tumble Dry 80 + 10 minutes						
1	15.5	0.7	11.4	0.7	6.6	0.1
2	17.3	0.7	11.5	0.6	6.2	0.1
3	18.5	0.3	11.4	0.5	6.2	0.2
4	19.5	0.5	11.3	1	5.4	1.3
5	19.7	0.6	11.6	0.9	6.1	0.2
mean	**18.1**	**0.6**	**11.4**	**0.7**	**6.1**	**0.4**
sd	**1.7**	**0.2**	**0.1**	**0.2**	**0.4**	**0.5**
Set 5: Tumble Dry 100 + 10 minutes						
1	15.3	0.4	11.6	0.5	6.1	0.1
2	17	0.3	11.7	0.5	6.4	0.1
3	18.6	0.4	11	1.2	6.3	0.1
4	19.4	0.3	12	1.2	5.8	0.1
5	19.6	0.5	10.9	0.7	6.1	0
mean	**18**	**0.4**	**11.4**	**0.8**	**6.1**	**0.1**
sd	**1.8**	**0.1**	**0.5**	**0.4**	**0.2**	**0**
Set 6: Line Dry 24 hours Standard atmosphere						
1	13	1.1	7.4	1.5	7.3	0.1
2	13.5	0.8	6.5	1.3	7.6	0.1
3	14.2	0.2	6.2	0.7	7.4	0.1
4	13.8	1.7	5.8	2	7.4	0.1
5	14.2	0.8	6.5	1.4	7.4	0.1
mean	**13.7**	**0.9**	**6.5**	**1.4**	**7.4**	**0.1**
sd	**0.5**	**0.6**	**0.6**	**0.5**	**0.1**	**0**

The level of width shrinkage which was developed after line drying was significantly less than for any of the tumble dried sets, but similarly did not increase with number of cycles. If anything there was a tendency for width shrinkage to decrease on average with the number of cycles (extension or growth).

Variation between specimens within a set improved between Set 1 and Set 2 but tended to increase slightly with extended tumbling times. The variation in the width shrinkage measurements was generally higher than that found for length shrinkage.

The variation in the width shrinkage measurements in the line dried set was similar to that found for Set 1.

c) **Moisture Content** *(Figures 5 and 7)*

The residual moisture content in the specimens reduced with the length of time in the tumble drier. Consistent minimum levels of residual moisture were only achieved with Sets 4 and 5, although the results obtained from Set 3 were also on average below 2% immediately on leaving the tumble drier.

The variation in residual moisture content between the specimens in each set also decreased with increased lengths of time in the tumble drier, and for Set 1 in particular with number of cycles.

The variation in moisture content of the line dried samples was insignificant.

4.2.2.2 Effect of Conditioning

a) **Length shrinkage** *(Figure 6)*

Conditioning after tumble drying generally reduced the variability of shrinkage measurement between the specimens for all sets. In addition conditioning caused a significant reduction in the levels of length shrinkage measured by between 1 and 2% for Sets 2, 3, 4 and 5. For Set 1 length shrinkage increased on average after conditioning.

b) **Width Shrinkage** *(Figure 8)*

Conditioning after tumble drying appeared to have little effect on the level of width shrinkage, either in the absolute values or the variation, and although there was a small decrease in width shrinkage the results were not significant.

c) **Moisture Content** *(Figures 6 and 8)*

The variation in moisture content for each set after conditioning was negligible as expected. However, there was a slight decrease in the average values recorded as time in the tumble drier increased.

The moisture content in the line dried specimens was on average similar to that found for the Set 1 specimens after conditioning. The moisture content in the specimens in Set 5 was on average 1% less, but more or less equivalent to the moisture content found in the original (unwashed) specimens.

These apparent differences in final moisture content between the sets are probably due to the effect of conditioning from the wet side compared to the dry side. However, there may also be an influence due to increasing weight loss in the specimens as time in the tumble drier is extended.

4.2.3 Third Trial

A third trial [22] was carried out along the same lines as Trial 2 but on this occasion using a 28 gauge single jersey fabric, knitted from twofold yarns (Ne 2/72, Stitch Length 2.87 mm) and piece mercerised before dyeing and finishing.

In this experiment an additional set of specimens (Set 0) was included and dried for 30 mins + 10 mins cool down. This was to ensure that at least one set would be removed from the tumble drier while still thoroughly damp, having regard for the much lighter weight of the jersey test specimens compared to those of interlock construction.

In addition a digital temperature probe was positioned in the exhaust outlet of the tumble drier and temperature readings were taken at 10 minute intervals during the drying cycles of Sets 1, 2, 3, 4, and 5.

In all other aspects the experimental procedures were identical to Trial 2.

4.2.3.1 Exhaust Temperature during Tumble drying

Measurements of the exhaust temperature were taken at 10 minute intervals during the drying cycles of Sets 1, 2, 3, 4 and 5. The results are summarised in **Table 20**, and illustrated in **Figure 9**.

N.B. The final temperature measurement for each set is after the ten minute cool down period.

Table 20

Exhaust Temperature in Degrees Celcius averaged over Five Replications and Five Cycles

Time min.	Set 1 Mean	sd	Set 2 Mean	sd	Set 3 Mean	sd	Set 4 Mean	sd	Set 5 Mean	sd
0	30.2	0.3	30.4	0.3	30.4	0.3	30.2	0.4	30.3	0.1
10	38.4	1.0	38.8	1.3	38.0	1.6	38.4	1.2	37.7	0.7
20	39.3	0.5	39.6	1.7	38.9	1.6	39.6	1.0	38.4	1.1
30	42.1	4.0	41.1	0.8	39.8	1.4	40.4	1.7	39.2	1.2
40	44.2	3.1	44.9	4.2	43.0	2.2	45.0	5.5	43.0	3.4
50	25.8	2.2	56.6	11.6	55.2	8.8	59.3	11.6	53.9	5.7
60			32.8	4.5	67.9	7.4	65.2	6.0	68.1	5.8
70					34.8	3.6	67.4	6.8	62.2	6.1
80							69.3	3.8	66.4	6.4
90							35.4	2.9	63.4	5.8
100									64.9	3.8
110									35.4	3.0

These results show that the exhaust temperature increases with time as the specimens lose moisture.

The temperature cut off for the tumble drier used in these trials is set at approximately 70°C. When this temperature is reached the heater turns on and off automatically causing the exhaust temperatures to fluctuate accordingly. This is best illustrated by the results obtained from Set 5.

For all sets the exhaust temperature rose sharply during the first 10 minutes, gradually during the next 20 minutes and rapidly from 40 minutes to 60 minutes - the period when the residual moisture content in the specimens was between approximately 20% and 2%.

The variability between measurements was also highest during this period of rapid temperature rise, peaking at around 50 minutes.

Final exhaust temperatures, after the 10 minute cool down period rose from approximately 25°C for Set 1 to approximately 35°C for Set 5. Starting temperatures were around 30°C.

Maximum exhaust temperatures in the region of 70°C were only recorded on those sets where tumble drying times were sufficient to reduce the average residual moisture content in the specimens to below 2%. In these trials this corresponds to a minimum of 60 minutes (Set 3), which is also the first where maximum shrinkage levels were developed.

The monitoring of exhaust temperatures would therefore seem to be a relatively simple method of controlling tumble drying times to ensure that all shrinkage specimens are uniformly dried to minimal levels of residual moisture content or, conversley, to ensure that the drying was interrupted at, or slightly above, the natural moisture content to prevent the full potential shrinkage from developing.

N.B. In subsequent investigations [26] the exhaust temperature of the tumble drier was monitored and related to the drum and fabric temperatures measured using thermo sensitive papers. The results indicated that, while the drum temperature remained close to the temperature of the exhaust air, the temperature of the fabric after completion of drying could be considerably higher. In one trial when the maximum temperature of the drum was 65°C, the maximum fabric temperature was over 104°C. The loads used in these trials consisted entirely of 100% cotton fabrics, and with these fabrics we have not found that prolonged tumble drying after minimum moisture content has been achieved has any adverse effect on shrinkage. However, this may not be the case with mixed loads containing thermoplastic fibres with low glass transition temperatures and therefore this should be kept in mind when developing information and guide-lines for the consumer.

With regard to the other aspects of the trial e.g. moisture content, length of tumble drying, conditioning etc. the conclusions were similar to those for Trial 2. The results for length shrinkage and moisture content before and after conditioning and width shrinkage and moisture content before and after conditioning are illustrated in **Figures 10, 11, 12 and 13**, respectively.

4.2.4 Trials 4 and 5

A further two trials [23,24] were carried out following the experimental protocols established in the earlier trials. Trial 4 used a 1x1 rib fabric and trial 5 used a single jersey fabric similar to that used in trial 3 with the exception that it was not piece mercerised prior to the dyeing and finishing operations. Similar conclusions were drawn from both these trials although the detailed behaviour of the specimens under test varied depending on their construction and processing history.

As the general trends observed in the influence of the conditions of tumble drying on the measurement and development of shrinkage in cotton knitgoods are similar for all the trials described above they are summarised in the following section.

4.2.5 Effect of Tumble Drying Conditions - Summary

The results obtained from the preliminary trial confirmed that:-

1. Shrinkage increases progressively as the residual moisture content in the specimens is reduced.

2. Maximum shrinkage is only developed at very low residual moisture content <2%.

3. For length shrinkage in particular, shrinkage is progressive with number of cycles.

4. Width shrinkage is more variable than length shrinkage, and on average the lowest levels of variation are obtained at minimum residual moisture contents <2%.

The results obtained from trials 2 to 5 showed that:-

1. On average shrinkage increases progressively as the residual moisture content in the specimens is reduced.

2. Maximum shrinkage is only developed at very low residual moisture contents, $<2\%$.

3. The effect of conditioning upon the measured shrinkage values depends on the fabric moisture content after tumbling.

   If the moisture content in the fabric is greater than about 10% then there is an increase in shrinkage after conditioning.

   If the residual moisture content in the fabric is less than about 10% then the shrinkage is reduced by conditioning.

4. Variation in shrinkage is generally higher at high moisture contents and lower at low moisture contents.

   In all cases variation in the shrinkage measurements between specimens improves with conditioning.

5. Variation in the results is generally greater for width shrinkage than length shrinkage.

6. Sets which were not tumble dried below their original air-dried moisture content (normal regain) retained higher residual moisture contents after conditioning. Those which had been dried below their original air-dried moisture content tended to have lower moisture contents after reconditioning.

7. Tumbling for extended periods of time after minimum residual moisture contents had been achieved, on average did not adversely affect the shrinkage results obtained.

8. Shrinkage in the length direction generally increases with the number of cycles, but on average maximum width shrinkage is achieved after the first cycle, provided that tumbling times are sufficient to ensure that minimum residual moisture contents are achieved.

   The difference in length shrinkage between 1 and 5 cycles depends on the fabric type and processing history, but is usually progressive over cycles.

   Width shrinkage can improve between 1 and 5 cycles, i.e. the fabric grows or extends in the width direction. This depends on the fabric type and processing history.

9. Line drying develops less shrinkage than tumble drying, although the size of the difference depends on the fabric type and processing history.

10. Length shrinkage shows a tendency to increase with the number of cycles of line drying.

    Width shrinkage shows little change with the exception of the 1x1 rib fabric which tended to grow in width in line drying.

11. Line drying is on average more variable than tumble drying especially in the width direction.

12. A temperature probe situated in the exhaust duct can be used to monitor the reduction in moisture content of the load and can therefore form the basis for a simple control mechanism.

4.2.6 Effect of the Direction of Tumbling

The latest models of domestic tumble drier are now often built so that the direction of tumbling reverses periodically during the drying cycle. This feature has been introduced in an attempt to prevent tangling of garments during the tumble drying process and also to assist in the preservation of fabric appearance.

Table 21

Effect of Tumbling action Reversing versus Non-reversing on Fabric Shrinkage after Five Cycles of Washing and Tumble Drying

Sample	Length Shrinkage % Set 1	Set 2	Diff.	Width Shrinkage % Set 1	Set 2	Diff.
1	4.6	4.5	-0.1	18.2	17.5	-0.7
2	9.3	9.9	+0.6	11.9	11.3	-0.6
3	20.6	18.8	-1.8	12.3	10.6	-1.7
4	10.2	7.8	-2.4	4.4	5.6	+1.2
5	14.3	15.4	+1.1	9.0	7.5	-1.5
mean	11.8	11.3	-0.5	11.2	10.5	-0.7

Table 22

Effect of the Direction of Tumble Drying on Length Shrinkage

	Fabric Reference	One cycle Set 1	Set 2	Diff.	Five cycles Set 1	Set 2	Diff.	Ten cycles Set 1	Set 2	Diff.
1	IWB	10.7	9.6	-1.1	10.6	11.2	+0.6	12.1	12.5	+0.4
2	SJ2D	12.1	12.1	0.0	13.3	13.5	+0.2	13.4	14.0	+0.6
3	SJ2MD	11.9	11.3	-0.6	13.8	12.8	-1.0	14.0	13.9	-0.1
4	SJ2MD	11.3	10.2	-1.1	12	11.0	-1.0	13.5	12.2	-1.3
5	SJ2D	7.8	8.0	+0.2	10.4	12.0	+1.6	12.6	14.1	+1.5
6	SJ1G	11.7	11.4	-0.3	14.6	14.2	-0.4	15.0	15.2	+0.2
7	RWB	10.5	9.8	-0.7	13.0	13.3	+0.3	14.0	14.4	+0.4
8	IWD	11.2	10.8	-0.4	14.7	14.0	-0.7	15.5	15.7	+0.2
9	SJ1J	14.6	14.3	-0.3	19.3	19.2	-0.1	20.5	21.3	+0.8
10	SJ1JD	9.2	7.7	-1.5	10.8	13.2	+2.4	14.1	15.3	+1.2
	mean	11.1	10.5	-0.6	13.3	13.4	+0.2	14.5	14.9	+0.4
	sd	1.8	2.0	0.5	2.7	2.3	1.1	2.3	2.5	0.8

Table 23

Effect of the Direction of Tumble Drying on Width Shrinkage

	Fabric Reference	One cycle Set 1	Set 2	Diff.	Five cycles Set 1	Set 2	Diff.	Ten cycles Set 1	Set 2	Diff.
1	IWB	10.6	9.7	-0.9	10.6	9.2	-1.4	9.4	9.4	0
2	SJ2D	9.8	9.5	-0.3	9.4	9.3	-0.1	8.9	9.6	+0.7
3	SJ2MD	9.5	9.6	+0.1	10.2	9.5	-0.7	10.9	10.4	-0.5
4	SJ2MD	8.7	8.5	-0.2	7.6	8.1	+0.5	7.7	8.0	+0.3
5	SJ2D	11.2	11.6	+0.4	6.2	4.7	-1.5	1.8	4.1	+2.3
6	SJ1G	4.2	5.0	+0.8	1.0	0.7	-0.3	1.2	1.2	0
7	RWB	12.8	11.3	-1.5	6.7	5.2	-1.5	5.9	6.3	+0.4
8	IWD	11.7	11.3	-0.4	11.4	11	-0.4	11.2	11.1	-0.1
9	SJ1JD	11.3	11.5	+0.2	7.4	8.1	+0.7	6.7	7.8	+1.1
10	SJ1JD	8.2	8.7	+0.5	5.3	6	+0.7	4.3	6.5	+2.2
	mean	9.8	9.7	-0.1	7.6	7.2	-0.4	6.8	7.4	+0.6
	sd	2.4	2	0.7	3.1	3.1	0.9	3.5	3.0	1.0

All of the IIC's early work on washing and drying conditions however, had been carried out using single direction (non-reversing) tumble driers. Therefore, when it was suggested, during discussions held at a meeting of the ISO working group on tumble drying test methods, that reverse action tumble driers could have a significant influence on shrinkage results, a small evaluation trial was carried out [(26)]. The objective of this trial was to discover whether the direction of tumble drying i.e. single direction (non-reversing) versus reverse action could significantly influence the shrinkage results obtained on cotton knitgoods.

4.2.6.1 First Trial

Two identical sets (5 replications, 50 cm square test area) of five different fabrics of various constructions were subjected to five cycles of washing followed by tumble drying.

Washing conditions were identical for both sets, i.e. 60°C wash in a Hoover automatic domestic washing machine.

The fabrics in Set 1 were tumble dried in a Hoover model D6074 single direction (non-reversing) tumble drier.

The fabrics in Set 2 were tumble dried in a Creda Debonair Reversair (reversing) tumble drier.

The average shrinkage results obtained are given in **Table 21**.

Although there is on average a small difference in the shrinkage results obtained from the two machines the differences are not consistent across all fabric samples. In addition, the average difference between the two sets of samples is within the level of reproducibility expected in shrinkage testing of cotton knitgoods. ($\pm$ 1% at best).

It was therefore concluded that for cotton knitgoods, at least, the influence on shrinkage measurements of using a reversing action tumble drier as opposed to a single direction (non-reversing) tumble drier was probably not significant. This conclusion was reinforced by the results obtained in another later trial which followed the development of shrinkage on 10 different fabrics over 10 laundering cycles [(27)].

4.2.6.2 Second Trial

In this second trial two identical sets were assembled using replicate specimens from ten different fabrics. Both sets were washed under identical conditions in a Hoover automatic, domestic washing machine at 60°C.

Set 1 was tumble dried using a non-reversing tumble drier, and Set 2 was tumble dried using a reversing tumble drier.

The average length and width shrinkage results from both sets after one, five and ten cycles are given in **Table 22** and **Table 23**, respectively.

The conclusions are the same as those from the first trial. Differences between individual samples which can be observed cannot be attributed to the type of tumble drier used. The size of the differences are on average within $\pm$ 1%.

It is perhaps worth noting, however, that these trials were carried out on flat specimens and although, several different fabrics and finishes were represented, the range of fabrics included was still relatively limited. The possibility that the action of tumble drying may affect shrinkage measurements should therefore be born in mind when garments are being evaluated. This may also be the case when fabrics or garments made from other fibres are included.

4.2.7 Consistency and Reliability of Shrinkage Testing

For a consistent and reproducible laboratory procedure for evaluating shrinkage in cotton knitgoods a laundering procedure which includes properly controlled tumble drying should be preferred. This is the only way of developing reproducible levels of relaxation in all types of cotton knitted fabrics.

An illustration of the difficulties in evaluation that can develop if other forms of drying are used is shown in **Table 24.** In this table the results obtained from an interlaboratory comparison carried out between five reputable testing laboratories are given. In this trial each laboratory was given samples of the same fabric (cotton interlock) and asked to launder them using identical conditions.

Table 24

Interlaboratory Trial: Area Shrinkages after One and Five Cycles of Laundering followed by Flat Drying or Tumble Drying

	Flat Dried		Tumble Dried	
	1 cycle	5 cycles	1 cycle	5 cycles
Laboratory				
A	15.4	10.2	26.7	28.7
B	17.8	18.1	25.0	28.3
C	11.1	7.9	23.6	25.5
D	17.6	18.1	25.7	26.8
E	20.0	21.7	25.0	28.5
mean	16.4	15.2	25.2	27.6
sd	3.4	5.9	1.1	1.4

The results are self explanatory.

5. IRONING OR PRESSING

It is often suggested that specimens which are being evaluated for shrinkage should, after the drying procedure, be given a restorative process such as ironing or pressing. This is suggested for three reasons.

1. The appearance of the fabric is improved by the removal of wrinkles and the smoothing action of the ironing or pressing procedure.

2. It is more representative of domestic laundering conditions where the consumer may often iron a garment after laundering and before wear.

3. Some shrinkage is easily recoverable by ironing or pressing and therefore it should be the shrinkage after just such a restorative process that should be assessed.

These arguments may hold good when garments are being evaluated (Section C) and when laundering and drying trials are being carried out specifically to provide information for the consumer. For a standard laboratory relaxation procedure, however, pressing or ironing of the specimens can be a further source of variation and subject to operator influence unless standardised pressing equipment is available e.g. Hoffmann Press.

An early trial [10] looked at the influence of pressing on the measurement of fabric shrinkage over five cycles of washing and tumble drying.

Table 25

Effect of Pressing on Fabric Shrinkage, Sets 1a and 1b

Cycle	Set 1a Wash and Tumble only				Set 1b Before Pressing				After Pressing			
	LS %	sd	WS %	sd	LS %	sd	WS %	sd	LS %	sd	WS %	sd
1	8.1	0.4	13.1	0.5	9.1	0.6	14.8	1.0	7.5	0.4	13.3	0.6
2	9.8	0.6	14.1	0.3	9.6	0.7	14.9	0.8	8.5	1.0	13.8	0.8
3	10.7	0.9	14.6	0.3	10.3	0.7	15	0.7	9.3	0.7	13.8	0.8
4	10.6	0.7	14.2	0.6	10.5	0.6	14.9	0.9	9.8	0.6	14.4	0.7
5	11.0	0.8	14.7	0.6	10.9	0.7	15.3	1.0	10.3	1.0	14.8	0.8
mean	10.0	0.7	14.1	0.5	10.1	0.7	15	0.9	9.1	0.7	14	0.7

Table 26

Effect of Pressing on Fabric Shrinkage, Sets 2a and 2b

Cycle	Set 2a Wash and Tumble only				Set 2b Before Pressing				After Pressing			
	LS %	sd	WS %	sd	LS %	sd	WS %	sd	LS %	sd	WS %	sd
1	7.1	0.8	18.2	0.4	8.9	2.0	18.0	2.0	7.6	1.9	16.9	2.0
2	8.0	0.7	18.8	0.7	9.7	1.6	18.0	2.2	8.4	2.0	17.4	1.8
3	9.0	0.9	19.1	0.3	10.0	1.9	18.2	2.0	9.1	2.1	17.7	2.1
4	8.8	0.8	19.1	0.5	10.4	1.9	18.1	2.2	9.6	1.8	17.9	1.9
5	9.3	0.6	19.7	0.5	10.3	1.9	18.2	2.0	9.9	2.1	17.9	2.2
mean	8.4	0.8	19	0.5	9.9	1.9	18.1	2.1	8.9	2.0	17.6	2.0

Two replicate sets of shrinkage specimens were prepared from two fabric pieces. Sets 1a and 1b were prepared from a single jersey fabric made from singles yarns, Sets 2a and 2b from a single jersey fabric of similar construction but knitted from two fold yarns. (Both fabrics were in the greige or machine state, i.e. not finished).

All four sets were washed in a Hoover automatic domestic washing machine at 60^{o}C, and tumble dried in a Hoover domestic tumble drier. Sets 1a and 2a were only tumble dried. Sets 1b and 2b were pressed after each cycle of washing and tumble drying. Five full cycles of washing and tumble drying were carried out on each set. Measurements of fabric shrinkage were made on all sets after each cycle after reconditioning the specimens in the laboratory and for Sets 1b and 2b after pressing and conditioning.

Pressing was carried out using a steam iron taking care that wrinkles and creases were removed from the specimens by lifting and replacing the iron at intervals, not by ironing.

The results for Sets 1a and 1b are given in **Table 25**, for Sets 2a and 2b in **Table 26**.

For Sets 1a and 1b the effect of pressing on the average levels of shrinkage measured over the five cycles is marginal, differences are within measuring error. There is also a hint that the results may be slightly more variable but the differences are probably not significant.

For Sets 2a and 2b however pressing appears to have had a significant effect both on the average levels of shrinkage measured over the five cycles, particularly in the width direction, and also on the variability of the results.

This would seem to confirm the idea that the introduction of ironing or pressing, even if carefully controlled, at the end of a standard testing procedure is likely to be a further source of variation in the measurement of shrinkage. In addition it appears that the influence of the pressing process may be variable depending on the fabric construction.

On the other hand there is also a suggestion that pressing may help to improve fabric shrinkage particularly in the width direction and this may therefore be useful information for the consumer. However, it should also be remembered that with certain fabric constructions the act of stretching the fabric in the width direction may also lead to additional shrinkage in the length.

6. REFERENCE RELAXATION PROCEDURE

Establishing a consistent and reliable testing procedure which can be used on a routine basis to bring all fabrics to an equivalent Reference State of relaxation for comparison can be problematic because of,

a) the influence of the testing conditions, and
b) the inherent variability of cotton knitgoods.

However, careful attention to the conditions of testing can maintain variation from this source within acceptable limits provided that the major sources of variation can be identified and controlled.

As a result of the trials reported above and many others besides the IIC has defined a standard testing procedure for obtaining a Reference State of Relaxation for cotton knitgoods. This can be summarised as follows:-

1) Wash in automatic domestic washing machine at 60^{o}C. (domestic detergent, no added softener)
2) Tumble dry to constant weight.
3) Wet out in washing machine (rinse cycle).
4) Tumble dry to constant weight.
5) Repeat steps 3 and 4, three more times.
6) Condition to normal regain.

This method together with the IIC test method for measuring shrinkage have proven to be reliable, consistent and reproducible for all the cotton knitted fabrics which have been evaluated during the course of the Starfish knitgoods research project. An analysis of a large number of shrinkage results obtained by the IIC laboratory using these methods found that the standard deviations of length and width shrinkage were 0.57% and 0.72% respectively. From these results it was calculated that the measured values would be within one shrinkage unit of the "true" value in 19 cases out of 20 or 95% of the time.

The detailed testing procedures which have been established are included for reference in **Appendix B** at the end of this report.

B. THE INFLUENCE OF PRODUCTION AND PROCESSING CONDITIONS ON THE DIMENSIONS OF THE REFERENCE STATE AND THE MECHANISM OF SHRINKAGE

1. INTRODUCTION

Once a Reference State of relaxation has been defined the influence of production and processing variables on the dimensions of the Reference State (tex, stitch length, courses, wales and weight) can begin to be quantified.

If the type of fabric, its method of production and its processing history can affect the dimensions of the Reference State, then this begins to offer an explanation as to why apparently similar fabrics or garments appear to shrink by different amounts during normal domestic laundering and wear.

The Starfish project has examined the Reference State dimensions of several thousand different fabrics. So far these have included plain single jersey fabrics made from both singles and two fold yarns, single jersey crosstuck (piqué) structures, interlock and 1x1 rib constructions made from singles yarns. The vast majority of these fabrics have been knitted from combed ring spun yarns but some data is also available on carded ring spun and combed and carded rotor spun yarns.

The fabrics have been produced in full scale and processed under commercial conditions in many mills throughout Europe, the USA and Japan. Wet processing routes include continuous and batch preparation (scouring and bleaching), tubular and open width mercerising, dyeing operations in winches, jets, overflow machines and by pad batch.

Drying operations have included the examination of conventional drum drying and the modern relaxed drying processes for tubular fabrics, and open width stenter drying.

Finishing operations which have been examined include calendering, compressive shrinking (compacting), calender-compacting and various levels of chemical cross-linking treatments.

A number of different types of inter-process fabric handling operations e.g. de-watering by centrifuge or squeezing, wet spreading etc. have also been investigated.

From these trials, and the analysis of hundreds of thousands of test data, many of the key variables in the production and processing of cotton knitgoods have been identified as having a significant effect on the dimensions of the Reference State and ultimately, therefore, on the shrinkage potential of the fabric in use.

It is not proposed to go into any great detail regarding the influence of production and processing variables on the dimensions of the Reference State within the context of this report. However, when undertaking research into the topic of fabric shrinkage it is important to be aware of all of the potential sources for variation in the results, not only from the testing procedures adopted but also from the choice of fabrics and/or garments selected for the evaluations. Therefore, the major production and processing variables which can influence the dimensions of the Reference State and consequently the potential shrinkage in a fabric or garment are summarised in the following sub-sections.

(Over one hundred internal IIC research records, together with numerous additional studies not formally reported provide the background for this section. They have not been itemised individually but a selection of some relevant IIC publications are included in the list of references for information [28 - 40]).

2. KNITTING VARIABLES

The two main constructional variables which can influence the dimensions of a knitted fabric in its Reference State are:

The average length of yarn in the knitted loop, and
The yarn from which the fabric is produced.

2.1 Average Loop Length

It has long been known that the most important constructional variable in a knitted fabric is the length of yarn in the knitted loop. The Reference Courses i.e. the course density or number of courses per unit length in the Reference State will vary according to the length of the knitted loop. Likewise the Reference Wales.

As loop length increases, the number of courses per centimetre decrease, or conversely as loop length decreases the number of courses increase. A similar relationship is found for the wales. **(Figure 14)**

Therefore, for a given count of yarn, a decrease in loop length will result in a shorter, narrower fabric, with more stitches per unit area and heavier weight. An increase in loop length will give a longer, wider and lighter fabric.

It follows from this that if fabrics with different loop lengths are delivered by the finisher with the same weight and width, then they will develop different levels of shrinkage during relaxation.

Thus the accurate control of loop length on the knitting machine is essential if variations in dimensions and weight of the finished fabric are to be avoided.

2.2 Yarn

The yarn chosen to produce a particular knitted quality will also have an influence on the Reference State dimensions.

2.2.1 Yarn Linear Density (Yarn Count).

For fabrics knitted to the same average loop length, the number of Reference Courses per unit length are reduced as yarn count gets finer, or conversely are increased as yarn count gets coarser. A similar relationship is found for Reference Wales but in this case the number of wales per unit length are increased as yarn count gets finer, or decrease as yarn count gets coarser **(Figure 15)**. That is, the fabric in its Reference State will be slightly longer and narrower at the same average loop length if a finer yarn is used.

Yarn linear density (weight per unit length of the yarn) has a direct influence on fabric weight irrespective of any associated dimensional effect, e.g. coarser yarn, heavier fabric **(Figure 16)**.

Thus since variation in yarn count will affect both the dimensions and weight of the finished fabric it is also equally important that the average yarn count used in a fabric and between fabrics of the same nominal quality should be maintained consistently.

The finisher attempting to deliver two different fabric pieces to the same weight and width will control the width very accurately. If, however, the yarn used in the two pieces varies significantly then in order to deliver the same fabric weight he will have to finish the fabric made from the lighter yarn with relatively more courses, and the fabric made from heavier yarn with relatively fewer courses. The potential shrinkage in the two pieces of fabric will in consequence be different even though the delivered weight and width is the same.

2.2.2 Yarn Twist/Twist Liveliness

The amount of twist put into a yarn is governed by the twist factor to which it is spun. Twist factor is a function of the number of turns per unit length and the square root of yarn linear density. For the same twist factor, therefore, finer yarns have relatively more turns per unit length than coarser yarns and are more twist lively.

Twist liveliness in a yarn, seen by the snarling and twisting of a yarn on itself when the ends of a hanging loop are brought slowly together, is the direct cause of spirality in single jersey fabrics (**Figure 17**). In addition, however, the yarn twist or twist liveliness can also influence the reference dimensions of the fabric. This is equally true for double jersey fabrics as for single jersey fabrics.

If the twist factor of a given count of yarn is increased the number of courses per unit length in the fabric in its reference state also increase (**Figure 18**). The effect on wales is similar although the magnitude is less. The significance of the effect of twist may also be different depending on the fabric type. e.g. the effects on courses and wales appear to be greater in interlock fabrics than single jersey fabrics.

The direction of twist in the yarn does not however appear to influence significantly either fabric spirality or reference dimensions apart from causing spirality to develop in the opposite direction.

However, if yarns of equal but opposite twist are mixed on alternate feeders in the same fabric, there is a marked influence on the reference dimensions. A fabric produced from alternate ends of S and Z twist will have considerably more courses and significantly fewer wales in the reference state than an equivalent fabric produced from yarn of one twist direction. i.e. it will be shorter and wider. In addition, in single jersey fabrics, spirality will virtually be eliminated but fabric appearance will suffer.

The choice of twofold yarns as opposed to singles yarns will also have an effect on both the reference dimensions of a fabric and its spirality. For an equivalent resultant count the twofold yarn will produce a lighter fabric with fewer courses and fewer wales in the reference state than a singles yarn knitted to the same average loop length (**Figure 19**). This means that when finished to the same weight and width the fabric knitted from the twofold yarn will potentially develop lower length and width shrinkages. In addition, because two fold yarns of balanced twist tend not to exhibit twist liveliness spirality in single jersey fabrics is virtually eliminated.

Fabrics knitted from rotor spun yarns have different dimensions in the reference state compared to similar fabrics knitted from ring spun yarns and there is some evidence to suggest that the properties of the cotton fibre as well as the preparation (carded or combed) will also have an effect. Similarly the use of dyed yarns or mercerised yarns may also have an influence and are therefore another source for the variation in shrinkage found between apparently similarly knitted fabrics.

Other knitting variables such as the machine gauge, take down tension, yarn input tension, yarn friction etc. have not, so far, been found to have a significant influence on the reference state dimensions of the fabric (within the range of adjustments normally used to ensure efficient knitting) provided that the average loop length in the fabric is consistently maintained by the use of positive feed mechanisms. The effect of these variables on knitting efficiency and fabric appearance however is another issue.

3. WET PROCESSING AND FINISHING VARIABLES

The consumer does not usually buy greige fabric (although fashion trends in recent years have sometimes dictated otherwise, and the current increase in popularity of complete garment dyeing for fast response means that variation in the greige goods is assuming a much greater importance) therefore the influence of the wet processing and finishing operations on the dimensions of the reference state must be taken into account if shrinkage control in the final finished product is to be achieved.

Much of the early work on fabric geometry suggested or implied that once the relaxed dimensions of a given greige fabric have been established, they remain fixed and that, irrespective of further processing, the fabric will always try to return to this relaxed "stable" state during any subsequent relaxation or laundering procedure. In fact the reference dimensions of commercially dyed and finished cotton knitted fabrics are quite different from those of the original greige fabric before processing. In addition, different wet processing treatments e.g. bleaching, dyeing, mercerising, chemical cross-linking (resin finishing) can all change the reference dimensions of a finished fabric by different amounts.

As far as reference courses or fabric length is concerned wet processing tends to reduce the number of courses in the finished fabric compared to greige **(Figure 20)**. That is the fabric is longer. However, the type of wet processing route used will affect the length by differing amounts. For example tubular piece mercerised fabrics have considerably fewer courses in the reference state than unmercerised fabrics. Winch processed fabrics have fewer courses than jet processed fabrics. Continuously bleached or prepared fabrics have fewer courses than winch prepared or bleached fabrics.

A similar situation exists for the reference wales or width of the fabrics although in this case the fabric may become narrower (more wales) or wider (fewer wales) depending on the processing route. For example, tubular piece mercerised fabrics are usually considerably narrower than unmercerised fabrics, jet dyed fabrics are wider than winch processed fabrics. In addition the direction and size of the influence of the different wet processing operations varies dependent on the type of fabric and its construction.

Additional changes may also be brought about by the inclusion of a final chemical cross-linking (resin finishing) process and the level of chemicals applied **(Figure 21)**. Similarly the detailed conditions of mercerising, time, tension, caustic concentration etc., and whether piece mercerisation is carried out in tubular or open width will also influence the dimensions of the reference state.

Furthermore for any given processing sequence the depth of shade to which the final fabric is dyed may also influence the final potential shrinkage of the fabric. This can be most easily explained if consideration is given to the fact that during bleaching, weight is removed from the cotton fabric, whereas if a fabric is to be dyed to a deep shade a significant amount of weight is added by the application of the dyestuff. Thus the two fabrics, even if they started out with the same average stitch length and yarn count, will have a different yarn count after finishing even if no other dimensional changes have taken place. If these two fabrics are then finished to the same weight and width the fabric which is deep dyed will have to be finished with fewer courses than the fabric which is bleached white or vice versa. Therefore, even if the reference dimensions of the two fabrics are the same after the wet processing operations, because the finisher has been forced to finish them with different levels of courses in order to deliver the same fabric weight, the potential shrinkage in the two fabrics after final finishing will be different.

It is not surprising therefore that fabrics or garments which are apparently similar when first obtained shrink by different amounts during laundering. In addition it exposes another potential hazard in the evaluation of the shrinkage behaviour of cotton knitted fabrics and the interpretation of the results. If the fabrics used for the purposes of evaluation are not thoroughly consistent, obtaining meaningful results becomes virtually impossible even if the test procedure itself is well controlled.

4. MECHANISM OF SHRINKAGE

The shrinkage behaviour of cotton knitgoods is unfortunately further complicated as the detailed mechanism of the relaxation process appears to be influenced both by the construction and type of fabric being examined and its processing history.

For example;

Tightly knitted fabrics relax more slowly than loose constructions.

Plain single jersey fabrics relax more quickly than single jersey crosstuck (piqué) constructions.

Interlock and rib fabrics relax more slowly than plain jersey fabrics.

Crosslinked fabrics relax more quickly than uncrosslinked materials.

In addition, the rate of relaxation may be different in the length direction compared to the width direction.

These mechanisms are further compounded depending on whether the laundering procedure includes tumble drying or line drying.

For example, mercerised fabrics may relax only slowly during the laundering procedure when washing is followed by line drying but if the same fabric is tumble dried the relaxation of the structure is accelerated significantly and what may have been an acceptable level of shrinkage to line drying turns into a totally unacceptable level of shrinkage after tumble drying.

Similarly some fabrics, particularly interlock or rib, may have an excellent width shrinkage after tumble drying but then, should the fabric or garment be line dried, the shrinkage will turn into a growth or extension. This is not an uncommon pattern of behaviour associated with cotton underwear made from these fabrics!

An illustration of the type of results which may be encountered is given in **Table 27**. These data summarise some of the results obtained from a series of preliminary investigations into the shrinkage behaviour of of cotton knitted fabrics. On separate occasions, shrinkage specimens were prepared from four different cotton fabrics. Measurements were made direct from the washing machine, while the specimens were still wet (AW), after one cycle of line drying (LD), after one cycle of tumble drying (TD) and after dry tumbling (DT). i.e. the specimens were tumbled in the tumble drier without a prior washing treatment [41].

Table 27

Variation in the Rate of Development of Shrinkage in Washing, Line Drying and Tumble Drying

Fabric Type	Length Shrinkage %				Width Shrinkage %			
	AW	LD	TD	DT	AW	LD	TD	DT
Mercerised Crosstuck	3.0	6.9	15.1	5.2	-7.2	-7.4	0.4	1.3
Bleached Interlock	13.5	17.1	15.6	4.0	1.2	-2.2	9.5	4.0
Striped 1x1 Rib	14.3	13.3	14.5	6.0	0.5	-4.9	5.1	8.0
Mercerised Single Jersey	2.9	3.6	11.1	n.a.	-3.3	0	3.3	n.a.

N.B. A minus sign indicates an extension or growth

A more detailed illustration of the development of shrinkage in tumble drying can be given by reference to a much larger and more comprehensive trial which was carried out by the IIC some years ago [13,14].

In this trial the development of shrinkage in twenty different fabrics (single jersey, 1x1 rib and interlock) processed in different ways (grey, mercerised, dyed, crosslinked) was followed over ten cycles of washing and tumble drying.

Table 28

Classification of Shrinkage Behaviour - Length

Sample	Fabric	Finish	Final	1/F%	5/F%	Class
1	I34/340	JDH	19.0	75.3	92.6	P
2	I34/340	MJD	20.1	60.2	87.6	P
3	R30/350	JDH	19.1	78.0	95.7	P
4	R30/350	MJDH	22.3	74.9	94.5	P
5	SJ2-72/287	G	21.0	91.4	98.8	N
6	SJ28/321	G	23.4	91.9	97.9	N
7	I38/340	G	24.5	88.3	97.5	P
8	R30/285	G	17.1	87.7	97.3	P
9	I38/340	MJDX	11.0	66.4	90.9	P
10	I38/340	JDX	16.1	76.1	91.4	P
11	R30/285	MJDX	12.1	73.8	93.8	P
12	R30/285	JDX	12.4	80.8	91.9	P
13	I34/324	MJDH	19.0	63.2	91.0	P
14	I34/324	JDH	14.2	74.2	95.3	P
15	R26/267	JDH	10.2	74.7	94.9	P
16	R30/267	MJDH	12.5	80.9	96.3	P
17	SJ28/306	BRAZ	14.1	86.6	95.5	P
18	SJ2-56/306	BRAZ	11.2	90.1	98.8	N
19	SJ2-56/306	MBRAZ	6.8	63.5	94.3	P
20	SJ28/306	MBRAZ	16.3	72.5	95.2	P

Table 29

Classification of Shrinkage Behaviour - Width

Sample	Fabric	Finish	Final	1/F%	5/F%	Class
1	I34/340	JDH	6.6	107.7	105.4	N
2	I34/340	MJDH	4.4	171.7	127.2	G
3	R30/350	JDH	5.7	181.7	129.6	G
4	R30/350	MJDH	1.6	510.7	200.0	G
5	SJ2-72/287	G	16.1	92.5	96.9	N
6	SJ28/321	G	15.5	93.1	99.0	N
7	I38/340	G	11.2	107.6	105.2	N
8	R30/285	G	20.6	96.5	100.8	N
9	I38/340	MJDX	9.2	112.0	105.2	N
10	I38/340	JDX	9.3	98.3	99.7	N
11	R30/285	MJDX	10.3	108.0	103.2	N
12	R30/285	JDX	7.3	109.4	109.8	N
13	I34/324	MJDH	3.4	170.5	126.6	G
14	I34/324	JDH	8.0	93.7	97.6	N
15	R26/267	JDH	7.9	100.4	98.6	N
16	R30/267	MJDH	4.7	117.9	103.5	N
17	SJ28/306	BRAZ	11.3	95.0	98.7	N
18	SJ2-56/306	BRAZ	12.6	92.3	96.6	N
19	SJ2-56/306	MBRAZ	21.0	103.2	100.0	N
20	SJ28/306	MBRAZ	16.1	112.5	100.1	N

Three different kinds of behaviour were noted as the number of cycles increased.

a) progressive shrinkage
b) little or no change
c) progressive growth after the first cycle.

The data in **Tables 28 and 29** make a comparison between the various fabrics concerning this aspect of shrinkage behaviour.

In these tables, shrinkages after one cycle and five cycles are compared with the "final" shrinkage (F), which is defined as the average of cycles 8, 9, and 10. The proportion of final shrinkage achieved after 1 and 5 cycles is shown as a percentage.

Each fabric is classified according to the proportion of final shrinkage achieved after 1 cycle, for example progressive shrinkage (P) - less than 90% of final shrinkage after 1 cycle, and progressive growth (G) - more than 110% of final shrinkage after 1 cycle.

Out of 40 possibilities (20 length and 20 width) there are 17 examples of progressive shrinkage, all of which are for the length direction. There are four examples of growth after the first cycle, all of which are in the width direction. There are 19 examples of little or no change (N), the majority of which (16) are in the width direction.

These rèsults also show that nearly all fabrics are within 90-110% of the final shrinkage after five cycles. They also indicate that greige fabrics (G) tend to relax faster than finished fabrics, mercerised fabrics (M) tend to relax more slowly than unmercerised fabrics and crosslinked fabrics (X) tend to relax a little faster than uncrosslinked fabrics.

A closer comparison between fabrics and over cycles can be made if all the shrinkage values are normalised by expressing the shrinkage after a given cycle as a ratio (percentage) of the final shrinkage (as previously defined).

Figure 22 shows clearly the progressive **nature** of length shrinkage and the relatively large differences between fabrics up to at least the fifth cycle. **Figure 23** confirms that with the noted few exceptions width shrinkage is essentially completed after the first cycle.

The divergence of behaviour between fabrics and especially the phenomenon of progressive growth after the first cycle thus illustrated tends to support the hypothesis proposed by Munden [4] that the mechanism of shrinkage of cotton knits may include (at least) two distinct relaxation processes which proceed simultaneously. More detailed investigations are required to determine the exact nature of these processes but on the basis of these results two mechanisms may be postulated.

1) relaxation of strain, and
2) consolidation of structure.

Relaxation of strain means the elimination of all extensions imposed during manufacturing and processing and could be expected to be a rather rapid process for most fabrics. One might suppose that such relaxation could be expected to be the most rapid for grey fabrics which have suffered only relatively minor extensions and these only in the dry state. On the other hand, the mercerised materials have suffered rather large tensions under conditions of drastic swelling and might be expected to require more than one wetting/drying cycle to relax the strains.

Consolidation of structure is meant to embrace any changes in the effective specific volume and the length of the yarns, which might be caused by the washing and tumble drying procedure as well as any changes in the natural shape of the loops (ratio of length to width) and any bending or twisting of the loops out of the plane of the fabric.

A regression analysis of the data obtained from these trials, was carried out assuming that the two processes were proceeding simultaneously, and that the effects of both were decreasing exponentially with the number of cycles but at different rates.

From the results of this analysis a few significant conclusions were drawn.

Assuming that the two-process model was adequate, then the two processes proceed at vastly different rates. The fast process (here attributed to relaxation) is essentially complete after one or two cycles. On average the fast process accounts for about 80% of the ultimate shrinkage in length and 150% of the shrinkage in width. The slow process (here attributed to consolidation) proceeds much more slowly and is still incomplete after the 10th cycle, although by this stage the effect is very small. The slow process accounts for about 20% of the ultimate length shrinkage and -50% of the ultimate width shrinkage.

For length shrinkage the two processes are complementary, leading to progressive shrinkage. In the width direction they are in opposition, leading to partial cancellation and a rather unpredictable behaviour that can range from mildly progressive to regressive.

This is illustrated in **Figures 24 and 25** in which the observed shrinkage averaged over all 20 fabrics is broken down into the two component processes.

5. SUMMARY

The Reference Dimensions of a given knitted fabric depend on its initial construction and its wet processing history.

The as-delivered dimensions are fixed by the finisher who will be attempting to meet strict target specifications for weight and width.

Once the weight and width are fixed, then the shrinkages are also fixed and will be translated directly to the garment, modified only by the amount of relaxation or stretching which occurs during the garment making operation.

If the final weight and width are accurately controlled by the finisher, then any variations in manufacturing parameters (changes in yarn, stitch length, wet processing) are directly translated into variations in shrinkage.

Thus the total amount of potential shrinkage in a given garment has already been fully determined by the manufacturers - there is nothing that the ultimate consumer can do to alter it. However, the rate at which this potential shrinkage will develop depends on the fabric type and its wet processing history as well as the laundering practices of the consumer.

Although the understanding of the underlying sources and the mechanisms of shrinkage in cotton knitgoods is obviously of industrial and academic interest, it is how this mechanism is manifested in the shrinkage of garments during domestic laundering procedures which is of fundamental importance to the consumer. Therefore the studies of shrinkage which have been undertaken by the IIC as part of the Starfish project have also investigated how the variables of fabric production and processing, testing procedures and laundering conditions effect the measurement, determination and development of shrinkage in garments.

C. THE MEASUREMENT AND DEVELOPMENT OF SHRINKAGE IN GARMENTS

1. INTRODUCTION

Many of the factors which can influence the reliable and reproducible measurement of shrinkage in fabrics are also relevant to the measurement of shrinkage in garments, e.g.

1.1 Testing Variables

Sample preparation

Marking of the test specimens
Number of replications

Laundering Procedures

Washing Conditions
Drying conditions
Ironing or pressing

Similarly the factors which can influence the dimensions of the reference state and therefore the potential shrinkage in the fabric from which the garment is manufactured also need to be considered, e.g.

1.2 Production and Processing Variables

Knitting variables

Stitch Length
Yarn Count and Type

Wet Processing and Finishing Variables

Preparation
Mercerisation
Dyeing
Crosslinking
Dimensions at which the fabric is delivered (distance from the Reference State).

In addition, however, the determination of shrinkage in garments will also be influenced by those extra sources of variation which are a consequence of the making-up process itself and the construction of the garment, e.g.

1.3 Garment Production Variables

Making-Up

Method of laying and marking
Method of cutting
Handling of garment pieces during sewing
Final finishing of the made-up garment
Transportation and storage

Garment Construction

Body Width (tubular) or Cut and Sew (side seams)
Basic style and size
Amount of sewing
Stitch types and seams
Sewing thread
Addition of trims and/or mixed fabrics

Finally, with garments, shrinkage can be assessed either by using flat measuring techniques or by means of a frame.

1.4 Method of Assessment

Flat or by frame.

The assessment and measurement of shrinkage in garments under standard laboratory conditions is unlikely to properly represent or adequately predict the consumer's perception of the performance of the garment worn and washed under domestic laundering conditions. This is not only because domestic laundering conditions are less well controlled than laboratory methods but also because the actual performance of the garment, and the consumers assessment of it, will be influenced by other factors. e.g.

The size of the wearer compared to the actual (Reference) size and fit (tight or loose) of the garment.
Whether the garment skews or twists.
The retention of shape and fabric appearance.
Seam pucker and quality of make-up.

The evaluation of garment shrinkage (and relating laboratory determinations to actual consumer experience) is therefore much more difficult and subject to more variation than the measurement of shrinkage in fabrics.

It has not been possible so far to address all of the potential sources of variation in the measurement of shrinkage in garments, nor have the trials carried out been as extensive or comprehensive as those carried out on fabrics. However, some information on the relationship between fabric shrinkage and garment shrinkage has been obtained together with an indication of the relationship between the performance of garments after domestic laundering and wear cycles compared to standard laboratory laundering and evaluation procedures.

The main objectives of the garment trials so far carried out by the IIC have been limited to the following:-

a) Establishing whether the reference state dimensions and shrinkage found in fabric (IIC standard laboratory method) correlates to the shrinkage and reference dimensions found in garments made from the same fabric.

b) Establishing the relationship between the shrinkage and dimensions of worn and washed garments to the shrinkage and reference state dimensions of the original fabric and to measurements made on similar garments under standard laboratory conditions.

c) Investigating the influence of different standard laboratory laundering procedures on the reference dimensions and shrinkage of garments.

d) Evaluating the relationship between measurements of garment shrinkage assessed from flat measurements compared to those obtained from measurements made using a frame.

Table 30

	Mean	sd	CV %
Stitch Length mm	2.77	0.02	0.72
Yarn Count tex	19.8	0.36	1.83

2. TEST METHOD REPRODUCIBILITY

As has been stated previously, the factors which can influence the reliable and reproducible measurement of shrinkage in fabrics apply equally to the measurement of shrinkage in garments and some of these aspects will be dealt with in the following section. Similarly the conditions of washing and drying will also affect the results and these will be addressed in the context of the trials outlined above.

The problem of obtaining reliable and reproducible results and correctly interpreting the results obtained from the measurement of garments is complicated by the variations introduced by the making-up process, the construction of the garment and the method of evaluation. When evaluating garments therefore it is essential that the dimensions and construction of the fabric from which the garments are made are also checked as well as the actual dimensions of the garment. This is important because the measurement of shrinkage in garments depends on the dimensions of the fabric (before washing as well as after washing) not just on the dimensions of the garment.

For example, it is quite possible to have two garments made to the same size and from apparently similar fabric which will shrink by different amounts during a standardised laundering procedure simply because during the making-up process one fabric has been stretched more or has relaxed more than the other prior to the final dressing (finishing) of the garment at the end of the making-up line. When this occurs it can cause problems of interpretation and misleading results.

2.1 Preparation of Samples

2.1.1 `Size

The size of the test specimen obviously depends on the size of the garment being evaluated. Therefore the size of test specimen is subject to less fredom of choice when assessing garments than when fabric samples are being considered. For example, a child's garment will be much smaller than that for a large man and this could be expected to lead to differences in the behaviour of the fabric due, for example, to the higher proportion of sewing to free fabric in the child's garment.

However, similarly to the results found in the investigations of fabric shrinkage, in trials where garments of similar style and construction (T-shirts) have been assessed, there has not appeared to be a significant independent influence of the garment size on the average shrinkage results obtained, although there may be an influence on the reproducibility of the results. It should be noted however that only a very limited range of garment styles have been evaluated and therefore this conclusion may not hold when for example a full length garment is included. (For example, the problem of spirality or garment skew in nightshirts made from single jersey fabrics is much larger than in T-shirts or briefs made from a similar fabric construction).

In those trials [42,43] which have attempted to discover whether or not size has an influence on the measurement of shrinkage the problem of obtaining misleading results if only shrinkage results are considered has been highlighted.

Thirty children's garments, ten in each of three sizes, were purchased from a leading chain store retailer. All the garments were nominally made from the same fabric, a navy 1x1 rib construction, and made-up in the same style, short sleeve T-shirts. The only apparent difference between the garments was the nominal size; chest measurements 55, 65 and 74 cm respectively. Six of the garments, two in each size, were subjected to full laboratory physical testing to establish whether the fabrics from which the garments were made were in fact the same. The results obtained for stitch length and yarn count indicated that all the fabrics had been knitted to the same quality, i.e. the measurements were within normal commercial tolerances. **Table 30.**

However, the measurements of courses and wales suggested that although the fabrics had been knitted to the same quality they had either been delivered at the end of the finishing line with different dimensions or had relaxed (or extended) to different extents during transportation and garment making. The variation in the courses especially was much higher than would normally be specified as a commercial tolerance. **Table 31.**

Table 31

	Mean	sd	CV %
Courses/3cm	49.5	2.0	4.0
Wales/3cm	30.7	0.8	2.7

Because the actual knitting quality was apparently the same, it was decided to randomly divide the remaining twenty four garments into four similar sets of 6 garments, two of each size per set, for evaluation under different standard laundering conditions. (The results from this aspect of the trial will be discussed in a later section). After laundering, which was followed over ten full cycles, twelve of the garments, (four of each size, three from each set) were again subjected to full laboratory physical evaluation. Similarly to the results obtained on the unwashed garments the results obtained for stitch length and yarn count confirmed that all the garments had been made from fabric of the same basic knitted construction. **Table 32.**

Table 32

	Mean	sd	CV %
Stitch Length mm	2.75	0.01	0.46
Yarn Count tex	19.6	0.51	2.62

Measurements of shrinkage had been made on all the garments after each laundering cycle. After the tenth cycle the results obtained for length and width shrinkage were averaged across the different laundering procedures for each garment size to determine whether the size of the garment had influenced the development of shrinkage. These results are given in **Table 33.**

Table 33

The Effect of Garment Size on the Measurement of Garment Shrinkage after Ten Cycles of Washing and Drying

		Nominal Garment Size			Average
		55 cm	65 cm	74 cm	all Sizes
LS %	mean	6.4	8.2	9.7	8.1
	sd	3.6	3.0	3.1	3.4
WS %	mean	4.9	7.8	4.8	5.8
	sd	4.2	3.1	3.9	3.9

From these results it would be easy to conclude that the development of length shrinkage is affected by the size of the garment. There is a progression of increasing length shrinkage as the size of the garments increased.

The results for width shrinkage did not show a similar progression however.

The variation in the results, as indicated by the standard deviations, are high because of the different laundering procedures. However there is an indication that the results obtained from the small garments may be relatively more variable than the other sizes.

However, as well as measuring the shrinkage of the garments, measurements of courses and wales were also made on all the garments before laundering and after each of the ten laundering cycles. Similarly to the shrinkage results, the values obtained for courses and wales were averaged across the different laundering procedures for each garment size. These results are given in **Table 34.**

Table 34

Courses and Wales Measured on the Garments Before and After 10 Laundering Cycles

		Nominal Garment Size			Average
		55 cm	65 cm	74 cm	All Sizes
Before Washing					
Courses/3cm	mean	50.7	48.0	47.9	48.9
	sd	1.3	0.9	0.7	1.6
	CV %	2.5	1.8	1.4	3.3
Wales/3cm	mean	29.8	31.1	30.5	30.5
	sd	0.7	0.8	0.8	0.9
	CV %	2.4	2.6	2.6	2.9
After Washing					
Courses/3cm	mean	53.9	52.6	52.4	53.0
	sd	1.6	1.6	0.5	1.4
	CV %	3.0	3.0	0.9	2.7
Wales/3cm	mean	31.9	33.2	32.4	32.5
	sd	1.0	1.0	0.6	1.0
	CV %	3.1	3.0	1.9	3.1

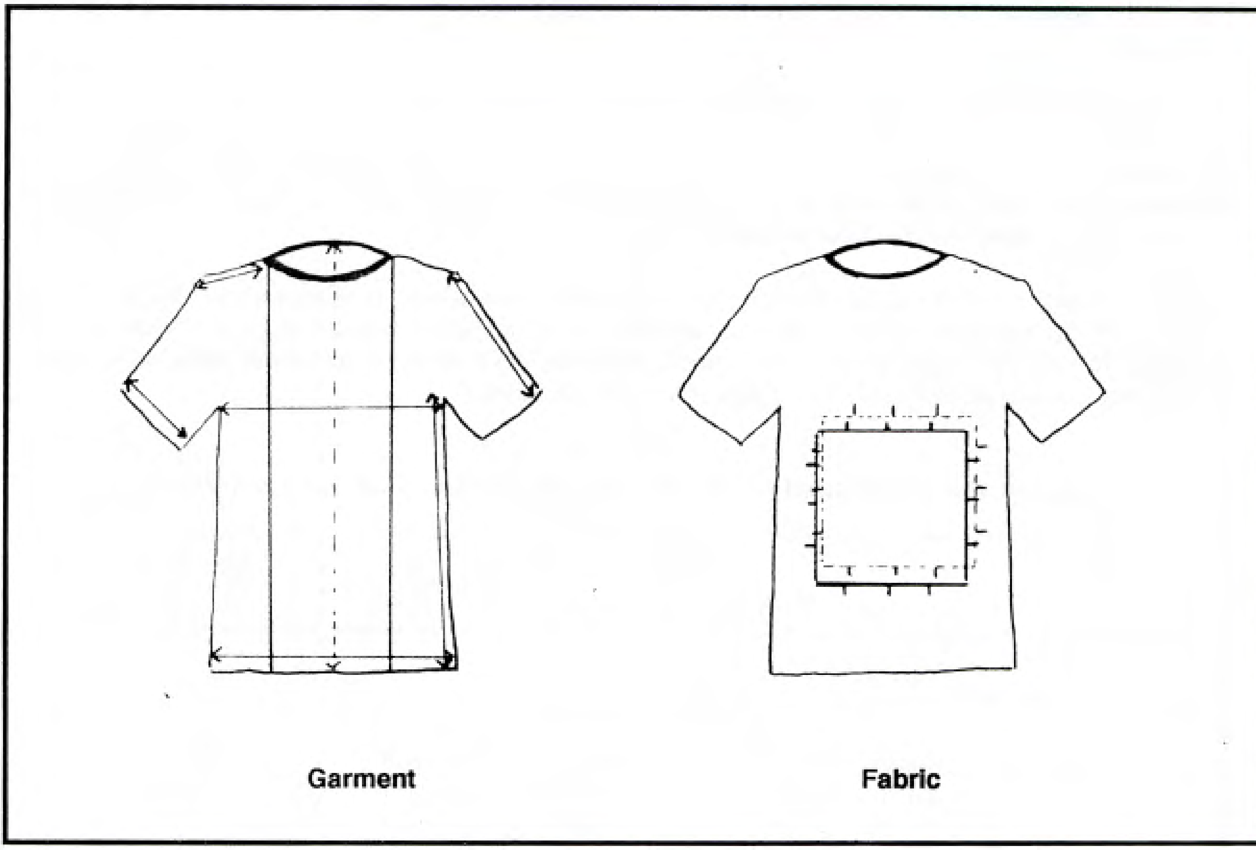
From these results the following observations can be made.

The average values for courses measured in the 55 cm garments before washing were significantly higher than those measured in the other garments. The variation in the measurements within this set was also higher.

There was no significant difference in the average wales measured on the garments before washing. Variation in the measurements was similar for all garment sizes.

The courses and wales measured in the different sized garments after washing were not significantly different from each other, although the 74 cm garments were less variable than the other two sizes.

Diagram 2



The total variation in courses across all sizes was lower in the after wash garments than the before wash garments. The variation in wales after washing increased marginally.

These results appeared to indicate therefore that although garment size may affect the reproducibility of measurements, it probably does not significantly influence the final dimensions of the fabrics as indicated by the after wash measurements of courses and wales. Differences in measured shrinkage must therefore be due primarily to variations in the dimensions of the garments (fabrics) before washing.

The reason why the small garments are shrinking less in the length direction is therefore either that the fabric from which they were manufactured had been finished with more courses than the fabric used for the other garments or that the fabric or the garments had relaxed (or extended) differently during transportation and making-up. It is not because smaller garments necessarily develop less shrinkage than larger garments, as may have been deduced solely on the basis of the shrinkage results.

2.1.2 Marking and Measuring

Most of the major retail outlets in the UK issue guide-lines with regard to the marking and measuring of garments for tests for dimensional stability. Similarly, there are national and international standards (e.g. BS 4931:1986, ISO 3759-1984) which give guide-lines regarding the appropriate location and number of measuring points required on the garment under test.

The differences which exist between various methods may be classified according to whether the objective of the test is to assess the shrinkage of the whole garment or the shrinkage of the fabric from which the garment is produced.

To assess changes in garment dimensions, measuring points should be positioned at appropriate places sufficient to enable an assessment of the changes in the whole garment dimensions to be made. e.g. along the side seams (underarm to hem), shoulder seam to end of sleeve, around the hem, across the width at the arm and at the hem, centre back neck to hem, centre front neck to hem etc. The number and location of the measuring positions will usually depend on the style and construction of the garment but should include at least five measurements for length and five for width distributed over both the front and back of the garment. Average shrinkage values for length and width can then be calculated from the individual measurements. The variation between measurements made at different locations on a garment can sometimes be quite large and this should be kept in mind during the evaluation of the results. If necessary, "rogue" values should be discarded before averaging if they will unfairly bias the overall result.

To assess changes in the fabric rather than the whole garment, marks should be placed in the body of the garment as far as is practical from any sewing or seams. Providing that the size of the garment allows it, a shrinkage template should be used to ensure accuracy and standardisation in the location of measuring marks between specimens and between operatives. If a template cannot be used maximum care should be taken to ensure that marks are accurately located perpendicular to each other in both the length and width directions. At least 3 pairs of marks for length and three pairs for width should be included. The shrinkage square should be defined on both the front and back of the sample. The results from both sides can then be averaged to give a single length and single width result.

An illustration of typical measuring reference points used by the IIC in the trials to assess the shrinkage in garments is given in **Diagram 2**.

Marking can be carried out either by means of a suitable indelible marker or, if the colour of the garment makes this difficult, by means of a sewn stitch. Distances between reference marks should always be remeasured prior to laundering.

2.1.3 Number of Replications

Given that to obtain good reproducibility of shrinkage measurements on fabrics requires at least four and preferably five replications per sample, then to obtain a similar level of reproducibility when assessing

Table 35

Comparison of Courses and Wales Measured on the Fabric (F) and on the Garment (G) after a Standard Laboratory Washing and Tumble Drying Procedure

Fabric Reference		Courses/3cm F	G	Diff.	Wales/3cm F	G	Diff.
Singlet							
1	IJDH	46.1	46.4	+0.3	42.3	41.8	-0.5
2	IJDH	40.0	39.8	-0.2	42.3	42.2	-0.1
3	ICBT	46.2	47.2	+1.0	43.7	44.0	+0.3
4	ICBT	49.3	48.6	-0.7	46.1	46.4	+0.3
5	RJDH	56.5	58.0	+1.5	34.6	34.2	-0.4
6	RJDH	48.0	49.0	+1.0	31.0	31.2	+0.2
7	RJDH	51.2	51.2	0	33.2	32.8	-0.4
8	RWDH	47.5	47.8	+0.3	32.8	32.6	-0.2
9	RWDH	54.6	56.2	+1.6	35.8	36.0	+0.2
10	RWBT	52.6	53.6	+1.0	32.8	33.2	+0.4
11	RWBT	55.8	56.2	+0.4	34.1	36.0	+1.9
12	RMJDH	41.5	41.8	+0.3	32.9	34.0	+1.1
T-Shirt							
13	IJDH	52.8	52.2	-0.6	43.4	44.2	+0.8
14	IJDH	42.7	43.6	+0.9	40.8	41.4	+0.6
15	IJDH	50.4	51.2	+0.8	45.7	45.6	-0.1
16	IMJDH	40.1	38.6	-1.5	46.1	47.8	+1.7
17	IMJDH	40.0	37.6	-2.4	49.7	50.0	+0.3
18	IWDH	49.5	49.4	-0.1	47.7	48.4	+0.7
19	RMWBT	42.7	43.6	-0.9	34.9	36.8	+1.9
20	RMWBT	52.0	54.2	+2.2	41.6	42.6	+1.0
21	RMJDH	57.4	57.2	-0.2	38.7	39.6	+0.9
22	RJDH	54.5	55.2	+0.7	31.7	33.2	+1.5
23	RWBT	48.7	47.2	-1.5	30.9	32.4	+1.5
	mean	48.7	48.9	+0.2	38.8	39.4	+0.6
	sd	5.5	6.1	1.1	6.1	6.0	0.7

N.B Average % difference in courses = +0.4%
Average % difference in wales = +1.5%

garments, at least the same number of replications should be required, considering the additional sources of variation in the starting garment dimensions due to the making-up process.

Having said that however, the evaluation of made-up garments is a much more expensive procedure than the evaluation of fabrics and it is not always possible to obtain an adequate number of similar garments for comparison for the ideal number of replications per variant to be included.

The marking and measuring procedure for garments adopted by the IIC does however ensure that at least two average assessments (1 front, 1 back) for both length and width are obtained for each garment. In addition where sufficient garments of similar style and fabric construction have been available, then at least two garments have been assessed. Ideally three garments should be included.

Having regard for these limitations therefore it must be accepted that results obtained from the evaluation of garments may often be more variable and less reproducible than measurements made on fabric specimens.

3. COMPARISON OF FABRIC SHRINKAGE AND REFERENCE DIMENSIONS WITH THE SHRINKAGE AND DIMENSIONS OF GARMENTS MADE FROM THE SAME FABRICS

An early and somewhat restricted trial [44] compared the dimensions and shrinkage of three garment styles produced from a wide range of interlock and 1x1 rib fabrics (different constructions and finishes) with the shrinkage and dimensions of the original fabrics in the reference state.

Samples of the fabrics from which garments were later produced had been measured for courses, wales and shrinkage both before washing and after relaxation to the reference state.

Garments were produced by a co-operating manufacturer from the same fabrics but not necessarily from exactly the same rolls which had been sampled for fabric testing.

For this comparison only one garment of each style/fabric variant was washed and tumble dried in the laboratory under standard conditions. Courses and wales were measured on the garments before washing, and courses, wales and shrinkage were measured on the garments after completion of five cycles of washing and tumble drying. The results obtained from some of the fabrics/garments which were evaluated are included in **Tables 35 and 36.**

A comparison of the results obtained indicated that measurements of courses and wales made on the fabric and the garments after five cycles of washing and tumble drying were on average giving similar results. The average difference in courses was +0.2 or +0.4% based on the fabric measurements, and for wales +0.6 or +1.5%.

A comparison of the courses and wales measured on the fabric and garments before wash however showed much poorer agreement. In particular, wales measured in the garments were on average higher than those measured in the corresponding fabrics. This would suggest that a certain amount of relaxation in the width had taken place either during storage and transportation of the fabrics or during the making-up procedure.

A comparison of the shrinkage results appeared to indicate that, on average, length and width shrinkages measured in the garments were lower by approximately 2.3% in length and 1.6% in width than those measured on the fabrics. In addition, there were large variations in the differences between different fabrics and finishes.

Thus, a certain amount of the discrepancy in the shrinkage results could be accounted for by the differences in the dimensions of the fabrics and garments (courses and wales) before washing.

The results of this trial again illustrate some of the potential problems associated with comparing the shrinkage of garments to that measured in the fabric.

Table 36

Comparison of Fabric Shrinkage (F) and Shrinkage Measured in the Garment (G) after a Standard Laboratory Washing and Tumble Drying Procedure

Fabric Reference		Length Shrinkage % F	Length Shrinkage % G	Length Shrinkage % Diff.	Width Shrinkage % F	Width Shrinkage % G	Width Shrinkage % Diff.
Singlet							
1	IJDH	17.5	16.3	-1.2	10.8	9.2	-1.6
2	IJDH	21.8	21.2	-0.6	13.6	17.2	+3.6
3	ICBT	11.8	11.4	-0.4	10.8	10.0	-0.8
4	ICBT	11.6	10.4	-1.2	9.8	8.4	-1.4
5	RJDH	15.1	12.4	-2.7	3.7	3.9	+0.2
6	RJDH	17.6	12.6	-5.0	6.0	5.2	-0.8
7	RJDH	17.4	13.6	-3.8	6.8	4.7	-2.1
8	RWDH	12.0	10.6	-1.4	9.8	5.9	-3.9
9	RWDH	13.1	10.6	-2.5	8.4	3.9	-4.5
10	RWBT	6.3	5.8	-0.5	7.7	5.3	-2.4
11	RWBT	3.9	5.1	+1.2	7.3	3.4	-3.9
12	RMJDH	22.9	16.7	-6.2	1.6	4.0	+2.4
T-Shirt							
13	IJDH	13.0	12.4	-0.6	10.6	8.3	-2.3
14	IJDH	19.7	16.4	-3.3	8.8	5.0	-3.8
15	IJDH	16.7	14.0	-2.7	8.4	6.9	-1.5
16	IMJDH	23.9	16.8	-7.1	3.7	3.3	-0.4
17	IMJDH	19.0	15.3	-3.7	8.0	4.2	-3.8
18	IWDH	18.6	12.8	-5.8	8.0	3.9	-4.1
19	RMWBT	7.7	7.8	+0.1	2.4	2.0	-0.4
20	RMWBT	6.2	6.3	+0.1	5.4	5.1	-0.3
21	RMJDH	12.3	10.6	-1.7	2.8	0.1	-2.7
22	RJDH	15.2	10.7	-4.5	4.9	2.9	-2.0
23	RWBT	7.0	8.2	+1.2	4.5	3.1	-1.4
	mean	14.4	12.1	-2.3	7.1	5.5	-1.6
	sd	5.6	4.0	2.3	3.1	3.5	2.0

During the making-up process the dimensions of the fabric may be altered depending on the tensions imposed on the fabric during laying and cutting, and they may alter again due to relaxation of the garments during handling and sewing, final dressing and transportation. The measurement of garment shrinkage is therefore likely to be subject to more variation than the measurement of fabric shrinkage.

On the other hand this trial also indicated that the measurement of courses and wales after a standard relaxation procedure (Reference State) may provide a more reliable basis for comparisons.

4. FABRIC SHRINKAGE AND DIMENSIONS IN THE REFERENCE STATE COMPARED TO THE DIMENSIONS OF WORN AND WASHED GARMENTS

As part of the same trial, described in 3 above, two garments per style/fabric variant were put out for wearer trials. Each participant was asked to wear the garments and wash them according to their normal laundering procedures. After five and ten home laundering cycles the garments were assessed for shrinkage.

At the end of the tenth cycle the singlets and T-shirts were returned to the laboratory and given an eleventh standard washing and tumble drying cycle. The dimensions, courses and wales, and shrinkage were remeasured after this eleventh cycle.

The shrinkage measured in the worn garments after the fifth and tenth cycles of home laundering varied widely, both between pairs of samples and between the various fabrics and finishes. The results obtained from some of these worn garments after the fifth home laundering cycle are illustrated in **Table 37** together with the results obtained on the laboratory washed garments after five cycles.

Table 37

Shrinkage Measured on Garments after Five Cycles of Laboratory Washing and Tumble Drying (Lab) Compared to that Measured on Worn Garments made from the same Fabric after Five Cycles of Home Laundering (HL1 and HL2)

Fabric Reference		Length Shrinkage %			Width Shrinkage %		
		Lab	HL1	HL2	Lab	HL1	HL2
Singlet							
1	IJDH	16.3	11.1	14.2	9.2	-2.6	5.6
2	IJDH	21.2	11.0	15.0	17.2	2.2	3.5
3	ICBT	11.4	0.2	7.2	10.0	3.6	5.3
4	ICBT	10.4	3.3	6.9	8.4	1.6	4.6
5	RJDH	12.4	9.7	8.8	3.9	6.5	-0.5
6	RJDH	12.6	11.0	6.7	5.2	3.2	1.3
7	RJDH	13.6	13.7	4.8	4.7	2.7	3.5
8	RWDH	10.6	6.1	3.5	5.9	3.4	1.4
9	RWDH	10.6	4.6	3.7	3.9	-8.4	-0.9
10	RWBT	5.8	3.0	-2.7	5.3	-0.9	2.2
11	RWBT	5.1	5.4	1.4	3.4	5.8	2.4
12	RMJDH	16.7	5.1	7.0	4.0	11.7	-1.0
	mean	12.2	7.0	6.4	6.8	2.4	2.3
	sd	4.5	4.2	4.9	4.0	5.0	2.3

N.B. A minus sign indicates an extension or growth

Table 38

Comparison of Courses and Wales Measured on Laboratory Washed and Tumble Dried Garments after Five Cycles compared to Courses and Wales Measured on worn garments after Ten Home Laundering Cycles followed by an Eleventh Standard Laboratory Wash.

Fabric Reference		Courses/3cm			Wales/3cm		
		Lab	HL1	HL2	Lab	HL1	HL2
Singlet							
1	IJDH	46.4	44.2	45.6	41.8	39.6	41.4
2	IJDH	39.8	40.2	38.4	42.2	40.6	39
3	ICBT	47.2	46.6	44.2	44.0	43.0	42.8
4	ICBT	48.6	49.0	47.6	46.4	46.0	44.4
5	RJDH	58.0	56.8	57.4	34.2	34.4	34.2
6	RJDH	49.0	48.4	46.6	31.2	29.8	30.8
7	RJDH	51.2	51.2	50.6	32.8	32.6	33.0
8	RWDH	47.8	47.0	48.0	32.6	31.4	31.6
9	RWDH	56.2	54.6	54.0	36.0	34.4	36.2
10	RWBT	53.6	52.6	51.2	33.2	33.0	32.6
11	RWBT	56.2	56.4	56.6	36.0	33.0	32.8
12	RMJDH	41.8	41.2	39.6	34.0	31.4	33.4
	mean	49.7	49.0	48.3	37.0	35.8	36.0
	sd	5.7	5.5	6.0	5.1	5.2	4.7

Length shrinkages measured on the home laundered garments were on average 5.2% and 5.8% less than the laboratory laundered garments. Width shrinkages were on average 4.4% and 4.5% less on the home laundered garments.

The main reason for the observed differences in shrinkage between the worn and home laundered garments and the laboratory laundered garments is primarily the different conditions of laundering and drying carried out as part of the home laundering procedures. At the time the trial was carried out (1979/80) many of the participants did not use tumble driers and, of those that did, not all tumble dried the garments after each washing cycle. In some instances garments were hand washed as opposed to machine washed, and some were ironed whilst others were not. These factors will have accentuated the differences for some of the garments since the rate at which shrinkage develops in washing and drying depends not only on the washing and drying procedures used but also on the construction and processing history of the fabric.

In addition, however, there was also an interaction between the body size of the wearer and the actual size of the garments. For some of the garments the relationship between the actual size of the garment and the size of the wearer altered due to the high levels of shrinkage developed. Some of the garments became very tight fitting across the width (chest). This meant that they were stretched in the width direction by large amounts during wear some of which was apparently not recovered during the laundering process, especially when the garments were not tumble dried. As a result some of the garments, in particular those made from 1x1 rib fabrics, extended in the width direction.

Both the length and width shrinkages observed in the worn and home laundered garments were almost always lower than those observed either in the fabric or in the laboratory washed garments. **Figure 26** illustrates the results for home laundered garment shrinkage after ten wash and wear cycles compared to that measured on the fabric after five cycles in the laboratory.

The agreement between the shrinkage results improved, however, after the eleventh standardised laboratory washing procedure and, in addition, courses and wales measured on the worn garments, after the 11th laboratory washing and tumble drying cycle, also showed better agreement with the measurements of courses and wales made on the fabrics and the laboratory washed garments. **Table 38** illustrates some of the results obtained.

The average % differences in courses based on the laboratory garments are -1.4%, and -2.8%, and the average % differences in wales based on the laboratory garments are -3.2%, and -2.7%.

A similar trial carried out by the South African Textile Research Institute (SAWTRI) and reported by Lawrence Hunter in 1985 [45] confirmed the problems of relating laboratory measurements of shrinkage to that found during domestic laundering and wear.

5. INFLUENCE OF DIFFERENT DRYING CONDITIONS ON THE DEVELOPMENT OF SHRINKAGE IN GARMENTS

The garments used in the following two trials [42,43] were obtained from two leading UK chain store retailers. The main objective of the trials was to assess the development of shrinkage in similar garments subjected to different drying procedures. In addition it was hoped to obtain some idea of the normal level of variation in size and make-up which could be found in garments offered for sale by large retail outlets.

5.1 First Trial [42]

Thirty garments were purchased from a major UK chain store retail outlet. All the garments were made from the same nominal fabric construction and made-up in the same style. i.e. navy blue, short sleeve, children's T-shirts made from 1x1 rib knitted cotton fabric.

Three sizes were sampled, ten garments in each size.

Table 40

Effect of Different Laundering Procedures on the Development of Shrinkage in Garments

Cycle	Length Shrinkage % First	Fifth	Tenth	mean	Width Shrinkage % First	Fifth	Tenth	mean
Procedure								
Set 2 WTD	7.6	11.2	11.2	10.0	8.1	8.6	8.4	8.4
Set 3 WLD	4.2	5	5.2	4.8	6.2	5.8	4.8	5.6
Set 4 WTDP	5.7	9.4	9.9	8.3	8.8	9.0	8.2	8.7
Set 5 WLDP	4.1	5.2	5.7	5.0	4.0	2.9	3.0	3.3
mean	5.4	7.7	8.0		6.8	6.6	6.1	

From the thirty original garments five randomly selected sets of garments were assembled. Each set containing six garments, 2 of each size.

Set 1 garments were subjected to full laboratory physical investigation to determine yarn count, strength and extension, stitch length, weight, courses and wales, spirality, thickness, and colour (RGB).

The results obtained for stitch length and yarn count confirmed that the fabrics used for these garments were all knitted to the same quality. The variation in the courses, however, was somewhat higher than would normally be accepted as being within commercial tolerances (specifications) and indicated that in fact the fabrics from which the garments were manufactured may have been delivered at different dimensions. This would be expected to add considerably to the variation in length shrinkage results between nominally the same garments. Variation in the wales was only slightly higher than would normally be accepted as being within commercial tolerances. These results are summarised in **Table 39.**

Table 39
Fabric Dimensions Measured on Set 1 Garments

	mean	sd	CV %
Stitch Length mm	2.77	0.02	0.72
Yarn Count tex	19.8	0.4	1.8
Courses/3cm	49.5	2.0	4.0
Wales/3cm	30.7	0.8	2.7
Weight gsm	178.9	6.1	3.4

The remaining four sets were subjected to ten cycles of a specified laundering procedure, measurements of courses, wales and shrinkage being made after each cycle. i.e.

Set 2 (WTD)	Wash at 60° C and tumble dry.
Set 3 (WLD)	Wash at 60° C and line dry (vertical wales).
Set 4 (WTDP)	Wash at 60° C, tumble dry and press.
Set 5 (WLDP)	Wash at 60° C, line dry (vertical wales) and press.

Pressing was carried out using a domestic steam iron.

All the garments were marked to enable measurements of garment shrinkage and fabric shrinkage to be made.

Measured shrinkage values for the whole garments and the fabric, as well as shrinkages calculated from changes in courses and wales were compared and found to return similar results within each set over all ten cycles.

The results were therefore averaged and used to assess the differences between laundering procedures. The results for length and width shrinkage over the ten cycles are illustrated in **Figures 27 and 28**, respectively. Measurements after the first, fifth and tenth cycles are summarised in **Table 40**.

Table 41

Standard Deviation of Shrinkage Measurements (Garment and Fabric) for each Set after Ten Laundering Cycles

	Length Shrinkage % Tenth cycle sd	Width Shrinkage % Tenth cycle sd
Set 2 WTD	1.8	1.6
Set 3 WLD	2.4	2.1
Set 4 WTDP	2.5	1.6
Set 5 WLDP	1.5	2.2
mean	2.1	1.9

5.1.1 Effect of Drying Procedure

a) Length Shrinkage

Length shrinkage increased progressively with number of cycles for both the tumble dried and line dried sets. The biggest changes occurring between one and five cycles. The difference in length shrinkage between the fifth and tenth cycles was very small.

The line dried garments (Set 3) shrank less than the tumble dried garments (Set 2) by on average 5.2%.

b) Width Shrinkage

In the tumble dried set there was very little change in width shrinkage over cycles.

In the line dried set width shrinkage decreased over cycles. i.e. the garments developed less width shrinkage after ten cycles than after five cycles or after one cycle, indicating an extension or growth in the width of the garments.

The line dried garments (Set 3) shrank less than the tumble dried garments (Set 2) by an average 2.8%.

5.1.2 Effect of Pressing

a) Length Shrinkage

For the tumble dried garments pressing had the effect of reducing the measured length shrinkage by on average 1.7%. The size of the improvement was marginally greater after one cycle (1.9%) than after ten (1.3%).

For the line dried garments, however, pressing had the effect of slightly increasing length shrinkage, on average, compared to those garments which had been line dried and not pressed. The differences appeared to be increasing slightly with number of cycles but they were very small and are probably not significant.

Pressing reduced the difference in length shrinkage between the line dried garments (Set 5) and the tumble dried garments (Set 4) to 3.3%.

b) Width Shrinkage

For the tumble dried garments pressing marginally increased width shrinkage over the ten cycles but the effect was not really significant.

For the line dried garments pressing reduced the width shrinkage by an average 2.3% over the ten cycles compared to the line dried garments which had not been pressed.

Pressing increased the difference between the line dried (Set 5) and tumble dried (Set 4) garments to an average 5.4%.

5.1.3. Reproducibility

The results obtained from the tumble dried garments (Set 2) were less variable in both length and width than those obtained from the line dried garments (Set 3). **Table 41**

Pressing increased the variation in the length shrinkage results from 1.8 to 2.5 for the tumble dried sets but improved the variation in the line dried sets from 2.4 to 1.5.

Pressing had no effect overall on the variability of the width shrinkage results.

On average the measurements of width shrinkage were slightly less variable than those for the length.

5.2 Second Trial [43]

Twenty four garments were obtained from a different major UK chain store retailer. All of the garments were manufactured in the same style from the same fabric construction. The fabric was dyed (different colours), 14 gauge 1x1 rib. The style was ladies round neck, short sleeve T-shirts. Three different garment sizes were sampled, eight of each size.

The garments were randomly separated into five sets. Set 1 containing four garments, the remaining sets each containing five garments.

The Set 1 garments were subjected to full laboratory physical investigation to determine yarn count, strength and extensibility, stitch length, weight, courses and wales, spirality, thickness and colour (RGB).

The results obtained for yarn count and stitch length confirmed that the fabrics used to manufacture the three different sized garments were knitted to the same quality. However, the variation in the wale measurements was a little on the high side indicating that the delivered dimensions of the fabrics may have been different. These results are summarised in **Table 42**.

Table 42
Fabric Dimensions Measured on the Set 1 Garments

	mean	sd	CV %
Stitch Length mm	2.803	0.004	0.13
Yarn Count tex	19.28	0.13	0.65
Courses/3cm	48.3	0.6	1.22
Wales/3cm	31.0	1.0	3.33
Weight gsm	172.3	6.2	3.61

The remaining sets were subjected to ten cycles of a specified laundering procedure. Measurements of courses, wales and shrinkage were made after each cycle after conditioning.

The garments were marked to evaluate total garment shrinkage. Five pairs of measuring marks were located to establish length shrinkage, and five pairs were located for width.

Laundering and drying was carried out according to the following schedule for five cycles:-

Cycles 1 to 5

Set 2 (WTD)	Wash at 60^{o} C and tumble dry
Set 3 (WLD)	Wash at 60^{o} C and line dry (vertical wales)
Set 4 (WTDP)	Wash at 60^{o} C, tumble dry and press
Set 5 (WLDP)	Wash at 60^{o} C, line dry and press

On completion of the fifth cycle, the drying procedures were reversed for all four sets, for a further five cycles making ten cycles in all:-

Cycles 6 to 10

Set 2 (WTD/WLD)	Wash at 60^{o} C and line dry (vertical wales)
Set 3 (WLD/WTD)	Wash at 60^{o} C and tumble dry
Set 4 (WTDP/WLDP)	Wash at 60^{o} C, line dry and press
Set 5 (WLDP/WTDP)	Wash at 60^{o} C, tumble dry and press

Pressing, where appropriate, was carried out using a domestic steam iron.

At the end of the ten laundering cycles, the shrinkage results were averaged across garments within each set for each cycle. The results obtained for length and width shrinkage over the ten cycles are illustrated in **Figures 29 and 30**, respectively. Measurements after the first, fifth, sixth and tenth cycles are summarised in **Table 43.**

Table 43

Average Shrinkage Measurements for each Set after One, Five, Six and Ten Cycles of Washing and Drying

	Length Shrinkage %		Width shrinkage %	
cycle	First	Fifth	First	Fifth
Procedure				
Set 2 WTD	8.2	9.1	11.1	10.1
Set 3 WLD	0.4	0.1	5.5	6.0
Set 4 WTDP	5.5	6.0	9.3	8.0
Set 5 WLDP	0	1.2	6.1	4.7
cycle	Sixth	Tenth	Sixth	Tenth
Set 2 WTD/WLD	4.2	5.0	6.8	7.3
Set 3 WLD/WTD	5.2	7.5	8.7	7.6
Set 4 WTDP/WLDP	2.9	2.3	5.3	4.6
Set 5 WLDP/WTDP	5.5	6.2	7.8	7.8

5.2.1 Effect of Drying Procedure (Cycles 1 to 5)

a) Length Shrinkage

For the tumble dried garments (Set 2), length shrinkage increased over the first five cycles.

Length shrinkage in the line dried garments (Set 3) improved marginally over cycles but the difference is not significant.

The line dried garments shrank less than the tumble dried garments by, on average, 8.4%. The difference was slightly larger after five cycles (9.0%) than after one cycle (7.8%).

b) Width Shrinkage

Width shrinkage in the tumble dried garments decreased over cycles, indicating a growth or extension after the first cycle.

Shrinkage in the line dried garments was progressive over cycles but the increase was very small.

The tumble dried garments shrank more than the line dried garments but the differences reduced between the first (5.6%) and the fifth (4.1%) cycle.

5.2.2 Effect of Pressing (Cycles 1 to 5)

a) Length Shrinkage

Pressing between cycles reduced the length shrinkage recorded in the tumble dried Set 4 garments compared to the Set 2 garments by about 3.0%.

Pressing, however, had a much smaller effect on the line dried garments, increasing shrinkage slightly over the five cycles by approximately 1.0%.

The line dried garments shrank less than the tumble dried garments, but pressing between cycles reduced the difference between the two methods of drying.

b) Width Shrinkage

Pressing reduced the width shrinkage of the tumble dried and pressed garments (Set 4), compared to the tumble dried only garments (Set 2), by approximately 2.0%.

For the equivalent set of line dried garments, pressing appeared to marginally increase width shrinkage after one cycle, but reduced width shrinkage after five cycles.

Width shrinkage measured on the line dried and pressed garments was lower than that measured on the tumble dried and pressed garments by, on average, 3.8%. This difference was less than had been found between the garments which had not been pressed.

5.2.3 Effect of Reverse Drying (Cycles 6 to 10)

a) Length Shrinkage

The length shrinkage measured on the tumble dried garments, (Set 2), was improved by approximately 5% after one cycle of washing followed by line drying. It remained at this lower level for two further cycles of line drying and then began to increase gradually.

The length shrinkage measured on the line dried garments, (Set 3), increased by approximately 5% after one cycle of washing and tumble drying and continued to increase over the remaining cycles. At the end of the tenth cycle, the length shrinkage had increased to almost the same level as was originally measured in the tumble dried garments (Set 2) after one cycle. Thus it seemed that the five wash and line dry cycles had slowed down the rate of shrinkage in subsequent tumble drying cycles. (If we assume that the two sets originally had the same levels of potential shrinkage).

Length shrinkage recorded on the Set 3 garments (WLD/WTD) over cycles six to ten was higher than that measured on the Set 2 garments (WTD/WLD) over the same number of cycles. The differences increased over cycles from 1% after the sixth cycle to 2.5% after the tenth cycle.

b) Width Shrinkage

The width shrinkage measured in the tumble dried garments (Set 2) improved by approximately 3.3% after one cycle of washing followed by line drying. Width shrinkage then began to increase gradually over the remaining cycles of line drying, but its progress was erratic.

The width shrinkage measured in the line dried garments (Set 3) increased by 2.7% after one cycle of washing followed by tumble drying but then began to improve gradually over the remaining cycles of tumble drying. However, the shrinkage after the tenth cycle (five tumble drying cycles) was still below that obtained by Set 2 after only one cycle of washing and tumble drying.

5.2.4 Effect of Pressing (Cycles 6 to 10)

a) Length Shrinkage

Pressing reduced the length shrinkage of the Set 4 garments (WTDP/WLDP) compared to the Set 2 garments (WTD/WLD) but the level of shrinkage was higher than had been measured in the line dried only garments over the first five cycles.

Pressing on average appeared to have no effect on the length shrinkage measured in the Set 5 garments (WLDP/WTDP) over cycles six to ten compared to the Set 3 garments (WLD/WTD). The average length shrinkage was the same as that recorded on the Set 4 garments (WTDP) after the first five cycles. In fact the behaviour of both Sets 3 and 5 over cycles six to ten was very similar to that of Set 4 over cycles one to five.

Considerably lower shrinkages were recorded on the Set 4 garments (WTDP/WLDP) than the Set 5 garments (WLDP/WTDP) over cycles six to ten.

b) Width Shrinkage

Pressing reduced the width shrinkage of the Set 4 garments (WTDP/WLDP) by approximately 2% compared to those in Set 2 (WTD/WLD) over cycles six to ten.

There was very little improvement in width shrinkage after pressing on the Set 5 garments (WLDP/WTDP) compared to the Set 3 garments (WLD/WTD) which had not been pressed.

Lower shrinkages were recorded on the garments in Set 4 (WTDP/WLDP) than were measured on the garments in Set 5 (WLDP/WTDP) over cycles six to ten.

5.3 Effect of Drying Procedure on Garment Shrinkage - Summary

From these trials the influence of the washing and drying conditions on the development of shrinkage in garments made from 1x1 rib fabrics can be summarised as follows:-

1. Tumble drying develops more shrinkage than line drying but some of this can be recovered by pressing between cycles.

2. Shrinkage in tumble drying is generally progressive over cycles in the length direction but can improve in the width direction (extension or growth) after the first cycle.

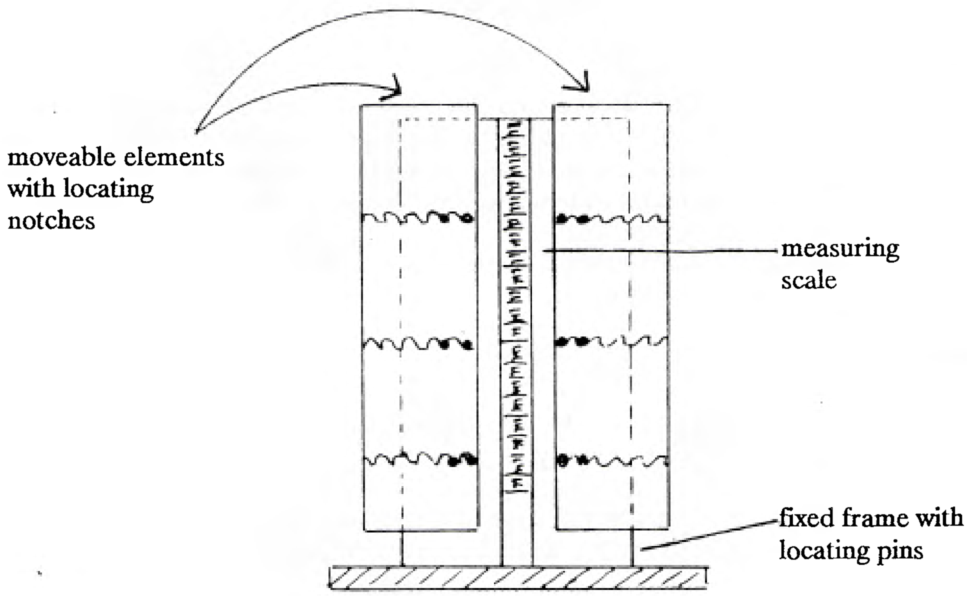
3. Line drying garments which have previously been tumbled dried can recover a significant amount of shrinkage in both the length and width directions. It does not however reduce shrinkage levels to those which were found on the garments which have never been tumble dried.

4. Line drying develops less shrinkage than tumble drying, but pressing can actually cause a slight increase in shrinkage, especially in the length direction. Width shrinkage is generally improved.

5. Shrinkage in line drying is generally progressive in the length direction but can improve in the width direction after the first cycle.

6. Tumble drying garments which have previously been line dried increases the shrinkage in both the length and width directions. However, there is an indication that the rate of relaxation of fabrics in tumble drying may have been slowed down by the previous line drying procedure. Garments which were tumble dried after five cycles of washing and line drying did not develop the same levels of length shrinkage as the tumble dried only garments. This was not however replicated in the sets which had received an intermediate press and it is an observation which deserves further study.

Diagram 3


moveable elements
with locating
notches
measuring
scale
fixed frame with
locating pins

A similar series of trials (which have not been described in this report) which looked at the effect of reverse drying procedures on the development of shrinkage in fabrics yielded very similar results.

6. THE RELATIONSHIP BETWEEN SHRINKAGE MEASURED IN GARMENTS USING A STANDARD FLAT MEASURING PROCEDURE COMPARED TO MEASUREMENTS MADE USING A FRAME

It has been suggested that the measurement of shrinkage in garments is more appropriately assessed by the use of a frame rather than by measuring the changes in dimensions of a garment laid flat on a bench or table. The main justification for this approach follows from the fact that garments have to fit bodies, and that although the dimensions of a garment might change during laundering, the dimensions of the wearer do not. Therefore consideration should be given to the potential additional change in length dimensions which could be developed simply as a result of putting on a garment that has significantly reduced in width during laundering. By placing the garment over a frame of appropriate dimension, to match the body/garment size represented, any additional increase in length shrinkage can be recorded, thus providing results which better represent the consumer's experience of a garment in wear.

There is certainly some validity in this approach especially when consideration is given to the performance of garments which are specifically designed to be close fitting to the body.

A considerable amount of research, into this aspect of garment design and performance, has been carried out by the Svenska Textilforskningsinstutet (TEFO). In particular, they have studied the relationship between garment fit and the physiological perception of comfort as measured by the pressure of a close fitting garment on the body. Their work has indicated that there is a certain level of pressure above which the wearer will find the garment uncomfortable.

The propensity of a garment to develop levels of pressure on the body, in excess of the comfort level, will obviously depend on the extensibility of the fabric, the design of the garment, and its dimensional stability in laundering (width shrinkage).

TEFO have developed a large data base of information on many of the factors which influence the design, comfort and fit of close fitting garments, including anthropometric data on body sizes.

In addition to the collection of this data base TEFO have developed a range of test instruments which are used to assess the performance (extensibility) of fabrics, and the fit (pressure) of a garment on bodies (frames) of standard size. These instruments are available for purchase by the garment industry and some companies have made the investment.

In the UK, however, one of the large chain store retailers (Marks & Spencer) decided to develop its own simplified version of a garment measuring frame to help in the assessment of garment performance after laundering, and the quality control of garments produced by different manufacturers. A schematic of the M&S measuring frame is included in **Diagram 3.**

The procedure for using the frame can be briefly described as follows. The garment to be assessed is placed over the frame with the side seams positioned down the edges of the frame. The width of the frame is adjusted prior to mounting the garment to the appropriate size specified. i.e. the maximum body size which the garment is supposed to fit. Once in position, the garment is tensioned in the length direction by hanging weighted clamps to the bottom hem, two at the front and two at the back. After a few seconds these are removed and after a further few seconds the length of the garment is read off against the scale marked on the frame, at two different places. The measurements are taken on the garment before and after laundering. The length shrinkage of the garment is calculated from the average values recorded before and after laundering [43,46,47].

The IIC obtained an M & S measuring frame for evaluation and carried out several comparative studies using the frame, in addition to conventional flat measuring techniques, to assess the performance (shrinkage) of garments after laundering.

Table 44

Measurements made on the M & S Measuring Frame Set at Different Widths. % Difference in Garment Lengths

	Frame Width	BW	5LD	5TD	5LD/5TD	5TD/5LD	Washed Mean
Resin							
	Ref + 5%	1.2	0.2	-0.5	0.3	-0.3	-0.1
	Ref + 10%	0.6	-0.3	0.1	-1.4	-1.6	-1.2
	Ref + 15%	-1.7	-1.8	0.2	-2.7	-3.2	-2.1
	Ref + 20%	-2.7	-3.4	0.4	-3.8	-4.1	-3.8
No Resin							
	Ref + 5%	0.2	0.3	-0.3	0.4	0.4	0.2
	Ref + 10%	0.2	-0.5	-0.3	0.6	-1.6	-0.8
	Ref + 15%	-2.1	-2.7	-2.4	-2.1	-2.6	-2.4
	Ref + 20%	-4	-3.8	-3.4	-3	-4.1	-3.6
	Ref + 25%	-5.9	-6.2	-5.6	-5.3	-5.6	-5.7

The results of these trials showed that length shrinkage results obtained by flat measurement were closely correlated (r = 0.96) with length shrinkage measurements obtained using the frame provided that the garment was correctly sized in the first place. An illustration is given in **Figure 31**. Generally there was no strong evidence to suggest that either method was more reliable or reproducible on the average although the absolute length shrinkage values obtained could be different. A part of this difference could be attributed to the magnitude of the shrinkage in the width direction.

The virtue of this approach in the general quality control of the garment manufacturing process is clear. By assessing garments on a frame problems of incorrect sizing can be detected between garments supposedly manufactured to the same size specification produced by different manufacturers. In addition, large variations in garment width and garment shrinkage can also be detected.

The potential additional influence on garment length shrinkage of incorrect garment sizing can be demonstrated by reference to an investigation concerning the comparative behaviour of garments which had been manufactured from standard finished as well as resin finished single jersey fabric [(47)]. The fabrics from which the garments were manufactured had both been knitted and finished to the same specifications of stitch length, yarn count, courses, wales and weight. Identical sets of garments were produced from the two fabrics with the objective of tracking the effects of the two different finishing processes on the shrinkage and appearance of the garments over multiple cycles of laundering and drying (tumble and line).

As an adjunct to this trial it was decided to investigate the effect on length shrinkage of the garments if the size of the frame (body size) on which they were measured was increased in increments between 5% and 25% over Reference Width. Reference Width is defined as the width of the garments after five cycles of washing and tumble drying, thus taking into account the potential width shrinkage of the garments.

The garment style chosen for the trial was a T-shirt. T-shirts are close fitting garments but, for a given garment size, they have to fit a range of body sizes. The actual width of the garments used in this trial was 51.5 cm which corresponds to a body size of 103 cm. In the reference state (after five cycles of washing and tumble drying) the average size of the garments was about 101 cm for the resin finished garments, and 99 cm for the non-resin finished garments. If the garments were to be worn by someone with a body size greater than the reference size, then the garment would be stretched in the width. This would have two consequences.

Firstly, the width extension would cause contraction in the length. i.e. additional length shrinkage must be added to the laundering shrinkage to assess the true performance of the garment.

Secondly, there is a certain level of extension at which the garment becomes uncomfortable due to excessive pressure on the body. This comfort level of pressure has been established by TEFO. The exact levels of extension in the fabrics included in this trial which equate to the comfort level of pressure had not been accurately determined but they were estimated to be in the range 15 to 20 % over reference width.

Ten garments which had received different combinations of washing, followed by either line drying or tumble drying, were measured on the M & S frame with the frame width set at the reference width. The frame width was then increased in intervals of 5% up to 20% for the resin finished garments and from 5% up to 25% for the non-resin finished garments. At each frame width setting the garment lengths were recorded and converted to a shrinkage value based on the length of the unstretched garments. The results are given in **Table 44**.

The trends are similar for all garments; as the frame width (body width) increases, the garment becomes shorter. At the comfort level of extension there is a shortening of the garments of between 2.5 and 4.0 percentage points in addition to any laundering shrinkage.

A simplified graph is shown in **Figure 32** which represents the averages of the resin and the pure finish garments broken down into only two classes, as received and laundered. From this chart the danger of incorrect sizing is obvious. e.g. in order to limit the length shortening effect to approximately 2% then the body width must be no more than 15% over reference width. For these garments that equates to 103 cm for the resin finished garments and 101 cm for the non-resin finished garments. Thus, according to this criterion, these garments were delivered at maximum acceptable body width.

The evaluation of shrinkage in garments is more difficult and subject to more variation than the measurement of shrinkage in fabrics due primarily to the difficulties in handling and measuring garments as opposed to flat fabrics, and because of the additional sources of variation introduced by the making-up procedure. It is therefore essential that the dimensions of the fabric as well as the garment are measured both before and after the laundering procedure to ensure that any differences in the fabric can be taken into account when assessing the relative effects of different laundering procedures on sets of apparently similar garments.

In addition, relating the shrinkage potential of garments laundered under standard laboratory conditions to the shrinkage of garments laundered under domestic conditions can also be difficult due to the interaction of the size of the wearer with the size of the garment, and the potential effects of variation in laundering procedures carried out in the home.

From the trials that have been carried out, at least, some of the potential problems in measurement and interpretation have been identified and these can therefore provide a background and starting point for future investigations which may be undertaken.

Figure 1
Shrinkage after the First Wash/Tumble Cycle (%)

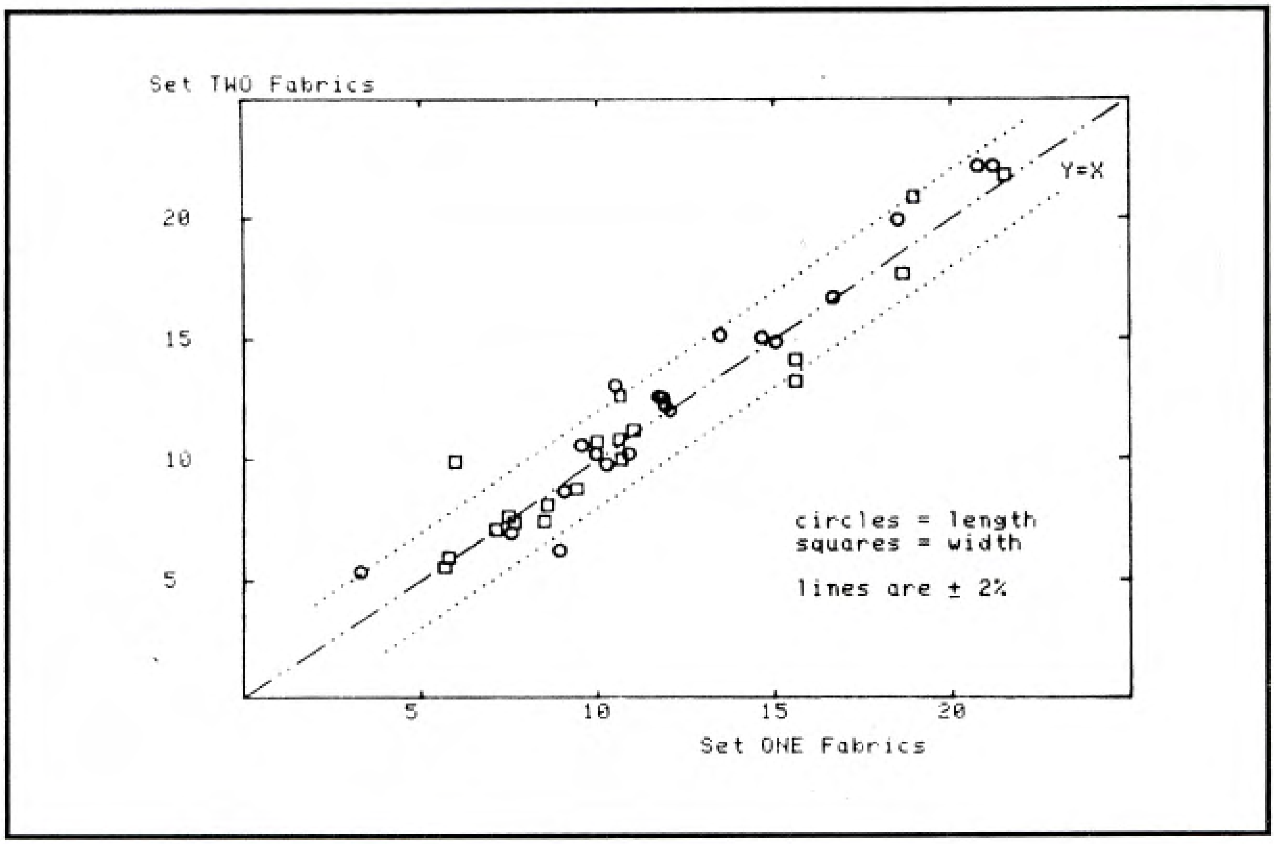


Figure 2
Length and Width Shrinkages over all 10 Cycles

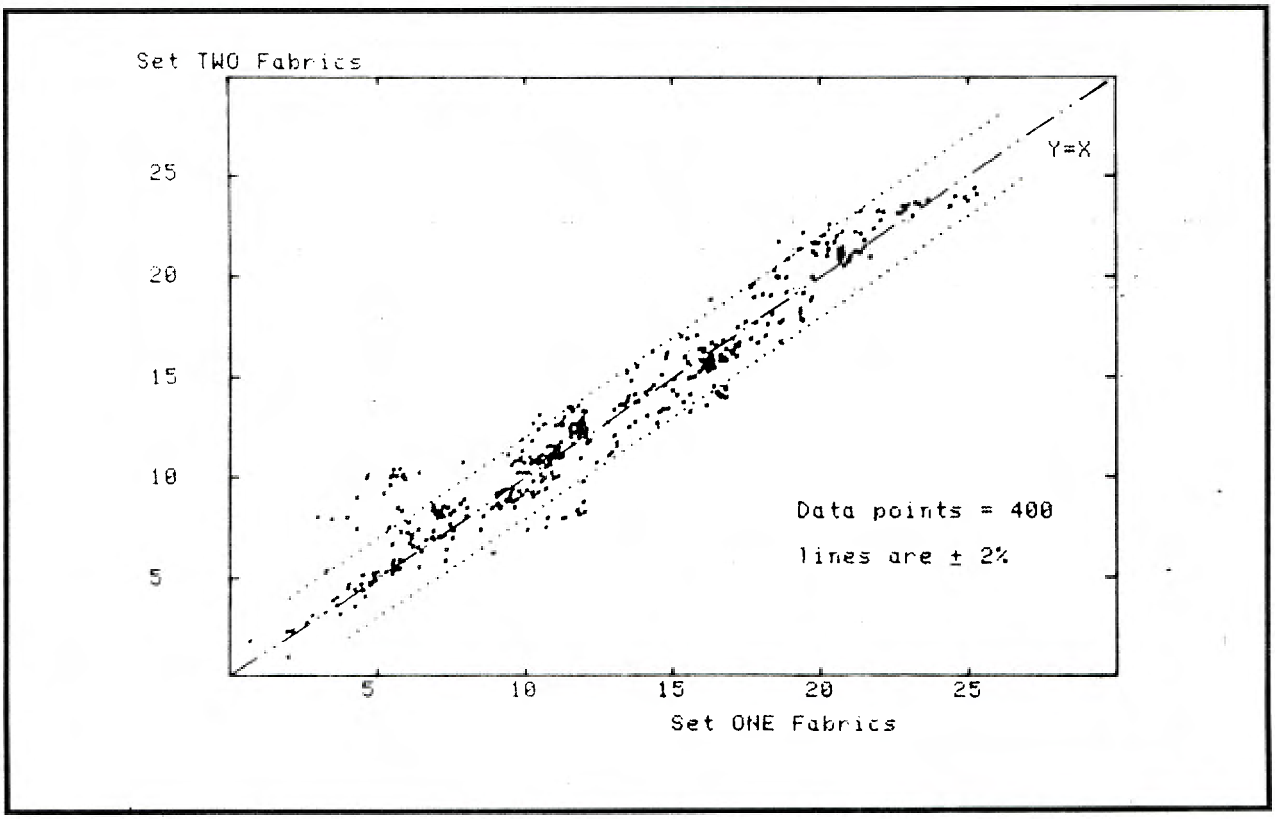


Figure 3
Change in Length Shrinkage and Moisture Content over Time
Trial 1

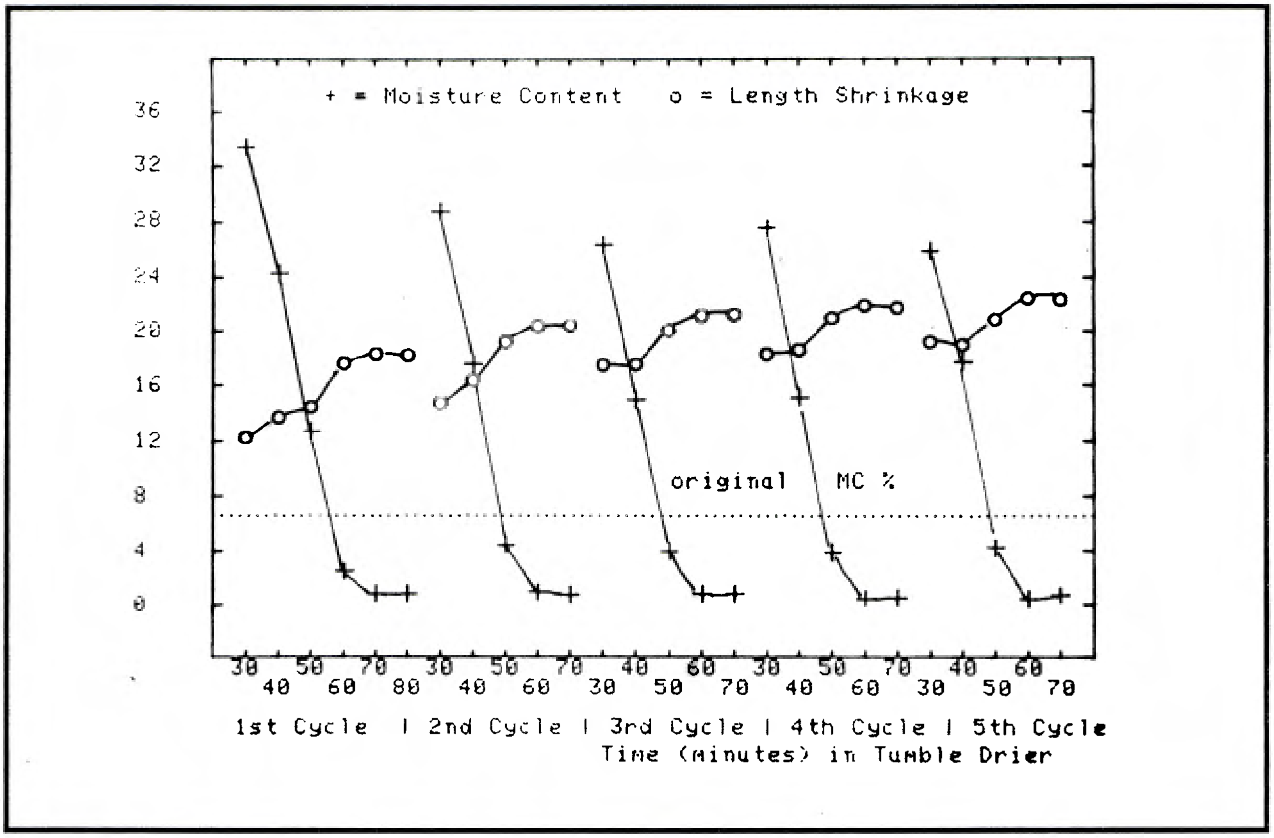


Figure 4
Change in Width Shrinkage and Moisture Content over Time
Trial 1

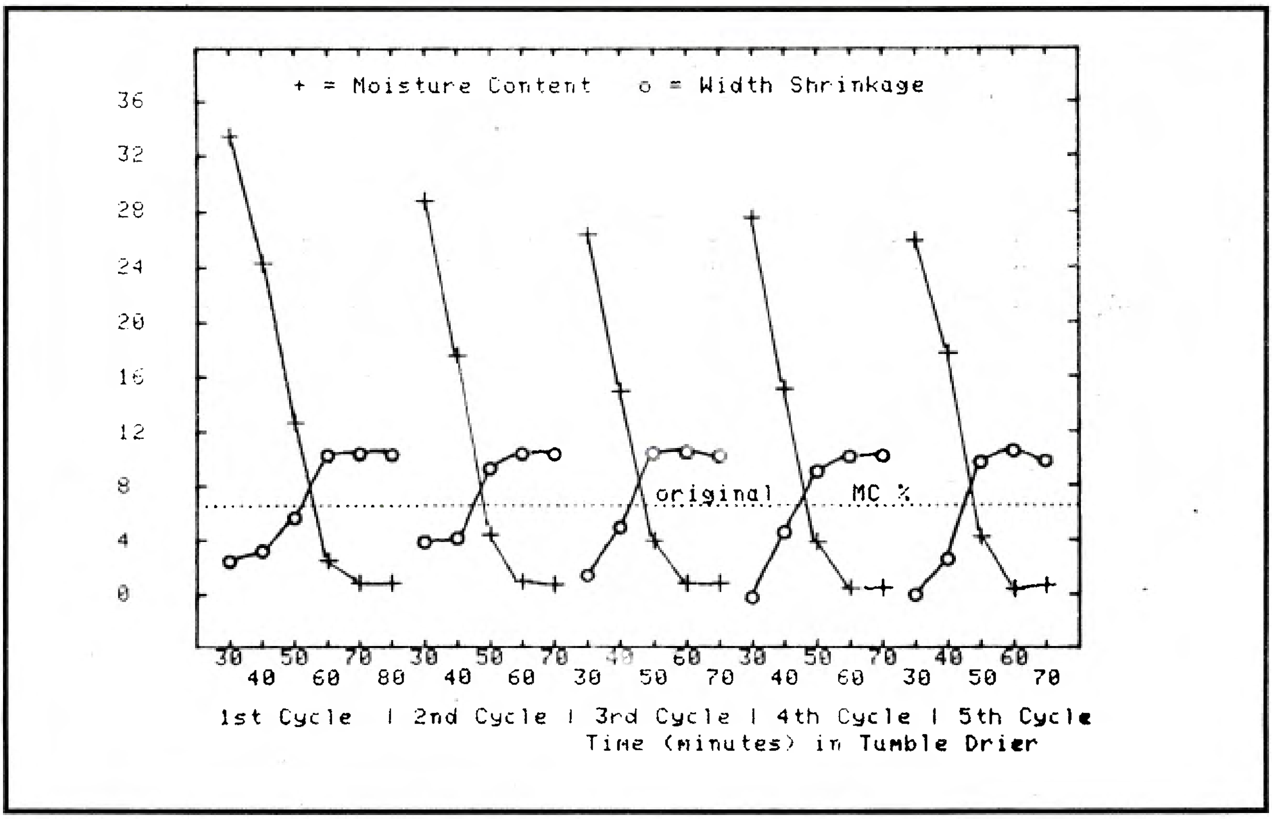


Figure 5
Length Shrinkage and Moisture Content after Drying
Trial 2

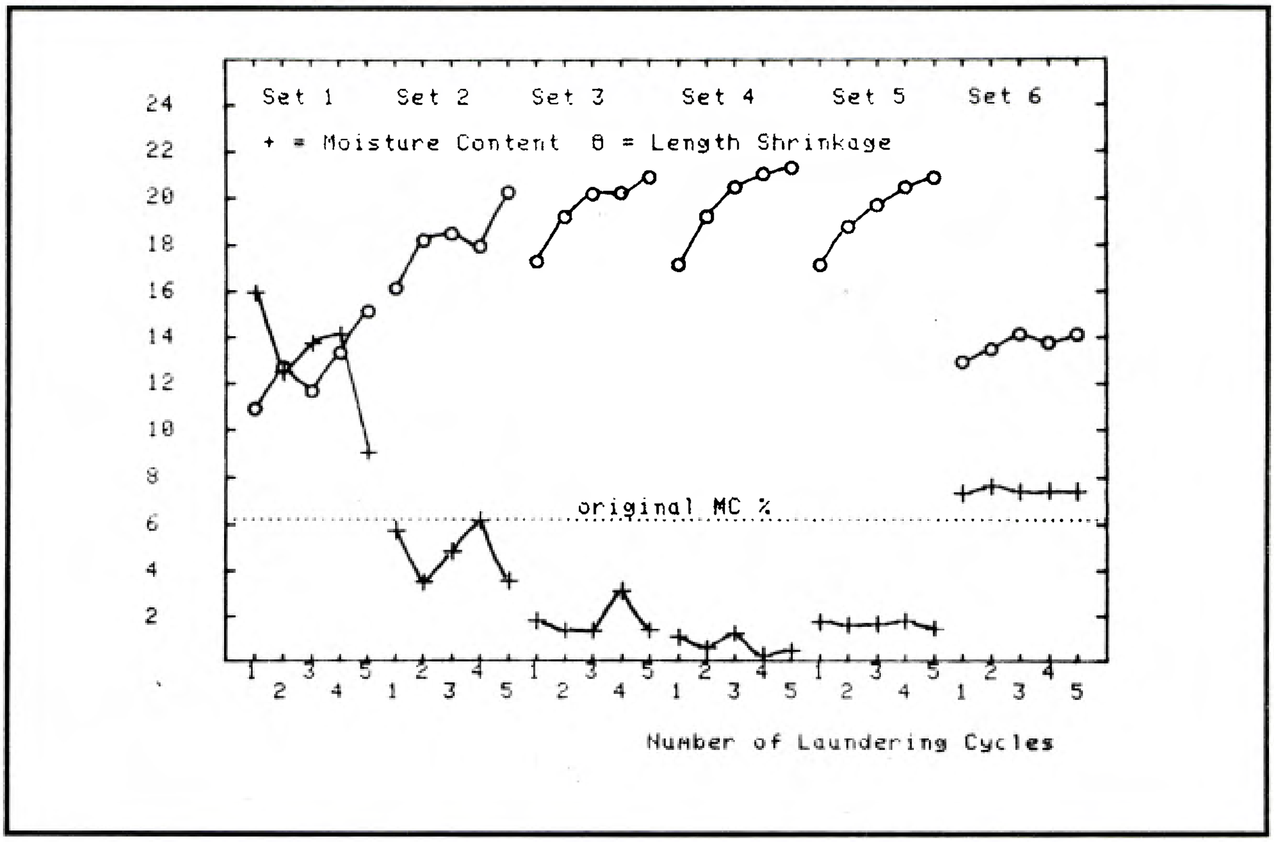


Figure 6
Length Shrinkage and Moisture Content after Conditioning
Trial 2

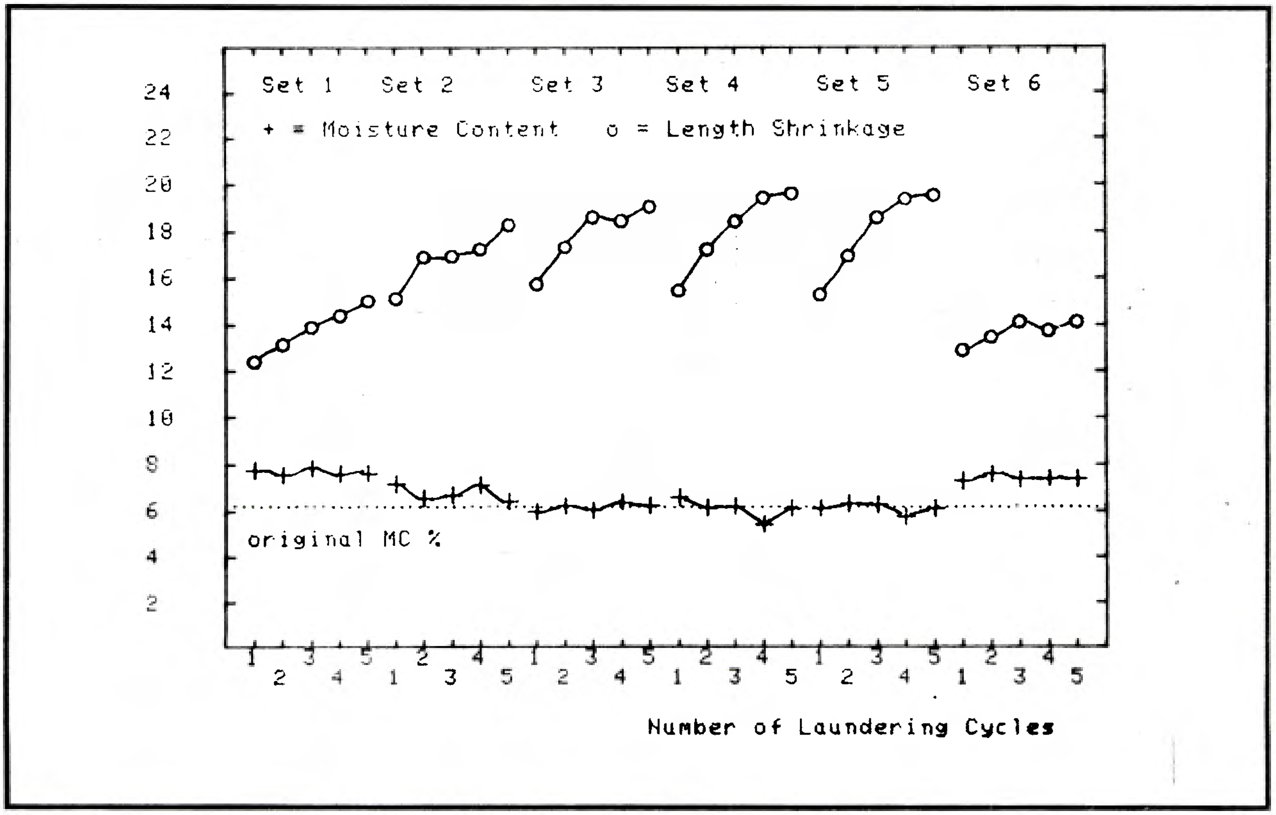


Figure 7
Width Shrinkage and Moisture Content after Drying
Trial 2

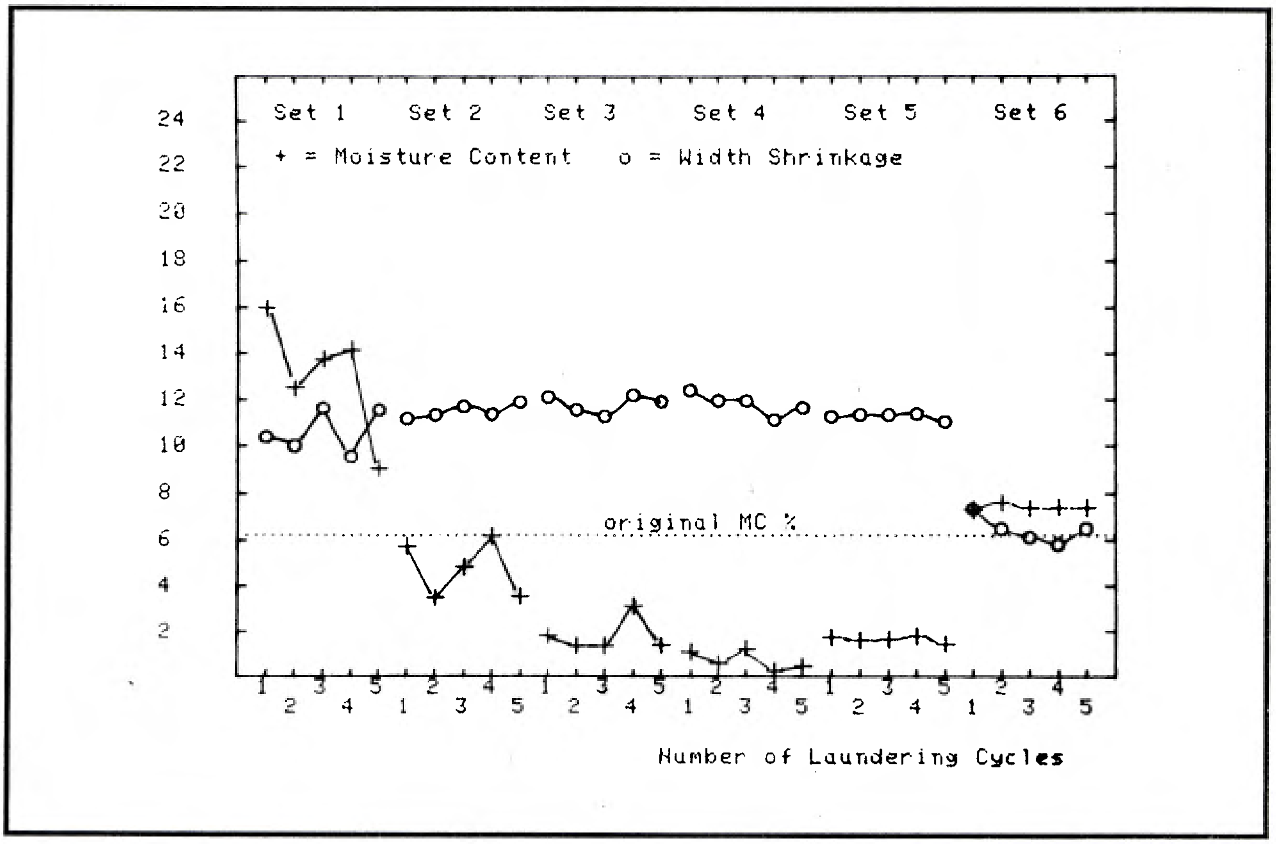


Figure 8
Width Shrinkage and Moisture Content after Conditioning
Trial 2

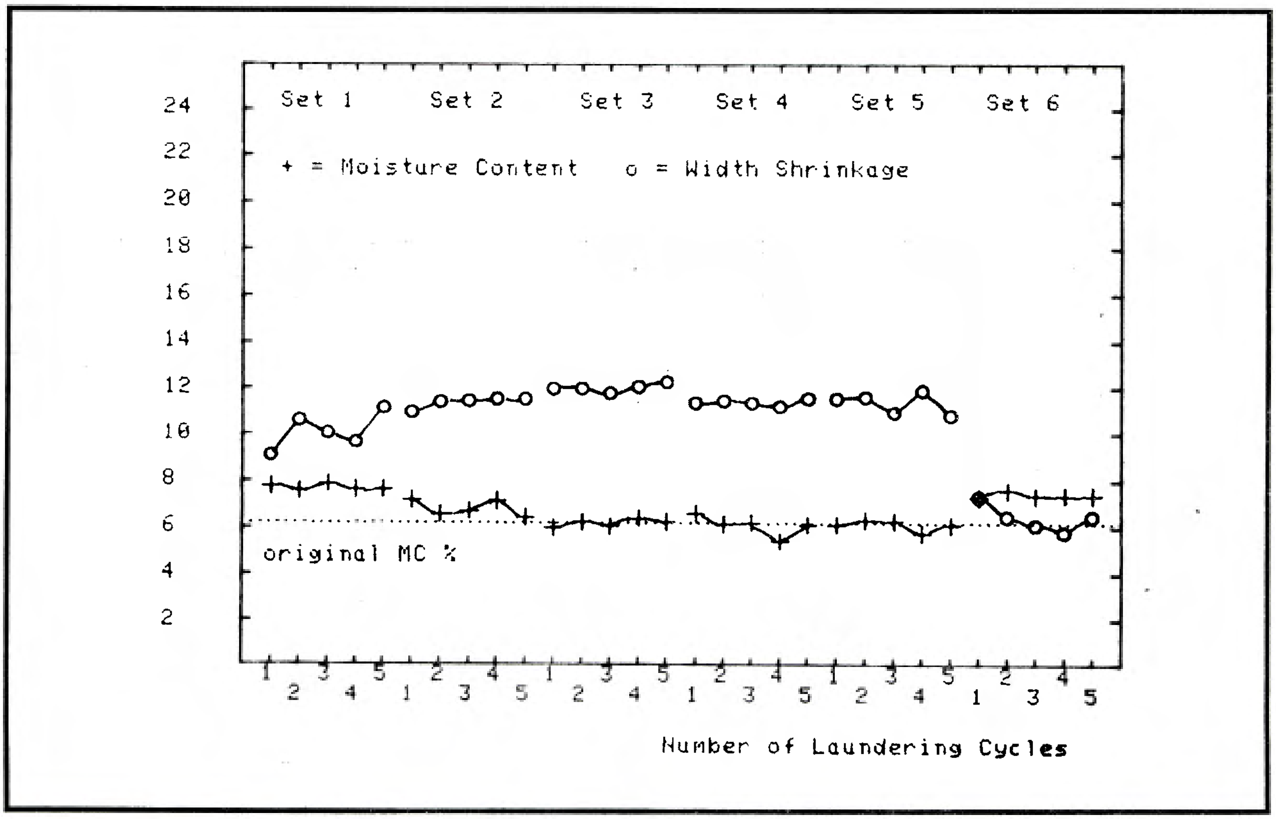


Figure 9
Change in Exhaust Temperature Over Time in Tumble Drier
Trial 3

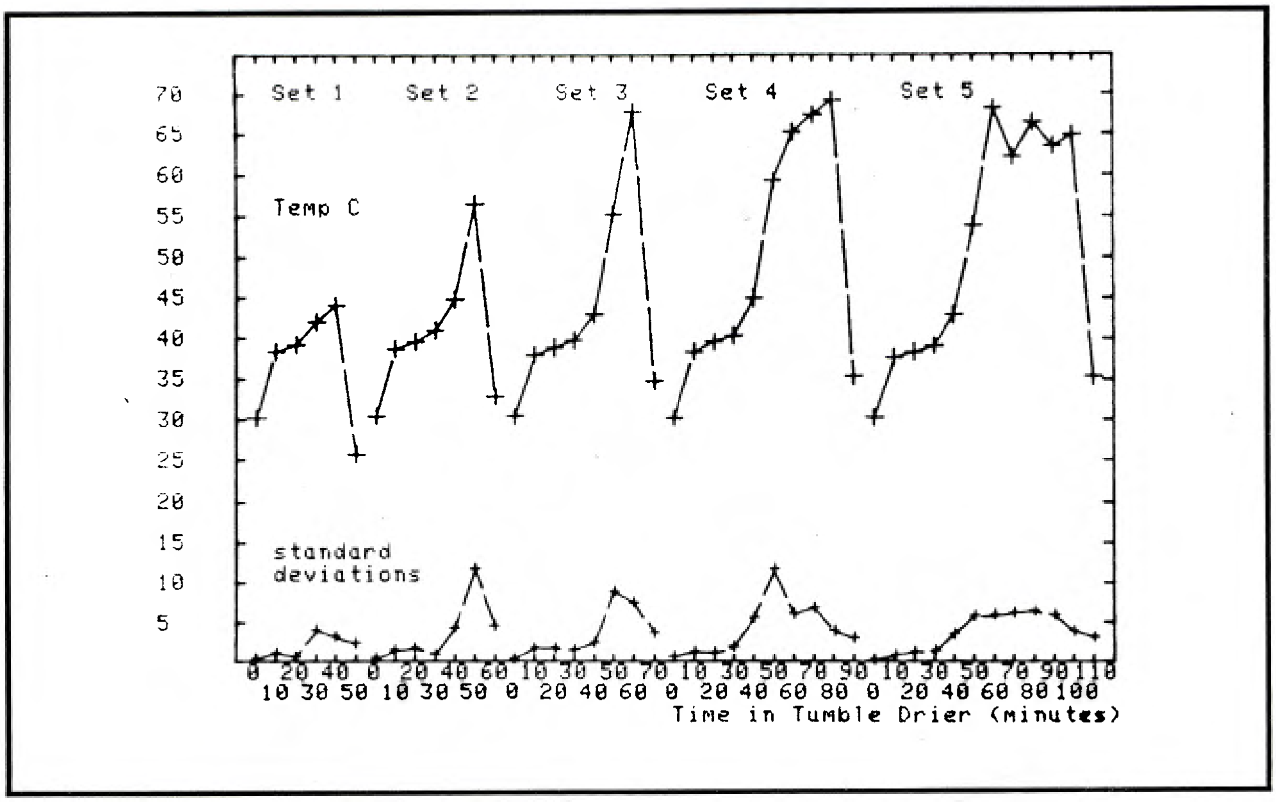


Figure 10
Length Shrinkage and Moisture Content after Drying
Trial 3

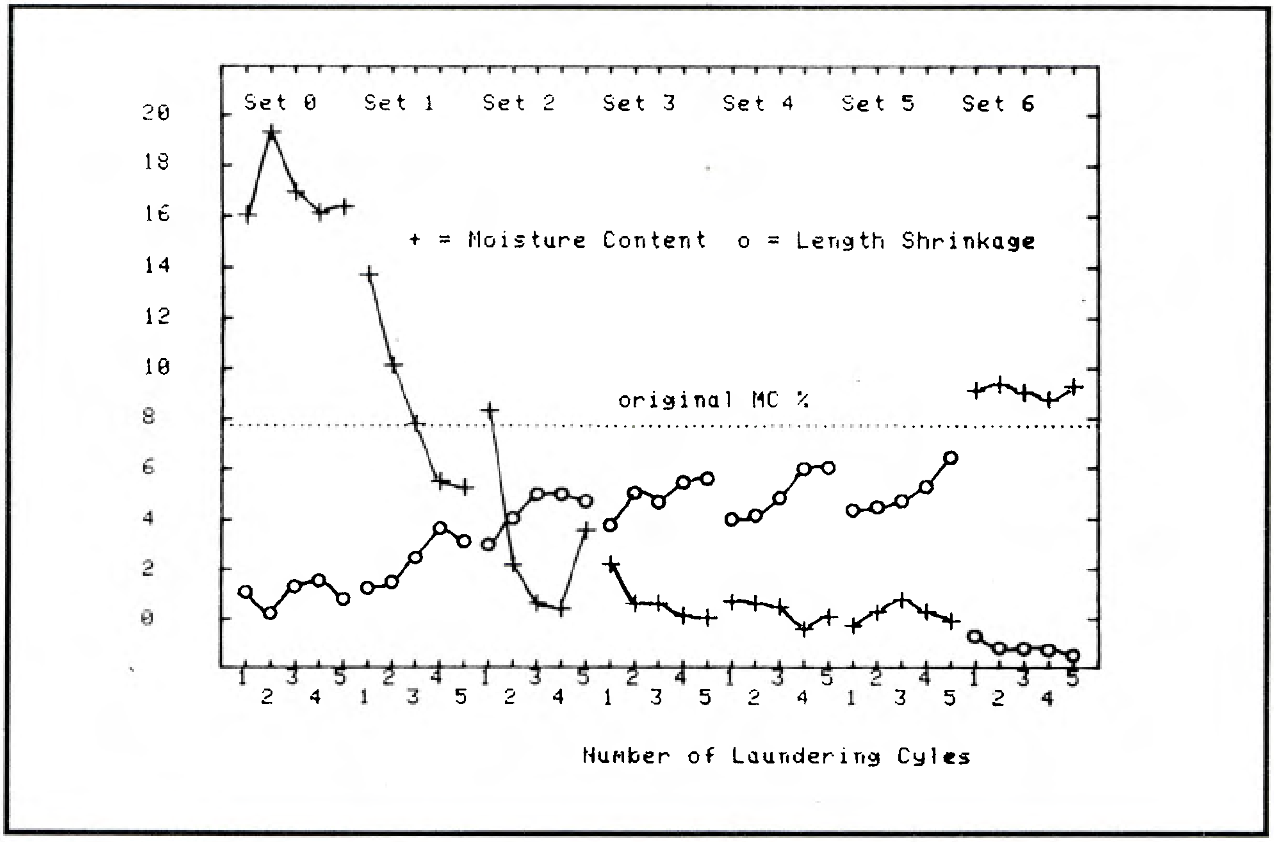


Figure 11
Length Shrinkage and Moisture Content after Conditioning
Trial 3

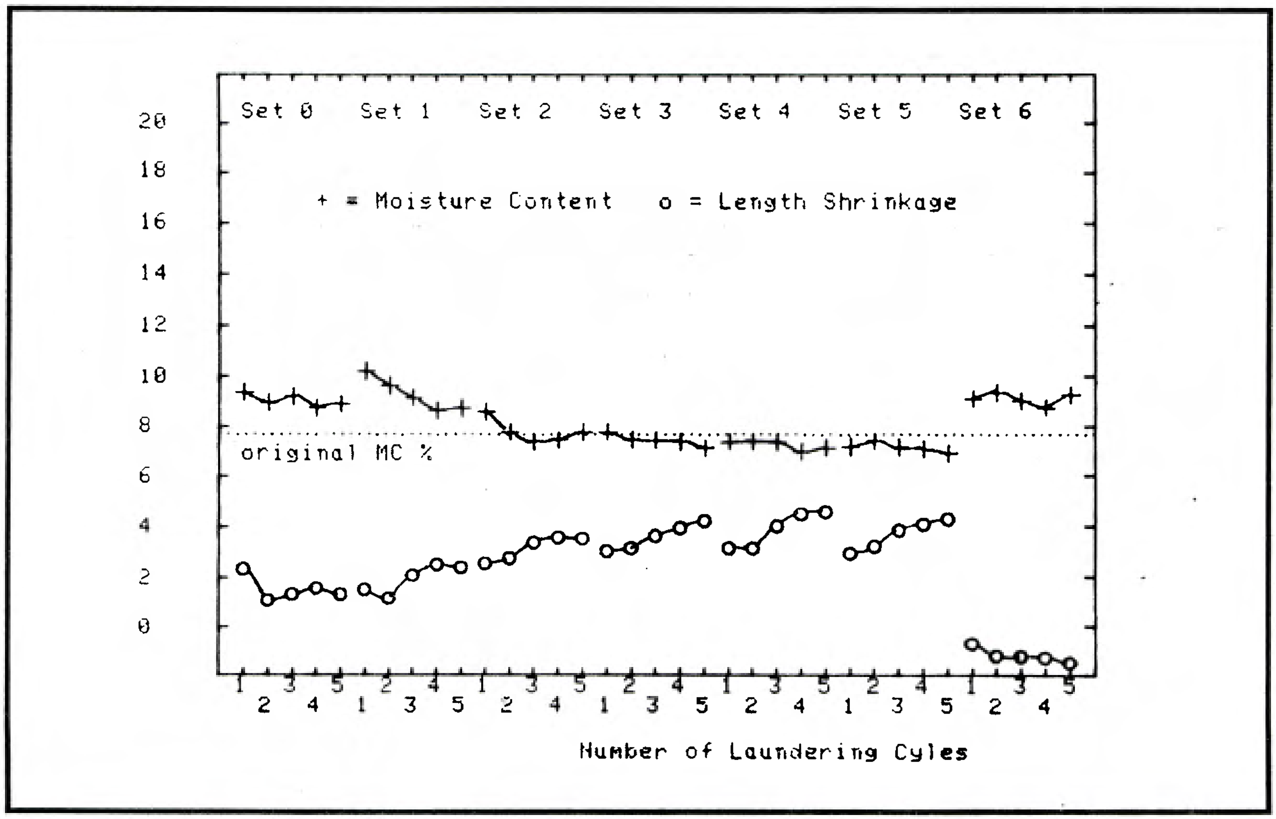


Figure 12
Width Shrinkage and Moisture Content after Drying
Trial 3

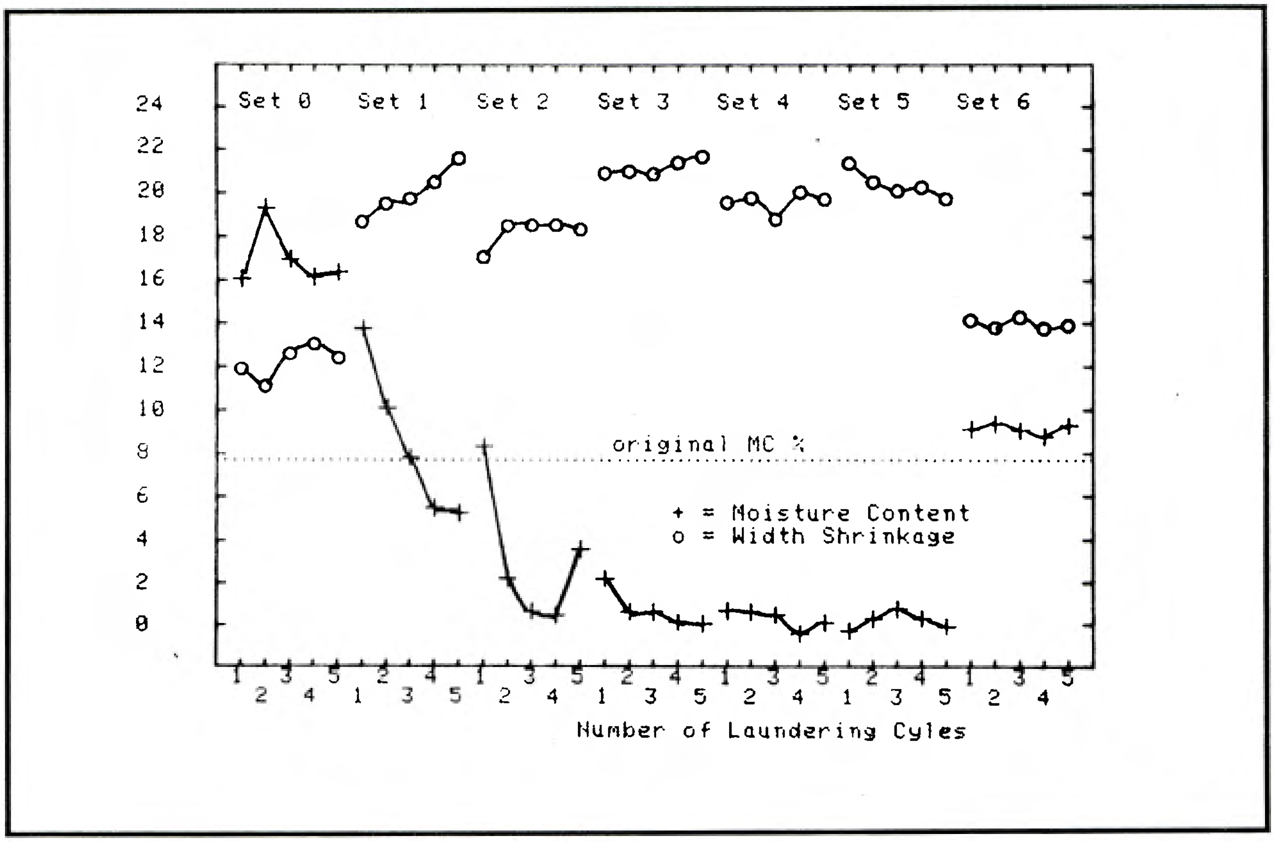


Figure 13
Width Shrinkage and Moisture Content after Conditioning
Trial 3

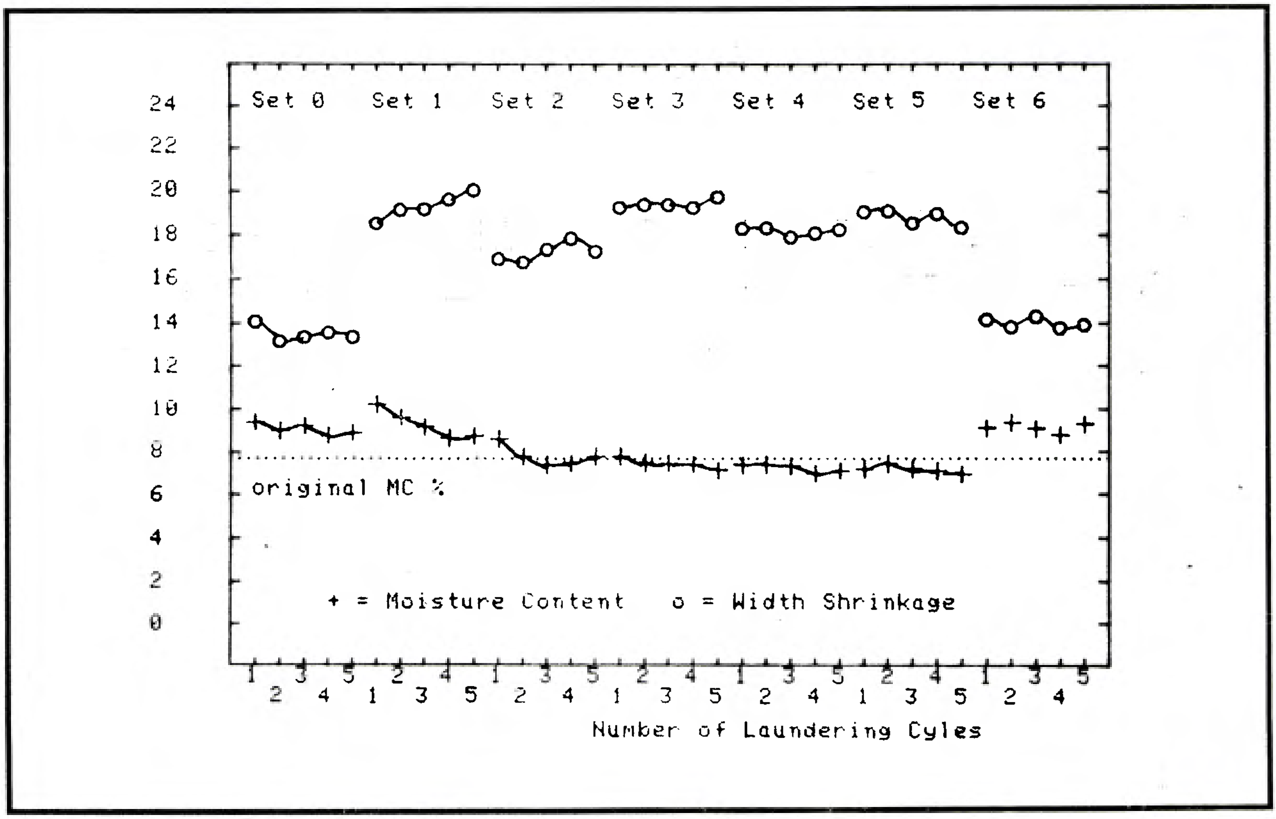


Figure 14
20G Interlock : Grey Reference State Dimensions

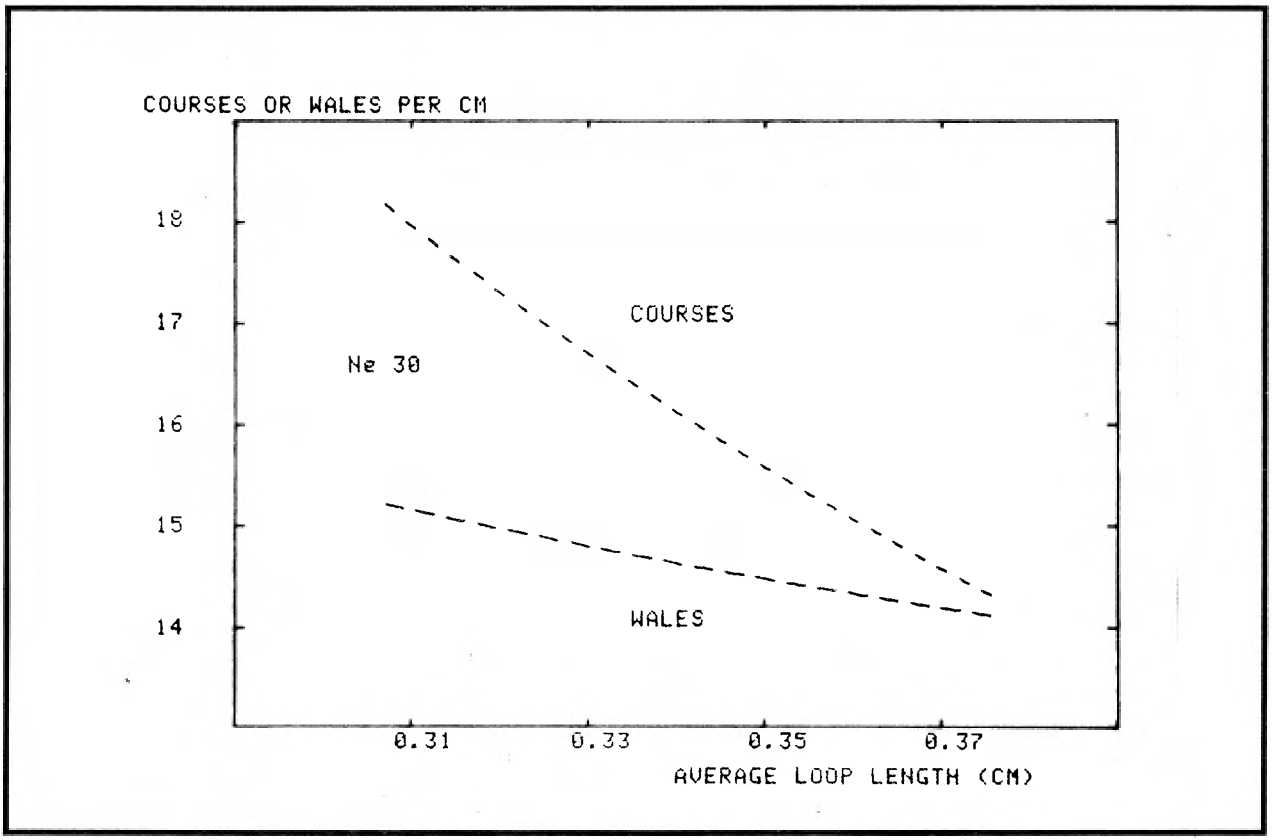


Figure 15
24G Single Jersey : Grey Reference Dimensions

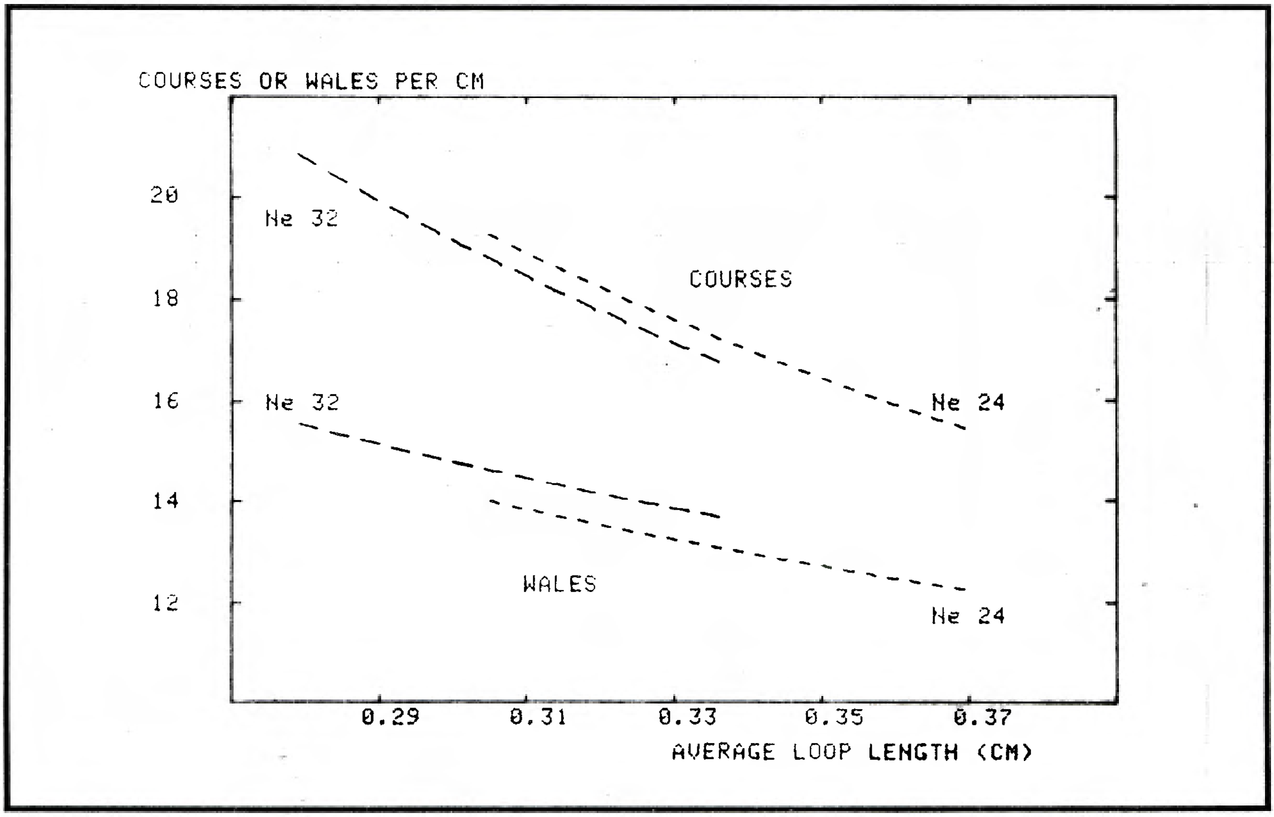


Figure 16
Plain Jersey Dyed & Finished Reference State

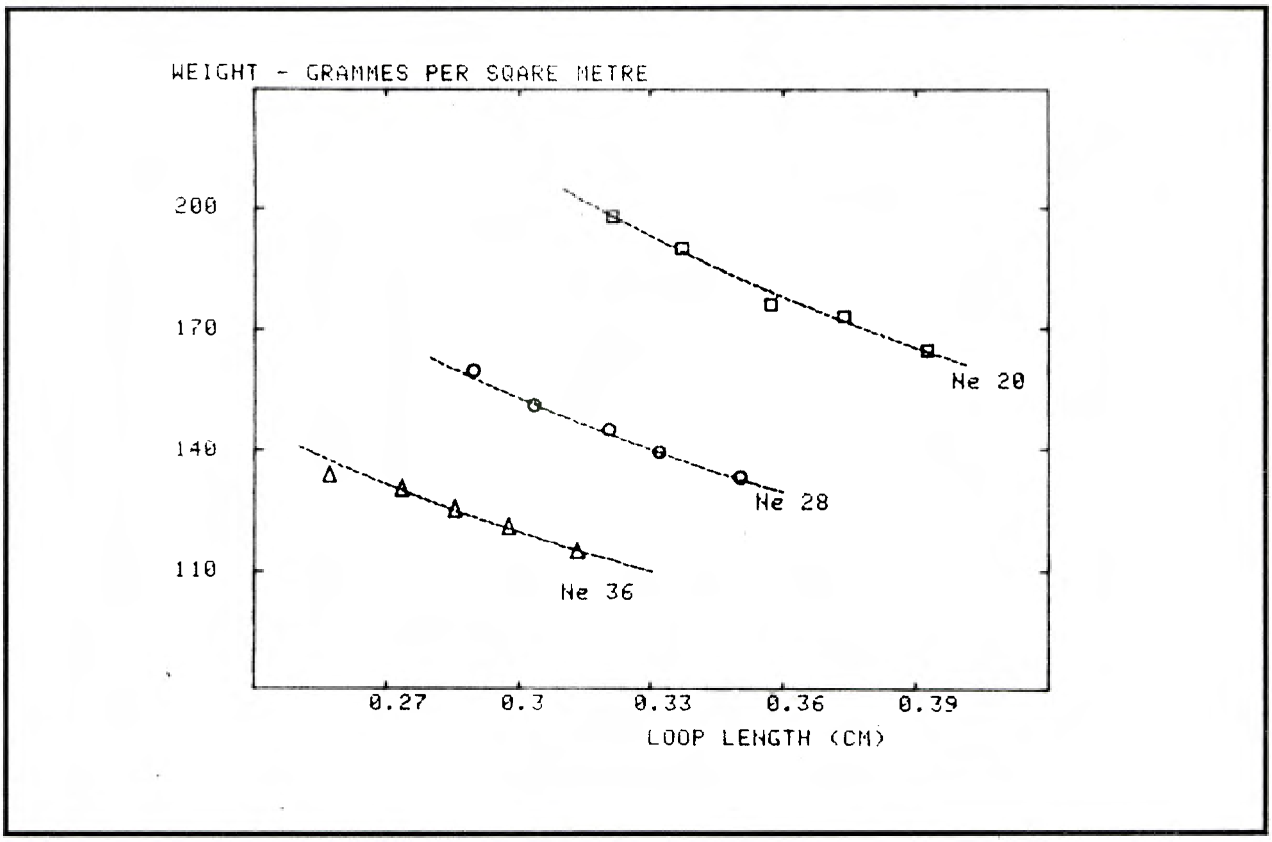


Figure 17
Single Jersey Fabrics : Grey Reference State

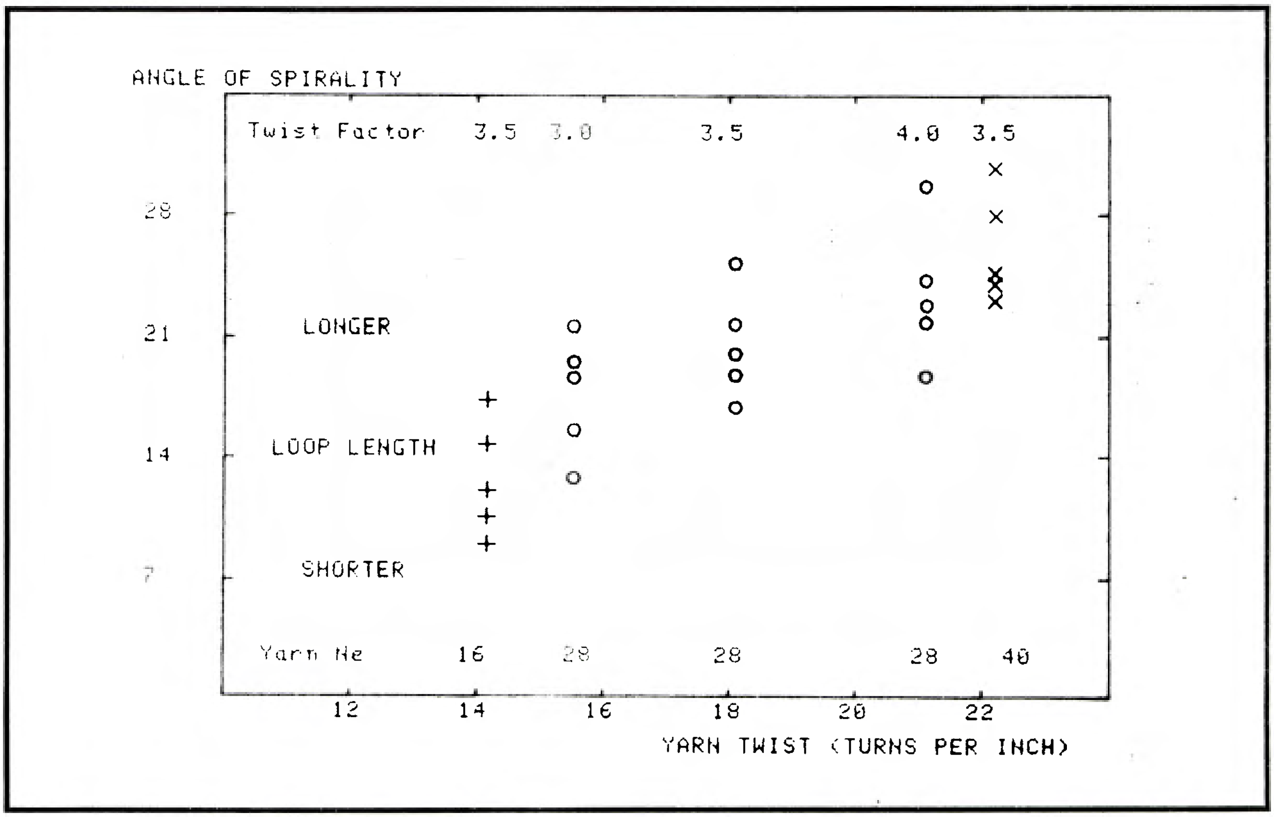


Figure 18
24G Single Jersey : Grey Reference Dimensions

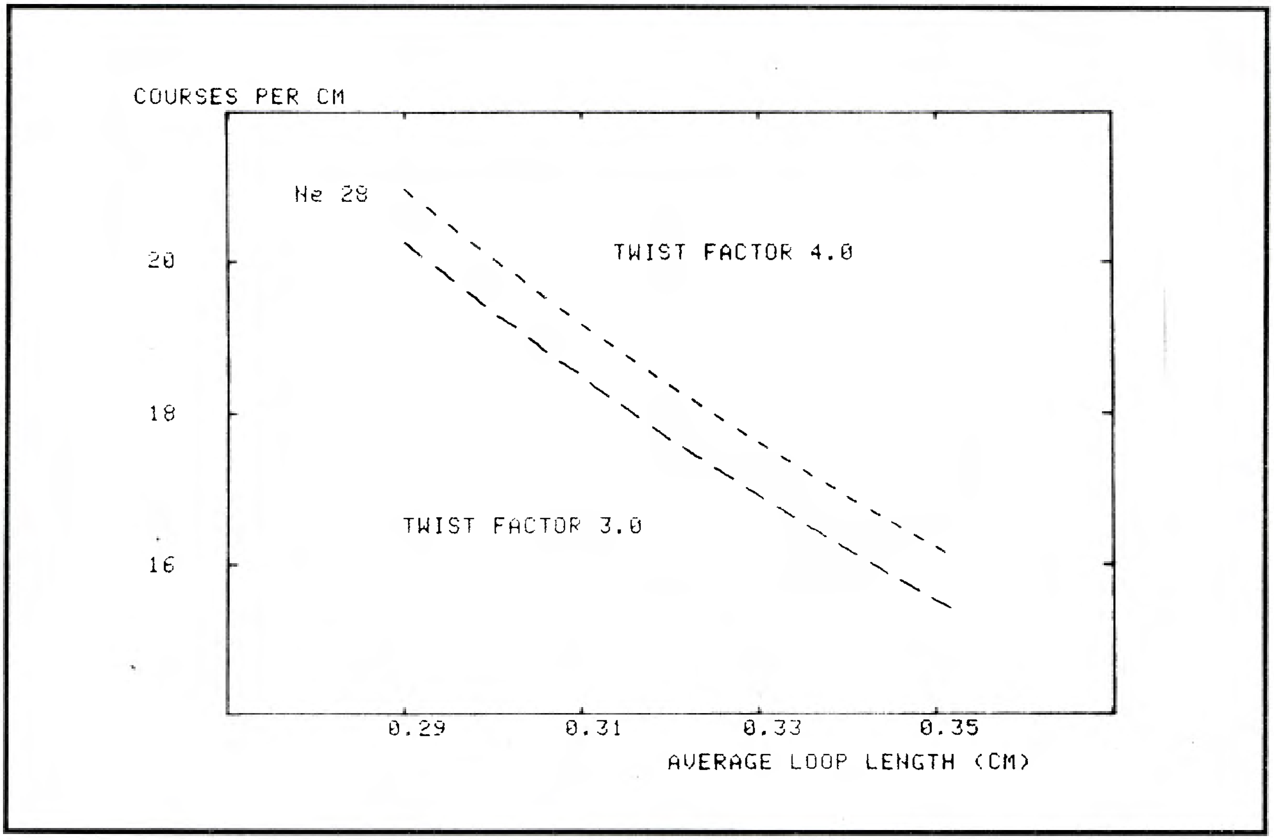


Figure 19
24G Single Jersey : Grey Reference Dimensions

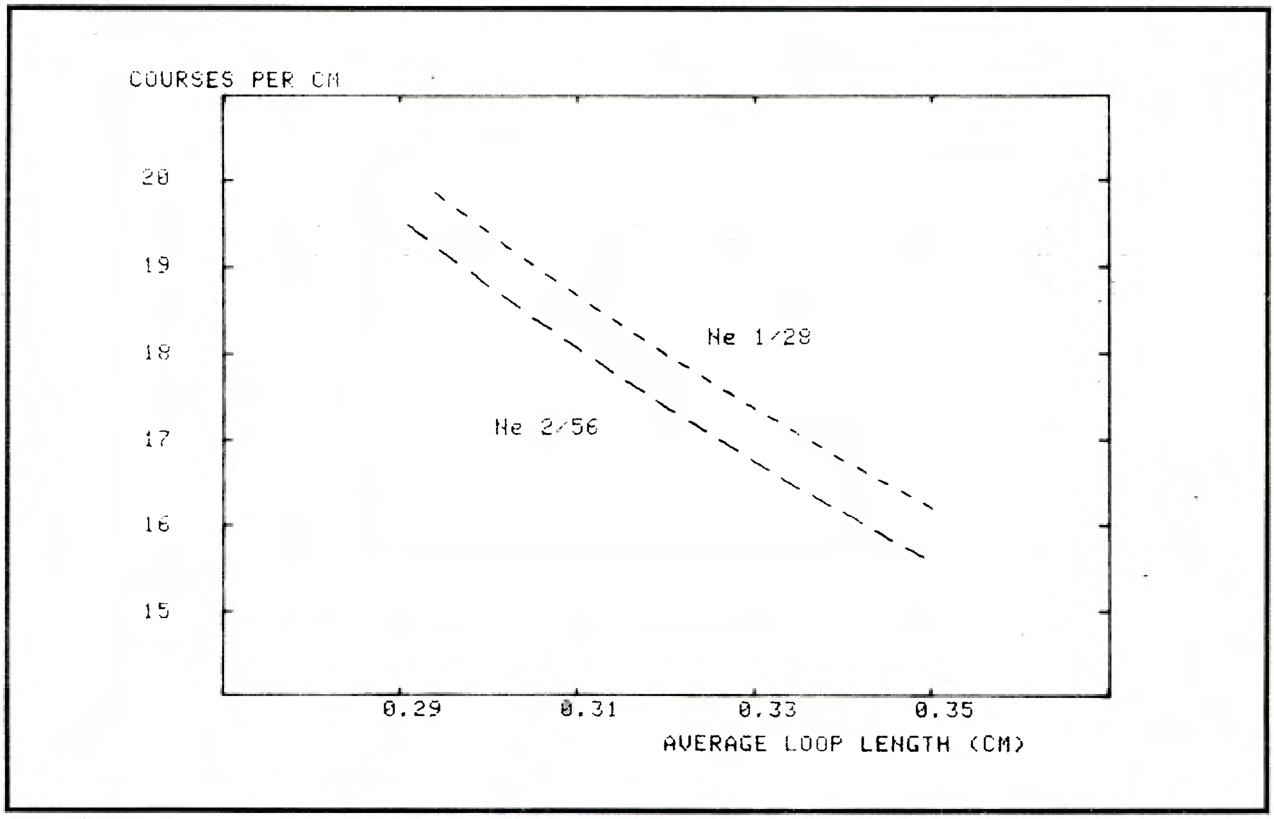
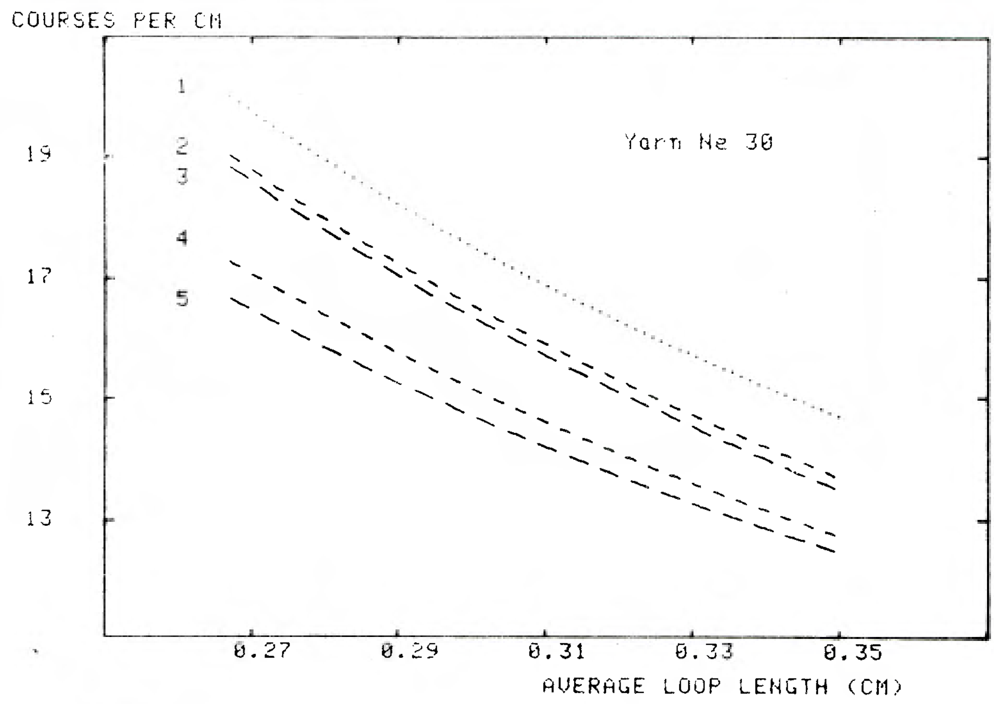
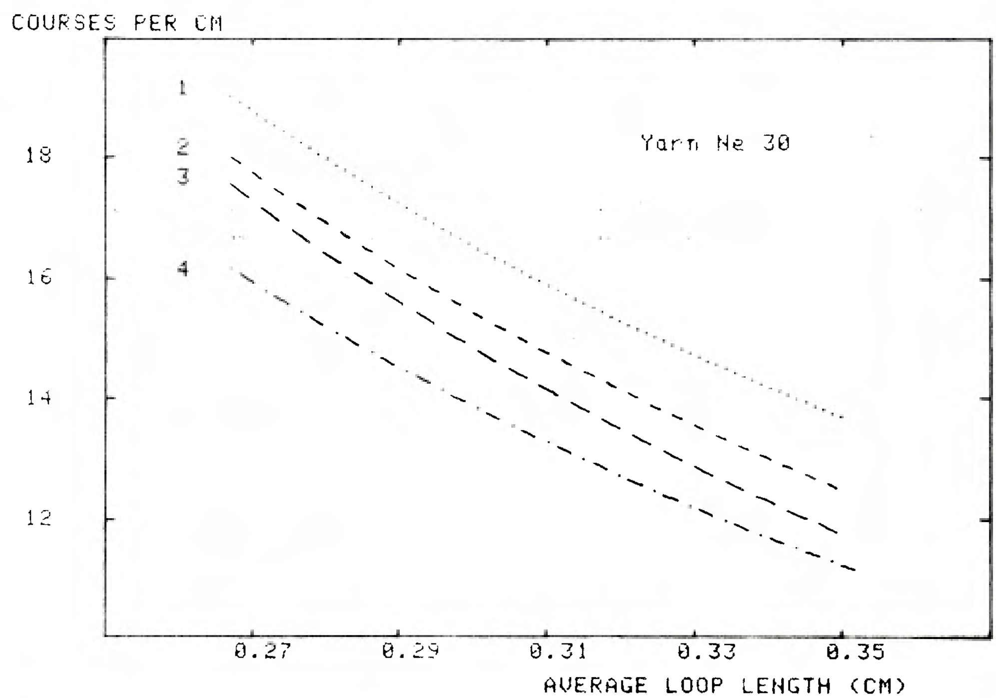


Figure 20
14G 1x1 Rib : Reference Dimensions



1 = grey
2 = jet dyed (deep)
3 = winch dyed (white)
4 = tubular mercerised, jet dyed (deep)
5 = tubular mercerised, winch dyed (white)

Figure 21
14G 1x1 Rib : Finished Reference Dimensions



1 = jet dyed
2 = jet dyed and resin finished 1% solids o.w.f.
3 = jet dyed and resin finished 1.75% solids o.w.f.
4 = jet dyed and resin finished 3.5% solids o.w.f.

Figure 22
Normalised Average Length Shrinkage for all 20 Fabrics

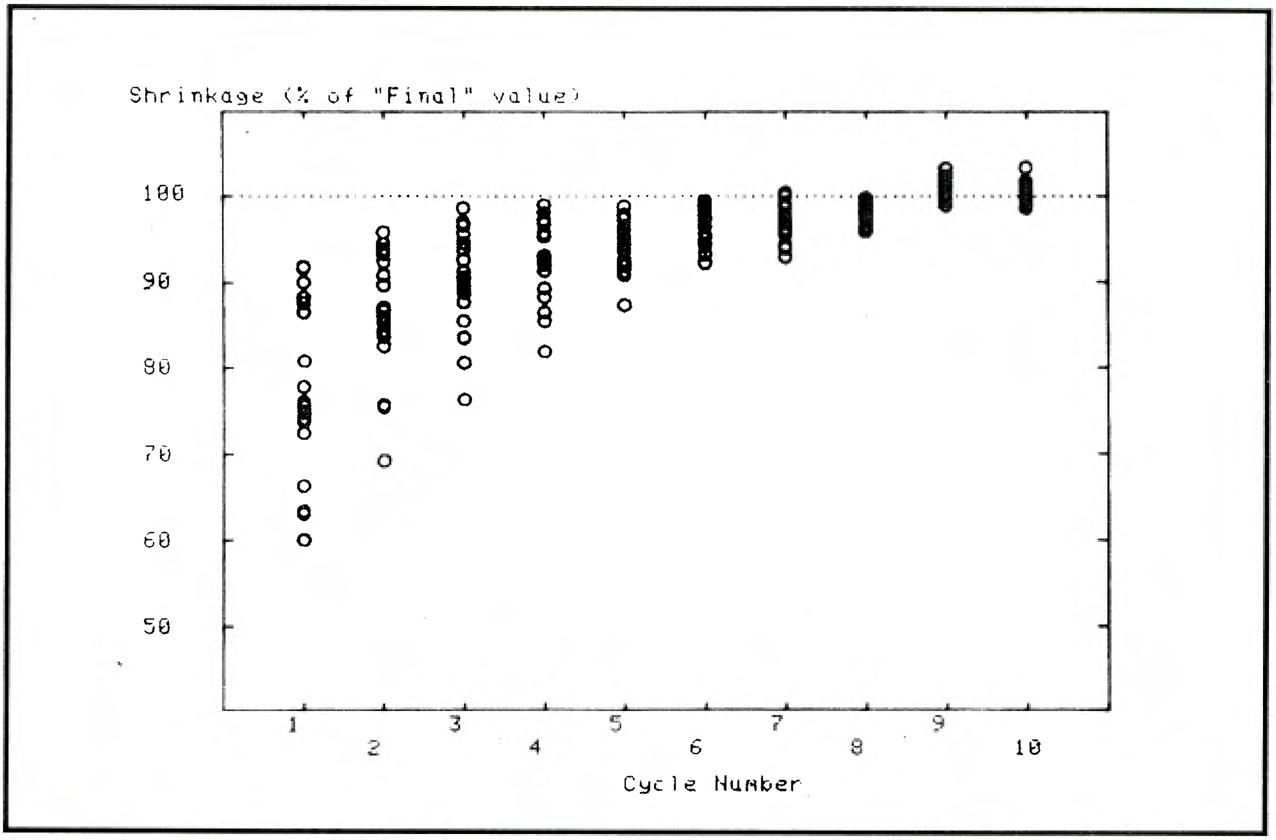


Figure 23
Normalised Average Width Shrinkage for all 20 Fabrics

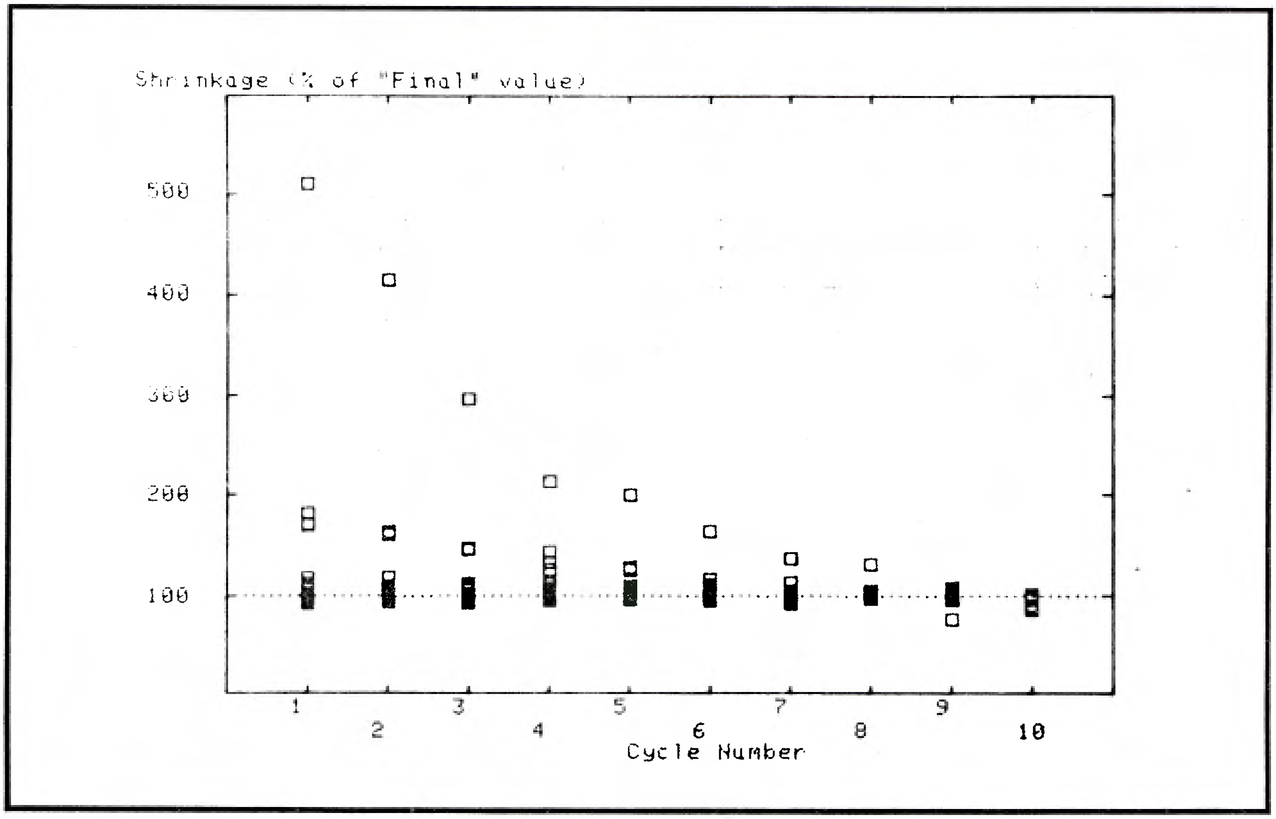


Figure 24
Length Shrinkage Averaged Over Fabrics and Methods

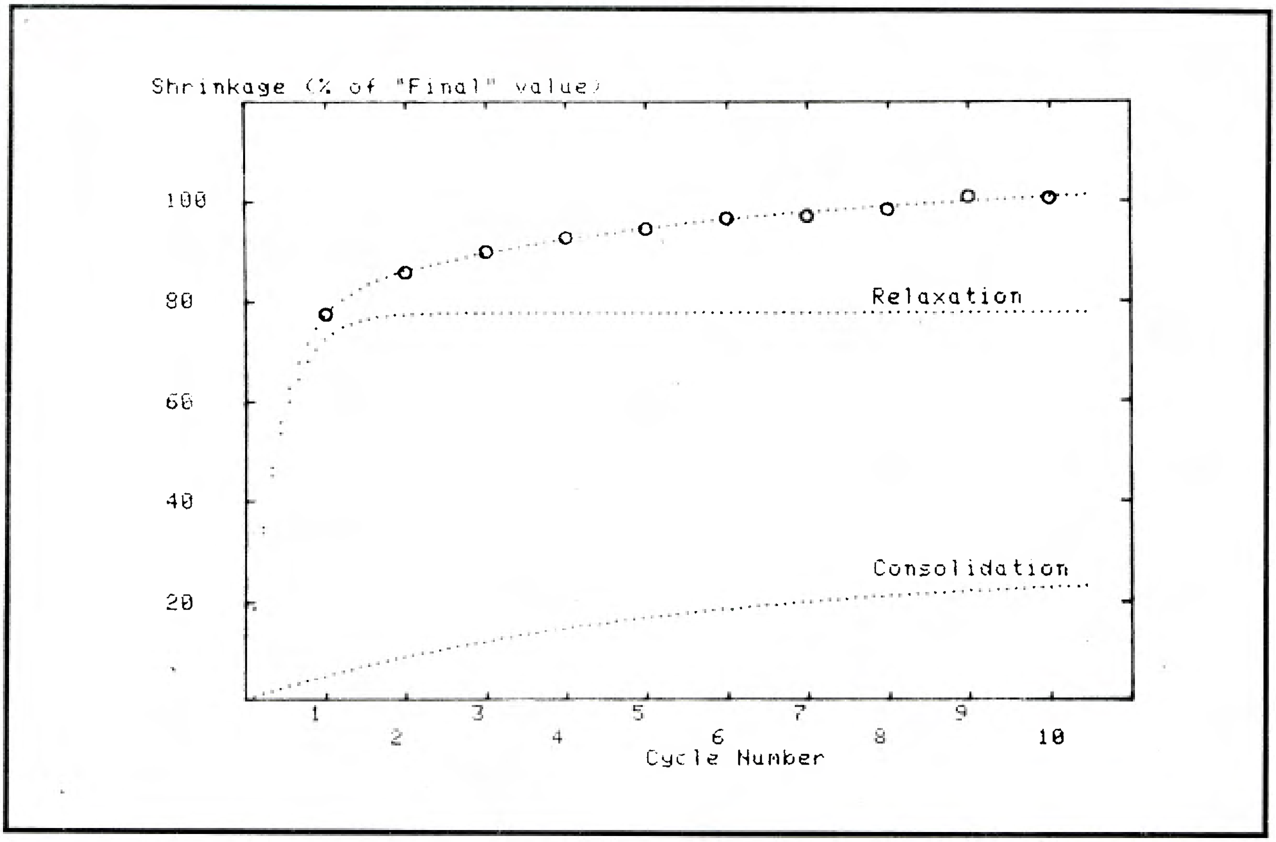


Figure 25
Width Shrinkage Averaged Over Fabrics and Methods

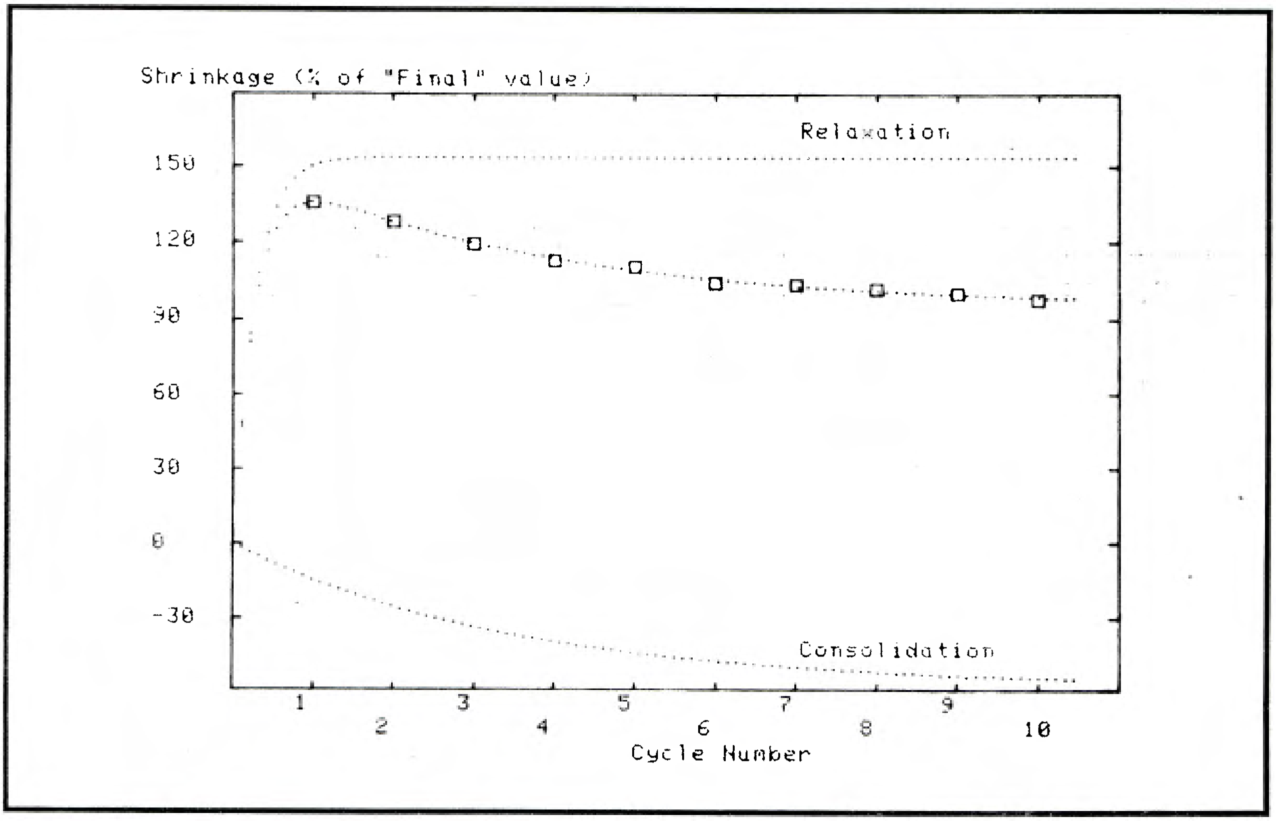


Figure 26
Average Shrinkage : Fabric versus Garment

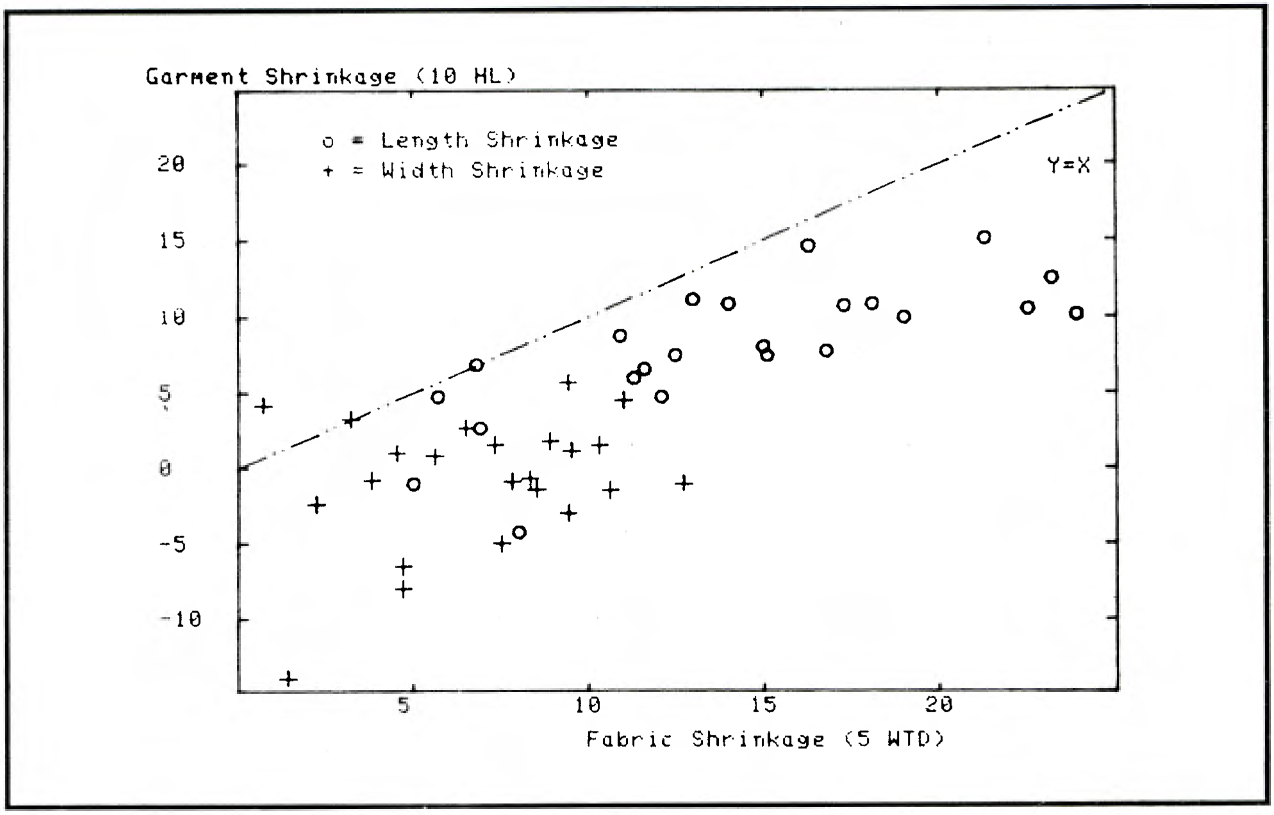


Figure 27
Average Length Shrinkage Over Ten Cycles
First Garment Trial

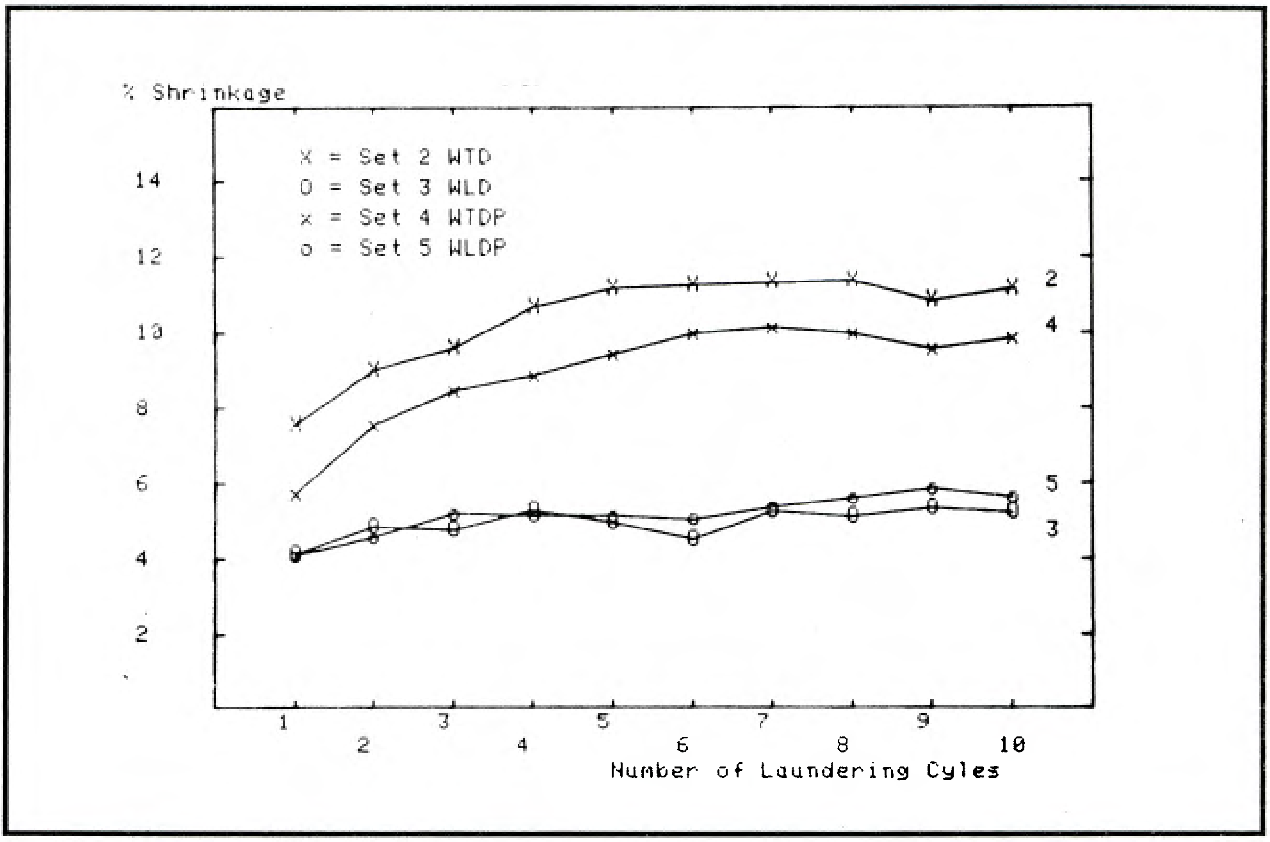


Figure 28
Average Width Shrinkage Over Ten Cycles
First Garment Trial

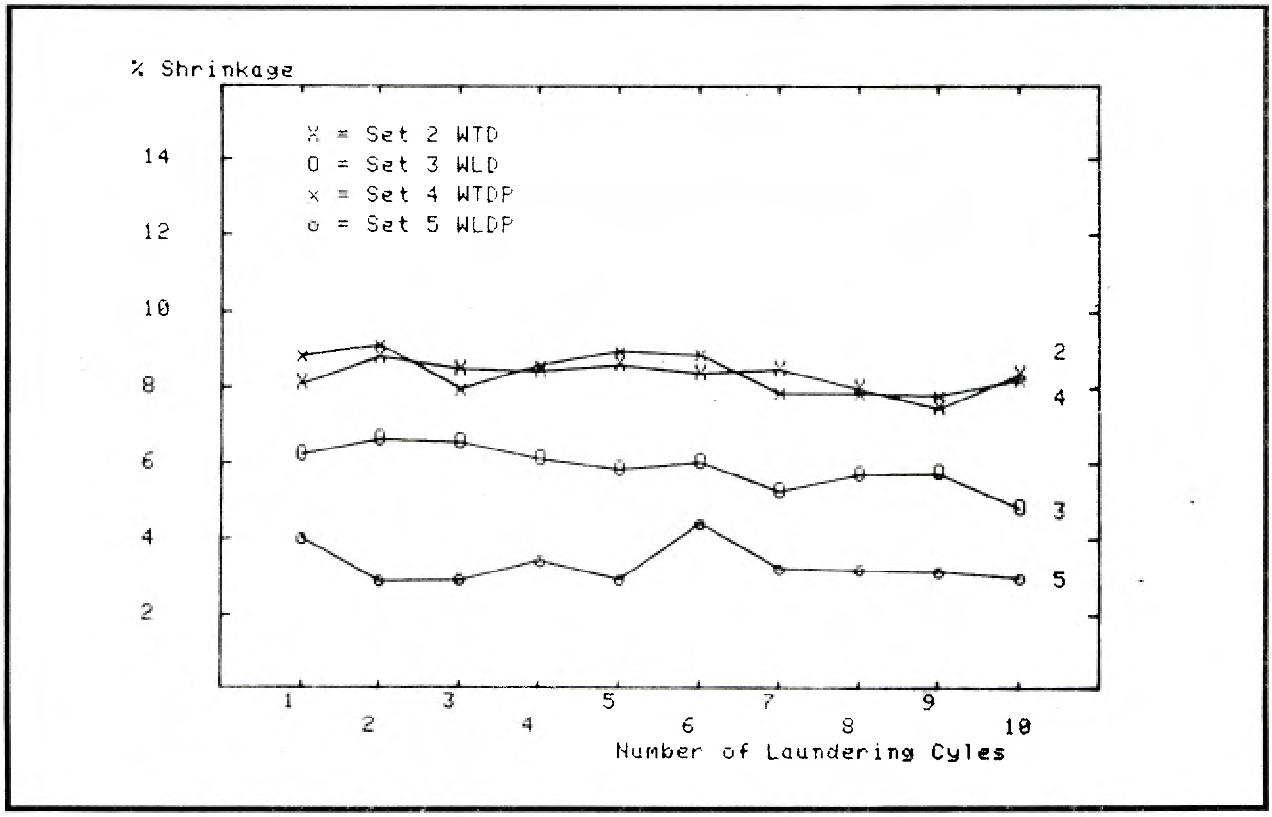


Figure 29
Average Length Shrinkage Over Ten Cycles
Second Garment Trial

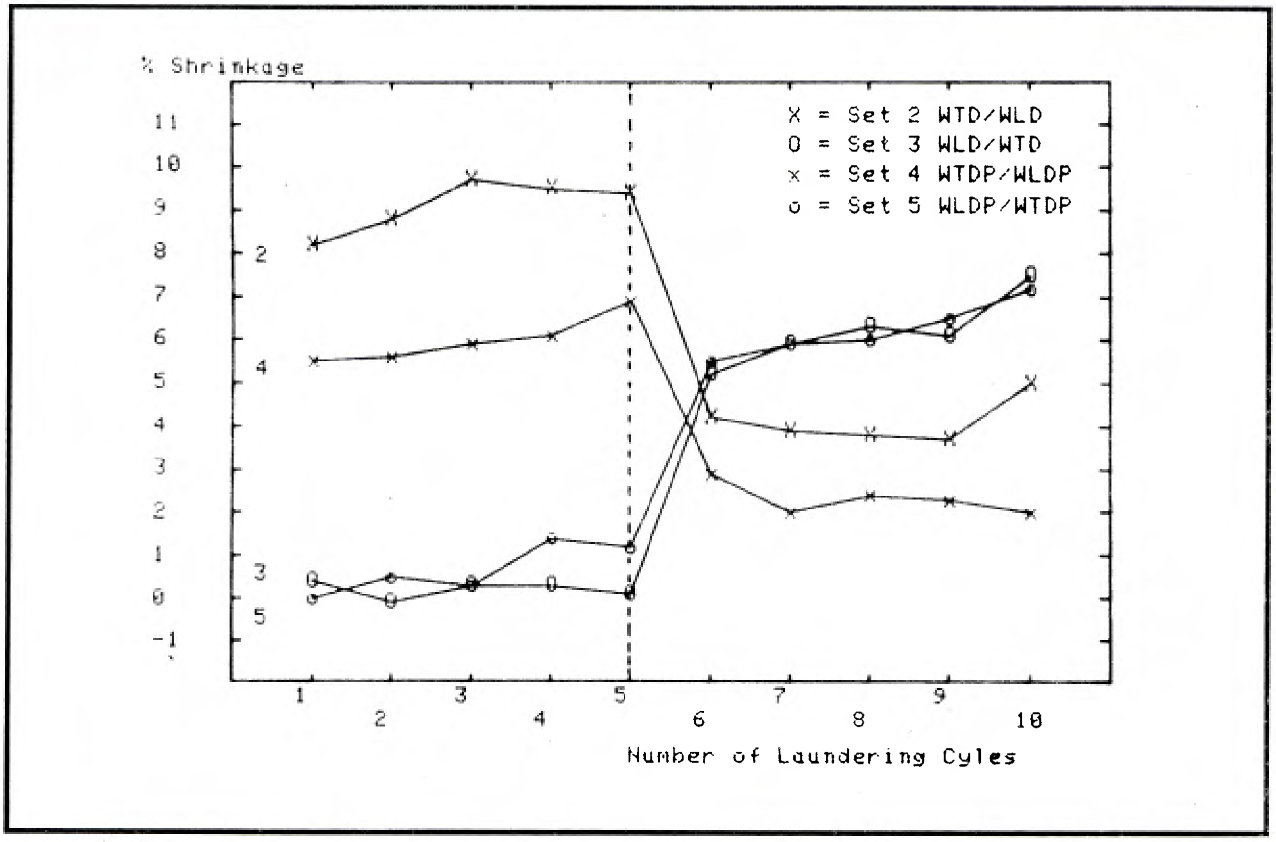


Figure 30
Average Width Shrinkage Over Ten Cycles
Second Garment Trial

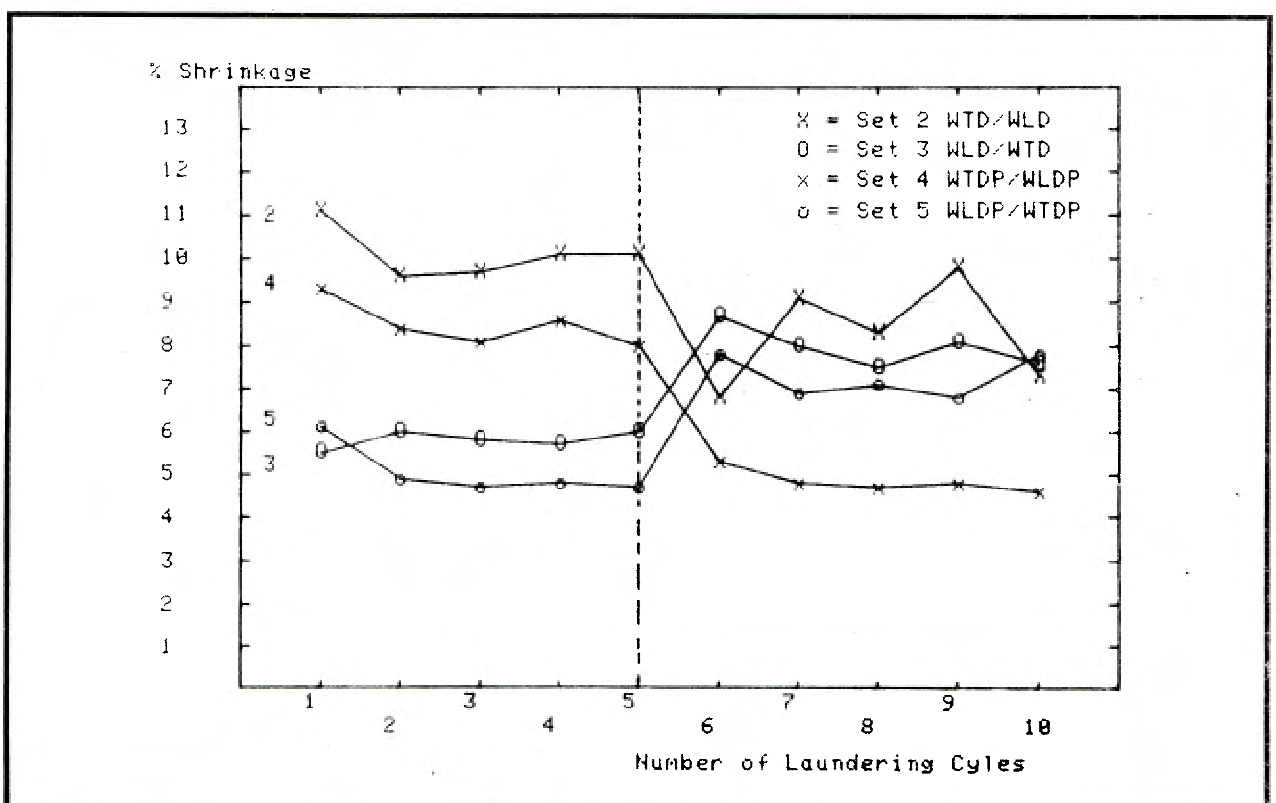


Figure 31
% Length Shrinkage : Flat versus M&S Frame

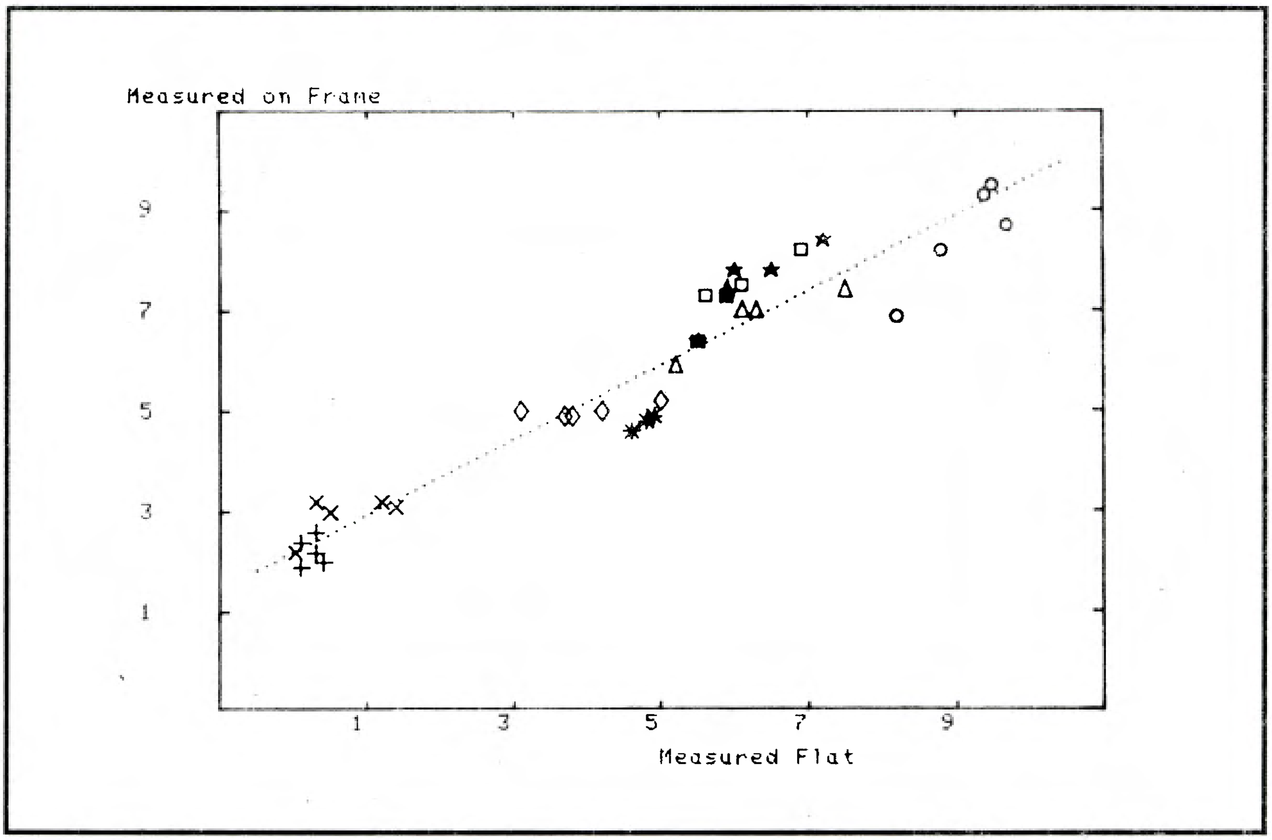
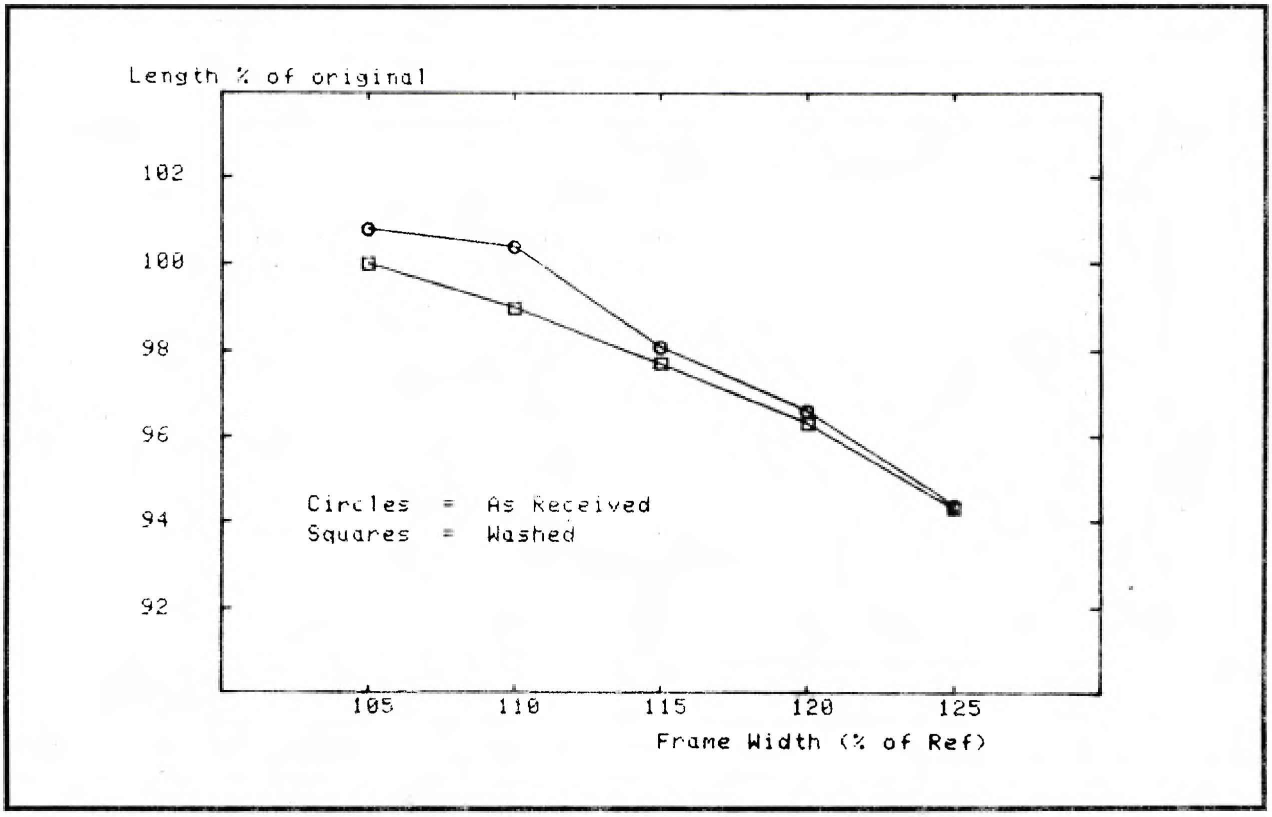


Figure 32
Garment Length as a Function of M&S Frame Width



PART 2

ESTABLISHING EXPERIMENTAL PROTOCOLS FOR THE EVALUATION OF DIFFERENT TUMBLE DRYING MACHINES AND FOR DEVELOPING CONSUMER RELEVANT INFORMATION ON THE OPTIMUM USE OF TUMBLE DRIERS IN THE HOME

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1. INTRODUCTION

This part of the report is based on the assumption that additional experimental work will be required to develop a better appreciation of:-

A whether and how different makes of domestic tumble drying machine develop different levels of shrinkage in similar knitted cotton garments.

B whether additional recommendations to consumers can be developed (over and above those which can be deduced from Part 1) which will help them to slow down the rate of development of shrinkage in their knitted cotton garments.

The selection of experimental protocols for these two areas is complicated by (at least) the following three dilemmas.

1.1 The Dilemma of Consistent Procedures

In order to evaluate the differences between various machines or laundering procedures, rigidly defined and standardised experimental protocols should be employed, in which the variability of test results has been reduced to a minimum. This would suggest that carefully specified fabric samples rather than randomly selected garments should be used, that the addition of softeners and the use of ironing or pressing should be avoided, that the test samples should always be tumble dried to well below normal regain, and that the degree of relaxation (distance from the reference dimensions) should be used as the evaluation criterion rather than shrinkage.

However, the behaviour of an individual consumer is completely unpredictable. Inevitably, different laundering and drying procedures will be used in different sequences from time to time, and dosages of both detergents and of softeners, as well as the use of ironing, will be erratic. For some consumers there may even be changes in equipment (home laundering versus commercial laundering versus coin operated launderette). Furthermore, the evaluation criterion which the consumer will apply will be based not only on the actual level of shrinkage developed in a given garment, but also on the perceived change in garment shape (length/width ratio), the change in goodness of fit (loose garments will be less critical than tight ones), and the price which was paid (shrinkage in a relatively inexpensive underwear garment may be tolerated more than in an expensive item of outerwear).

1.2 The Dilemma of the Test Equipment

In the evaluation of different domestic tumble drying machinery, one is inevitably constrained by the equipment currently available on the market. However, it is quite likely that the ideal design of tumble drier does not actually exist in the market. It is not easy to separate the influence of the different design parameters when one is faced with a series of fixed designs with fixed operating characteristics. Therefore, in the absence of an unambiguous attribution of cause and effect it is somewhat risky to make recommendations to consumers about what type of machine to buy and the best way to operate it.

1.3 The Dilemma of the Target Objective

An important component of both Dilemma 1 and Dilemma 2 is the problem of moisture content at the end of the tumble drying step. In order to preserve adequate reproducibility of the test data, tumble drying should be continued until the residual moisture content is below the "natural" moisture content of the fabrics. On the other hand, in order to minimise the levels of shrinkage developed, the tumble drying should be interrupted at a point just before the natural moisture content has been achieved. This is just the region where the test data are at their most variable.

The problem is actually much deeper than it appears in the simple statement given above. To resolve it, experimental conditions have to be established which will reliably reproduce a given level of moisture content, slightly above the natural moisture content, on every occasion. Considering that some trials may include fabrics or garments of different weights, made from different fibre types, and at different loading factors, then the problem seems quite difficult. Added to this is the high probability that no existing commercial tumble drier actually contains the required control circuitry with the "correct" settings to enable these ideal experimental conditions to be fulfilled.

There are two approaches to resolving this dilemma.

The first approach is that adopted by the IIC where the experimental protocol is designed to investigate a series of humidity levels so that the behaviour at a given level can be obtained by interpolation. This can be described as a "software" approach.

The second possibility is to instrument a standard drier with various temperature and/or humidity sensors and to develop calibration data which will enable the point when the required average specimen moisture content has been reached to be determined. This can be described as a "hardware" approach.

A decision on whether the software or the hardware approach is to be taken is a first requirement before proceeding with any experimental work.

In the following three sections, some attempt has been made to resolve these dilemmas and to provide suggestions for the design of a series of trials which will enable the two main objectives of SIFO's proposed investigations to be achieved. In reviewing these suggestions, the reader should bear in mind that, by and large, their form is more important than their content. In other words, one may easily change the detail of the trials - for example to examine other variables - but the general outline of the trial procedure can be maintained.

Section A addresses the problem of evaluating different domestic tumble drying machinery.

Section B makes some suggestions regarding the more complex problem of how the effects of different consumer behaviours may be investigated.

Section C gives detailed guide lines for those aspects of the selection of fabrics and garments, testing and laundering procedures, and data quality control techniques, which are common to both Sections A and B. However, in the initial planning and in carrying out the experimental procedures of Sections A and B, the following three general guide lines should be kept in mind.

Guide-line 1

In principle, the average reference dimensions of any test materials included in the trials should always be established, in order to identify the inherent variation in the samples due to their production and processing history, and to establish what the maximum level of shrinkage is likely to be. This means that sufficient test material should be acquired at the start so that a series of random samples can be extracted and subjected to the full Reference Relaxation Procedure, followed by measurements of the reference stitch length, yarn count, courses, wales, and weight. The remaining test material should preferably also be randomised over all of the experiments to be carried out.

Guide-line 2

Whenever basic trends in behaviour are to be studied, fabric samples rather than garments should be used in order to contain costs and maintain minimum variation within the test materials. In addition, courses and wales should be measured on all of the test specimens, both before and after washing, as well as measuring shrinkage. Changes in courses and wales provide an independent check of the degree of relaxation of the test specimens (distance from the Reference Dimensions).

Once the basic trends have been elucidated, the results can be verified on garments.

Guide-line 3

Whenever more complex aspects of consumer behaviour are being evaluated, for example when looking for interactions between the use of softeners and ironing between cycles, or the use of mixed wash loads i.e. loads containing garments of widely different weights, sizes, and fibre compositions, then it can be argued that garments should probably be preferred to fabric pieces. However, the additional costs and problems involved with obtaining sufficient quantities of standard garments may outweigh any gain in realism. In such cases, therefore, it may be useful to consider the use of simulated garments by assembling tubes of various sizes from the standard test fabrics. If and when real garments are used, the precautions mentioned in guide-lines 1 and 2 should also be followed and consideration should be given to increasing the number of specimen replications to allow for the extra variability.

A. EVALUATION OF TUMBLE DRYING MACHINERY

1. PRELIMINARY CONSIDERATIONS

Two questions must be answered before a programme of investigation can be drawn up.

Question 1. Are we to take the hardware approach or the software approach?

The hardware approach involves the instrumentation of one or two drying machines with temperature and/or humidity sensors followed by extensive calibration trials so that the critical moisture content of the load can firstly be more closely defined and then either predicted or at least identified during the course of a drying run. Logic circuits can be relatively easily designed, or a computer programme can be easily written, which will monitor the course of the drying and will shut down the heater when certain conditions are fulfilled. These conditions can easily be established by experiment. They are likely to be governed by the temperature and the rate of change of temperature in the exhaust.

The attraction of the hardware approach is that it promises to cut down the amount of experimental time and materials required when it comes to running actual comparative trials. The drawback is that the instrumentation and the calibration work itself represents a fair investment in time and money.

There is one further potential drawback in that the final conclusion from the calibration trials could be that it is not possible, without further investment in instrumentation, to obtain close enough control over the drying conditions. There is also one further advantage in that the results of the calibration trials will yield a very good insight into the drying process around the critical moisture content which will surely be capable of being used to design the most appropriate control system.

Obviously the choice of the hardware approach implies the availability of technical staff who are capable in this field of instrumentation and computer programming.

The software approach is the most simple option. It sets no preconditions, needs no particular expertise, and embodies no unforeseen risks in time and expenditure. Its only disadvantage is that it may turn out to be more expensive in the long run in terms of materials and labour. However, the labour involved is presumably of a cheaper type than that involved in the hardware approach.

It is recommended that a compromise be adopted. A simple temperature probe should be inserted into the exhaust outlet of the machine under investigation. The probe should be connected to a digital read-out or a chart recorder so that the temperature can be noted at given time intervals. The rest of the experiment should proceed according to the software approach. This will be similar to the procedure used by the IIC and described in **Part 1A, Section 4.2.**

Question 2. Are we content simply to evaluate machines which already exist in the market or do we want to develop basic information against which any present (or future) machine can be judged?

So far as this question is concerned, once again there are compelling arguments on both sides. The development of basic information, against which all present and future machines can be judged has the attraction that only two, or at most four, actual machines will be required (e.g. large and small drum, slow and fast speed). However, it may be that the appropriate four machines do not actually exist in the market so that existing machines may have to be modified (and instrumented) in order to hold some variables constant whilst others are changed.

On the other hand, the evaluation of every machine available on the (Norwegian) market may mean that twenty or so different makes and models have to be tested, which would be prohibitive in time and cost. In principle, new evaluations would also have to be carried out every time a new machine appeared on the market.

Here again a compromise is recommended. Firstly, design information should be collected on all of the most popular machines. The information required is (at least) the following:-

Drum size and drum speed (delivery of mechanical energy),
Heater rating and air flow rate (delivery of heat energy),
Heater control system parameters (variation and control of heat energy),
Automatic shut down systems, if any (control of final moisture content).

In addition, some machines may have provision for recirculating part of the exhaust and/or condensing moisture out of the exhaust. Furthermore, it may turn out that some machines may have adjustment points which, though they may be factory set at certain levels, could be adjusted to vary the experimental conditions.

This information would be most efficiently collected by visits to the machine manufacturers. This is firstly because they will probably reveal more detail in a personal interview than by mail and secondly because a discussion of the project may prompt them to reveal work of a similar nature which they have conducted in the past. It could also result in offers of financial support for the proposed work programme in return for rapid access to the results.

Having gathered the information on all of the popular machines, they should be classified according to:-

Drum size
Drum speed
Rate of delivery of energy to the load at each setting
Possession of automatic shut-down systems

With any luck it will be possible to select two or three machines which can serve as representatives for a whole set or subset. It may also be possible to eliminate a variable from the study if it is found that the variation across machines appears insignificant. Consideration should be given to the inclusion of an industrial type tumble drier with a very large drum and a relatively high rate of energy delivery as being representative of the type of drier which may be found in commercial laundries or launderettes.

2. EXPERIMENTAL PROGRAMME

Having decided on the basic approach, and selected the machines to be evaluated, the actual investigations are relatively straight forward although somewhat demanding in time and test materials.

The guiding hypothesis is the following:-

All domestic tumble driers are equally capable of developing the ultimate level of potential shrinkage in a given garment made from knitted cotton. However, some machines may develop this shrinkage at a slower rate than others, under any conditions of usage, whereas with some machines it may be possible for the consumer to operate them in a way which will minimise the rate of development of shrinkage.

Following this hypothesis it is only necessary to establish:-

a) the ultimate level of shrinkage which is developed in a standard set of fabrics and/or garments for each drier in turn.

b) discover how the consumer may intervene to reduce this level, or postpone it for a greater or lesser number of cycles.

For a given machine, the only ways that the consumer can intervene are:-

a) selection of the low or the high heat setting

b) interruption of the drying cycle at a point where the average moisture content of the load is above the natural moisture content.

Thus the differences, if any, and the scope for intervention by the consumer will be established by running experiments similar to those described in **Part 1 A, Section 4.2** and outlined in more detail in 3 below.

Variables which concern consumer habits, rather than machine design, such as the use of softeners or ironing between cycles are dealt with in **Section B.**

3. OUTLINE OF TRIALS

The objective of these trials will be:-

- to develop calibration curves against which all other machines and/or laundering procedures can be compared,

- to discover the optimum moisture content (or range in moisture content) at the end of tumble drying for slowing down the rate of generation of shrinkage,

- to discover whether drying machine design parameters affect the rate of generation of shrinkage **either** when fabrics are consistently dried to low moisture content **or** when they are dried to the optimum moisture content,

- to provide fully shrunk fabric specimens with which to study the effectiveness of remedial measures in recovering shrinkage which has already been developed.

For each fabric selected for inclusion, the natural moisture content should be established, in the standard atmosphere, from separate specimens taken at random. The natural moisture content may be significantly different in the different fabrics because of their separate manufacturing and processing histories. This is especially the case when mercerised or resin finished fabrics are included.

Series 1

For each selected fabric type in turn, establish the shrinkage profile of over ten cycles of washing and line drying, as follows.

1. Prepare the shrinkage specimens as described in **Part 2, Section C** and **Appendix B.**
2. Weigh each specimen and measure length, width, courses, and wales.
3. Assemble standard loads from the specimens under test, using make-weights where necessary.
4. Wash the standard load using the chosen standard washing cycle and detergent.
5. Weigh the wet test specimens, hang them on a line (wales vertical) and allow to dry in the standard atmosphere. Drying in a non-standard atmosphere can be tolerated provided the conditions are not too extreme, and provided the specimens are conditioned in the standard atmosphere before measuring.
6. Weigh each specimen and measure its length, width, courses, and wales.
7. Return the full load to the washing machine and re-wet using the rinse/spin cycle.
8. Weigh the wet specimens, and line dry as in 5
9. Weigh and measure as in 6
10. Repeat steps 7 to 9 a further eight times, making ten cycles in all.

Series 2

For each selected fabric type and tumble drying machine in turn, establish the shrinkage profile over ten cycles of washing and tumble drying to different moisture contents with the drying machine switched to the high heat setting. The time required to tumble dry a standard load of each fabric to about 2% moisture content will already have been established if the recommendation for determining the reference dimensions for each fabric type in advance has been followed. A series of intermediate drying times, with increments of, say, ten minutes can be used for this series. An additional set with a drying time in excess of the bone-dry time, say by 30 minutes, could also be useful for the trials of **Section B.**

1. Prepare, measure, and weigh a set of shrinkage specimens and assemble a standard load.
2. Wash the load using the standard washing cycle and detergent.
3. Weigh the wet load, transfer it to the tumble drier, and tumble for the selected time period.
4. Weigh the whole load in a plastic bag (to reduce evaporation)
5. Return the load to the drier and tumble for a further ten minutes with the heat turned off (cool-down)
6. Weigh the specimens immediately after the cool-down tumble, and transfer them to the standard atmosphere for conditioning.
7. Weigh and measure each specimen, as in Series 1.
8. Return the load to the washing machine and re-wet using the rinse cycle.
9. Repeat steps 3 to 7.
10. Repeat steps 8 and 9 a further eight times, making ten cycles in all.
11. Repeat steps 1 to 10 for the next tumble drying time interval.

For each load, each tumble drying time, each cycle, and each drying machine, record the exhaust temperature at frequent time intervals - say every minute.

Series 3

For each selected fabric type and tumble drying machine in turn, establish the shrinkage profile over ten cycles with the drying machines switched to the low heat setting.

Repeat Series 2 once again using the low heat setting

NB It may be possible to reduce the number of different fabric types included in this series if it becomes clear that the rates of generation of shrinkage are identical to those in Series 2. For this reason it is recommended to start with the heaviest fabric, then the lightest, then an intermediate weight of a different structure. If these three are all identical for at least two of the dryin machines, then Series 3 can be suspended at this stage (although, in this case it will surely be found that the addition of the Series 3 data to that of Series 2 will provide a much more reliable way of developing curves of e.g shrinkage vs moisture content).

4. RESULTS

These three series of trials - line dry, high heat, and low heat - will provide the basic data to establish:-

a) Calibration curves for each drying machine in terms of the rate of evaporation at a given level of moisture in the fabric, given rate of energy delivery, and the temperature of the exhaust, for different fabric weights. They can be used to erect smoothed curves of moisture content as a function of time and exhaust temperature, and can be used to estimate drying times for a given residual moisture content under given conditions as well as to pin-point the exhaust temperature at which to terminate the drying process.

b) Shrinkage profile curves for line drying which presumably represent the best performance attainable, by any drying process, for the given fabrics.

c) Shrinkage profile curves for tumble drying to the lowest moisture content attainable by each drying machine, which represent the worst-case situations for each machine for the given fabrics.

d) Shrinkage profile curves for tumble drying to any chosen moisture content (obtained by interpolation) which can be used to determine the optimum humidity of the load at the end of tumble drying.

Shrinkage rates and drying rates can be quantified by regression analysis, if required, and the influence of the different dryer characteristics can be evaluated or deduced. Prediction equations could be developed and tested by running supplementary trials with new samples.

Taken together, the various shrinkage profile curves, and/or regression equations, can be used to establish how the ideal tumble dryer should be designed and how it should operate. Furthermore, each drier in the study, as well as others not studied in detail, can be assessed and rated in terms of how closely it conforms to the ideal from the point of view of controlling the development of shrinkage.

If it turns out that, due to unexpected effects, the whole of the required data has not been generated by these trials, then at least it will be obvious exactly where further work should be directed.

B. EVALUATION OF THE POTENTIAL EFFECTS OF CONSUMER PRACTICE

1. PRELIMINARY CONSIDERATIONS

This section deals with those parts of the total laundering procedure which are independent of the design and operating characteristics of the tumble drying machine itself, but which might have an influence on the rate of development of shrinkage.

It is this section which is most subject to the dilemma of consistent procedures, outlined earlier. That is, we are faced with the need to use consistent and reproducible laundering procedures in order to clearly associate cause and effect, whereas the consumer will certainly be thoroughly inconsistent in the application of any number of different procedures.

All that can be done is, firstly to identify and quantify in a systematic way those parts of the laundering procedure which have a significant effect on the end result and, secondly, to remember that "Murphy's Law" always applies.

Murphy's Law states that

"ANYTHING WHICH CAN GO WRONG, SOONER OR LATER WILL DO SO."

In the present context this means that, for example, despite all advice to the contrary, sooner or later the consumer will tumble dry a load to complete dryness (assuming the drying machine will allow it) and develop the greater part of the potential shrinkage. Therefore it would be wise to consider the development of remedial procedures for garments which are approaching their reference state of relaxation.

A few key variables have already been identified in **Part 1** as having an influence on the rate of development of shrinkage and on the recovery of shrinkage already developed. These are:-

1. **Moisture content at the end of tumble drying**
2. **Use of softeners**
3. **Ironing between cycles**
4. **Use of line drying on occasions**

In addition, one can imagine other variables which may influence the rate of development of shrinkage;

5. **Rate of drying**

   The bulk of the shrinkage occurs whilst the moisture content of the load lies between certain limits (roughly 30% down to 5%). It may be that the faster the garments pass through this stage, the less shrinkage will develop. This aspect will already have been investigated to some extent in the experiments listed in **Part 2, Section A** but there are other ways to alter the rate of delivery of energy to (the cotton portion of) the load. For example, by reducing the weight of the load and by including garments made from synthetic fabrics.

6. **Uniformity of drying/ mixed loads**

   If the load is too heavy, if the load contains mixed garment sizes, if the load contains mixed garment weights, if the load contains garments made from different fibre types **and** if the drying cycle is interrupted before all garments are bone dry, then it is likely that some garments will end the drying cycle with much higher moisture contents than others. Lightweight garments may be overdried whilst heavy garments remain damp.

7. Overdosing with softener

Use of greater than recommended amounts of softener is bound to occur from time to time. Does this affect the result? What happens if excessive doses of softener are used consistently? Does it matter if the softener is applied as part of the detergent, or during the rinse, or in the tumble dryer?

8. Interaction between variables.

Are the beneficial effects of variables 1 to 4 additive, or are they just alternative ways of obtaining the same improvements.

On the basis of this discussion it is clear that the experimental programme should be designed to answer two basic questions:-

Question 1

Is there a standard laundering and tumble drying procedure which can be described in a simple set of guide-lines and which, if followed consistently, can prevent the development of the full potential shrinkage or postpone its development for a greater or lesser number of laundering cycles?

Question 2

Once a garment has developed its full potential shrinkage, what is the best procedure which can be recommended to recover a significant part of the shrinkage?

In the same way that the selection and classification of drying machines, in **Part 2, Section A**, was preceded by personal discussions with the machinery makers, it is recommended that the first step in the detailed planning of this section should be to make visits to the research and development sections of the major detergent manufacturers, who have carried out a great deal of work in this area - especially concerning the influence of softeners - and who will be very interested in the results of the trials to be described here. In the UK, the Home laundering Consultative Council (HLCC) have also carried out quite a few studies which may be relevant, and ISO has a working group on tumble drying whose activities are co-ordinated in the UK by BSI.

2. EXPERIMENTAL PROGRAMME

Based on the results obtained in **Part 2, Section A**, it should be possible to confine the experiments of this section to, at most, two tumble drying machines. One machine will have a more or less effective temperature or humidity control system to interrupt the drying process at about the natural moisture content. The target level of moisture content will have been identified in **Part 1, Section A**. This machine will represent the best available choice for the consumer from this point of view (although it may not necessarily be the best value for money). The second machine will have no such controls and will be needed to develop the maximum potential shrinkage in some of the test materials. Consideration may also perhaps have to be given to the inclusion of a third machine (very large drum size), depending on the results of **Part 2, Section A.**

In what follows, it is assumed that the trials described in **Part 2, Section A** have actually been carried out so that the basic calibration curves are available.

For these trials, it could be argued that garments should be used rather than fabrics. However, fabric samples will be much cheaper and will deliver essentially the same information. In any event, the same selection criteria should be used as for the fabrics selected in **Part 2 Section A**, and described in **Section C.**

3. OUTLINE OF TRIALS

The number of trials which could be carried out is enormous. Detailed experiments should be limited to an examination of those variables which are thought to be most important to establish the basic ground rules. These are probably variables 1 to 4 given in the preliminary discussion. An example of a reasonable scheme is given below, but there are several other reasonable schemes which could be devised - some of which may be quicker and cheaper.

The results obtained from the trials carried out in **Part 2, Section A** will act as the control set for this series of trials and, in addition, some of the actual specimens produced in the earlier trials can be included, alongside new specimens, to see how much, if any, of the shrinkage which was developed can be recovered.

For each fabric selected, sets of specimens should be prepared and assembled into standard loads in order to study the rates of shrinkage generated by alternative laundering regimes. The most important regimes to study would probably be as follows:-

1. Softener, best machine, no ironing
2. Softener, best machine, ironing
3. No softener, best machine, ironing

4 - 6. Repeat 1 to 3, using the worst machine

7 - 9. Repeat 1 to 3, using line drying

Where "best" machine is the drier with automatic cut-out and the "worst" machine is the one without. At least five cycles of full washing (no rinse-only cycles) and drying should be carried out, preferably ten. The high heat setting of the tumble drier should be used in each case.

Some attention should be given to standardising the ironing procedure. Operatives should be trained, and should train each other, before the trials begin to ensure at least a degree of consistency - e.g method of laying out the specimen, length direction ironed before width, etc.

4. RESULTS

At this stage the major variables and their interactions will have been thoroughly elucidated. Time should be taken for a detailed consideration of the results. Variance analysis and regression analysis techniques may be employed to establish significant differences and to quantify shrinkage rates but, in fact, the most important conclusions should be apparent from simple graphical presentations. A detailed comparison should be made with the basic curves developed in the trials of **Part 2, Section A.**

Consideration should then be given to whether the main conclusions can be reduced to a few simple guide-lines for consumers.

Only after these basic data have been thoroughly studied and reviewed should attention be turned to the study of more complicated procedures such as those involving mixed loads, reduced loads, or overdosing of softeners. The results from any such subsequent trials can be judged against the behaviour patterns established in the first series, and can consequently be more limited in scope. If real garments have not been used in the main trial series, then they can be introduced at this stage. Consideration should also be given to the inclusion of garments made from man-made fibres. However, if these are to be used simply as makeweights, for example to increase the average drying rate, then the selection criteria need not be so strict and, indeed, they can simply be fabric specimens or simulated garments to conserve cost.

C. GUIDELINES FOR THE SELECTION OF FABRICS AND TESTING PROCEDURES

1. INTRODUCTION

In **Part 1** some of the most important sources of variation in testing procedures, fabrics, and garments have been described. With these in mind, and to enable the results obtained from the investigations suggested in **Part 2, Sections A and B** to be evaluated with confidence, the following guide-lines and recommendations for the selection of test materials, laundering, and testing procedures are offered for consideration.

2. SELECTION OF FABRICS

For the bulk of the evaluations, the use of fabrics rather than garments is recommended for the following reasons:-

Costs of obtaining representative test samples will be contained,

A consistent and reliable testing procedure has been developed for fabrics by the IIC which, if adopted, will ensure that reproducible measurements can be expected to be obtained within known limits.

It avoids the addition of other sources of variation in the samples due to the making up procedure.

The measurement of garments is intrinsically more difficult, may be less consistent, and may require additional replications to ensure adequate reliability of the test results.

Basic trends in the rate of development of shrinkage in fabrics under different conditions of laundering and drying can be quantified equally as well on fabrics as on garments. Verification of the discovered trends, or the investigation of more complex interactions, can then be followed on garments, if necessary, when a more limited set of samples will probably be required.

However, given that knitted fabrics are inherently variable, careful consideration should be given to the selection of the standard fabrics to use for the evaluations. The following guidelines may be found to be useful.

2.1. For all of the fabrics included in the trials, detailed information about their production and processing history should be obtained from the manufacturers. In addition, their construction (tex, stitch length, courses, wales, and weight) should be checked, by physical determination on receipt (before the trials commence), and after relaxation to the reference state. These tests should be carried out using standard (e.g. BS 5441:1988) testing procedures for knitgoods. The IIC standard procedures for these determinations can be made available on request.

N.B. *In the IIC laboratory, measurements of courses and wales are made on each of the prepared shrinkage specimens before laundering, distributed across the specimens (e.g. 2 on each) rather than on other parts of the sample. This enables direct cross checking of shrinkage measurements to be made (Section 5 below). Destructive tests such as yarn count, stitch length and weight should be carried out on the starting material well distributed throughout the sample, avoiding creases and edge marks. Measurement of wales should be made in a direction perpendicular to the wale line; courses should be measured along a wale. This allows for the problem of spirality in single jersey fabrics and enables direct comparison with the shrinkage measurements.*

When preparing specimens for the measurement of fabric weight using a cutting die, check that compression or distortion of the sample is not being caused by the downward pressure exerted on the *fabric during cutting. This can be a problem, especially with thick fabrics and with those which have been relaxed and consolidated by tumble drying, and can lead to discrepancies or inaccuracies in the measured weights. Any distortion introduced during cutting can easily be identified by comparing the prepared test specimen with a standard template, prepared using the cutter with a rigid material such as thin card. If the dimensions of the specimens are found to be significantly different, then the actual area of the test specimen can be calculated and the weight per unit area can be corrected accordingly.*

2.2. Several different fabric types and finishes, representative of the most popular types of fabrics found in Norway, should be included to allow for differences in the behaviour of different fabrics under standard laundering conditions. The selected fabrics should all have relatively high levels of potential shrinkage to tumble drying. Fabrics with low potential shrinkages will obviously cause no particular problems for the consumer and will therefore not provide an adequate test for the experimental procedures outlined.

2.3. The choice of which fabrics, and how many of them, will obviously be constrained to large extent by availability, cost, and the time which can be allowed. In principle, as many different types and weights should be included as can be justified. In any case, if the number of different fabric types has to be severely restricted, then at least two weights should be represented ie lightweight and heavyweight. Plain single jersey fabrics tend to be the cheapest but they are susceptible to the problem of spirality which can cause difficulties in measurement. Interlock and rib fabrics tend to show larger differences between line-dry and tumble-dry procedures; they also tend to exhibit the phenomenon of growth after the first cycle.

2.4. Some types of fabrics which should be considered are the following.

- A heavy weight plain single jersey, which might be used for e.g. rugby shirts
- A lightweight plain single jersey, which might be used for underwear or T-Shirts.
- A mid weight interlock, which might be used in underwear or outerwear.
- A standard 1x1 rib fabric, used in underwear or outerwear.
- A cross tuck or pique, used in tennis or sports shirts.
- A heavyweight fleece, used for track suits or sweat shirts.

2.5. All the standard fabrics should be white or dyed and finished. Special finishes, such as mercerising or resin finishing, although interesting, should probably be avoided in the first instance, as these finishing procedures can be an additional source of variation. However, if these do actually represent a significant proportion of fabrics found in the Norwegian market, then their inclusion should be considered because their shrinkage behaviour, especially the differences in shrinkage between line-dry and tumble-dry cycles, can be quite different to that of fabrics which have been finished using "standard" procedures.

2.6. Ideally the test fabrics should be obtained in one roll, of sufficient length for all of the machinery and laundering evaluation trials contemplated, direct from the manufacturer with full knitting and finishing details. This should help to ensure that within fabric variation is kept to a minimum. Fabrics obtained from a variety of sources or at different times should be regarded as different fabrics even if they have the same nominal specification.

3. SELECTION OF GARMENTS

If it is decided to include garments in any of the trials, then the ideal solution would be for standard garments to be made up out of the selected standard fabrics by a single garment maker.

If this is not possible, then garments of a standard style and size should be obtained from a single manufacturer, all made from the same batches of fabrics. It is not recommended that garments be purchased "off the shelf" for the basic investigations if this can be avoided, because of the very serious problems of containing variation within and between garments.

In any case, sufficient garments should be obtained to allow full destructive testing of a representative selection of the garments to enable the fabric construction to be properly quantified. In addition, courses and wales should be measured on all of the garments included in the trials before washing as well as after laundering.

4. TESTING PROCEDURE

It is recommended that the standard IIC test method for measuring shrinkage (**Appendix B**) be used for all tests on fabrics and that the guidelines for garments outlined in **Part 1, Section C** should be considered when garments are involved.

4.1 Preparation of specimens

Specimens should be marked and measured in a consistent manner. This is best achieved by the use of a template as described in **Part 1, Section A** and **Appendix B.**

For each fabric included in the trials, five replicate test specimens of 50 cm test area should be prepared. Fewer replications are not recommended. If smaller specimens are used, then consideration should be given to the fact that the results may be less reproducible.

4.2 Laundering Procedure

Although the detailed conditions of washing, with the exception of the addition of fabric softener, have not been found to have a significant influence on the dimensions of the reference state or the reproducibility of testing when laundering is followed by tumble drying, good practice demands that a standard laundering cycle is defined at the beginning of the trials and maintained throughout. It is not essential that full wash cycles are repeated after the first cycle for the trials of **Part 2, Section A.** Rinse cycles may be substituted in the second and subsequent cycles without adversely affecting the results. This reduces the time required for testing considerably. However, for the trials of **Part 2, Section B,** full washing cycles should probably be used throughout.

Thus ideally the same washing machine/s and washing programme should be used for all the laundering cycles. The standard washing cycle used by IIC utilises a 60^{o} C wash programme. The weight of load should be standardised according to the make and model of machine being used. However it is recommended that the recommended loads of different machinery manufacturers should be checked against the volume of their respective washer and dryer drums. It would presumably be a good idea to try to standardise on a constant ratio of drum volume to weight of load, particularly for the drying machines, if at all practical. Make-weights, when required, should be of similar size and weight to the specimens under test.

The same detergent should be used for all of the trials. A standard domestic detergent can be selected but it should not contain any softener in the formulation. Alternatively, the standard EEC detergent may be used. For those trials where the addition of softener is being evaluated, it is recommended that a single popular brand of liquid product is selected for the basic trials. Other types of softener and other modes of application can be studied in supplementary experiments. Discussions with the detergent manufacturers will be useful here.

4.3 Conditioning

After each laundering and drying cycle, and before final measurements are taken, the specimens should be properly conditioned in the standard atmosphere (65% RH, 20^{o} C). This is especially important after tumble drying because fabrics leaving the dryer in a completely dry state will begin to absorb moisture rapidly, but not necessarily uniformly or consistently. Therefore proper reconditioning is essential to ensure that all specimens have reached equilibrium before measuring. In addition there is a small but measurable improvement in shrinkage with conditioning.

5. LABORATORY QUALITY CONTROL

In order to ensure that the results obtained from testing are consistent and reliable, it is important to maintain quality control procedures to monitor accuracy. In the IIC laboratory one way that this is achieved is by using internal consistency checks.

With knitted fabrics there are certain relationships between the test results which can be used on a routine basis to ensure that the results from these tests are mutually compatible. In the IIC laboratory we make use of two such relationships.

1. Mass per unit area, $M = \frac{Tex.L.C.W.F}{10}$

where L is the stitch length in cm
C is the number of courses per cm
W is the number of wales per cm
F is a factor which depends on fabric construction and the method used for counting courses and wales

2. Relaxed stitches per unit length, $R = \frac{100.B}{(100-S)}$

where R is the number of stitches per unit length after relaxation,
B is the number of stitches per unit length before the relaxation treatment, and
S is the corresponding shrinkage (%)

Assuming that all of the required measurements have been made on a given sample, then these two relationships can be applied to calculate mass per unit area, and the course and wale densities. Then the internal consistency factors can be calculated as:-

C1 $\frac{\text{Calculated mass/unit area}}{\text{Measured mass/unit area}}$ (before relaxation)

C2 $\frac{\text{Calculated mass/unit area}}{\text{Measured mass/unit area}}$ (after relaxation)

C3 $\frac{\text{Calculated course density}}{\text{Measured course density}}$ (after relaxation)

C4 $\frac{\text{Calculated wale density}}{\text{Measured wale density}}$ (after relaxation)

For these four consistency factors we apply an acceptance range of 0.95 to 1.05 for the average of five specimens. If the required acceptance range is not achieved then additional testing must be performed. Failure to meet the acceptance range after further testing must be advised by a cautionary note. In addition, the factors are monitored over time to see if one or more is consistently showing values greater than or less than 1.00 on average. Significant consistent deviation from 1.00 constitutes grounds for launching an investigation of the test methods to discover the source of systematic bias.

Therefore for those specimens which are subjected to the standard reference relaxation procedure, the dimensions of the test specimens should be remeasured. i.e. tex, stitch length, courses/cm, wales/cm, and weight per unit area.

Measurements should be spread across all of the shrinkage specimens to ensure an adequate representation of the sample under test. Not only does this enable the internal consistency of measurements to be checked, but it also allows an independent check on the actual construction of the fabric, and it provides an independent measure of the variation within the replicate samples

For those specimens which can not be subjected to destructive testing (because they are required for further laundering cycles, or for reference purposes), the measurements of courses and wales both before and after laundering provides data for an independent check of the shrinkage measurements. The level of agreement between these two measures of shrinkage is a good indicator of the degree of control over the laboratory procedures. In addition, the average of the two measures will generally be a better indicator of shrinkage than either one alone.

Thus : Length shrinkage $= \dfrac{100\,(C/cmR - C/cmB)}{C/cmR}$

and : Width shrinkage $= \dfrac{100\,(W/cmR - W/cmB)}{W/cmR}$

Where : R is after Relaxation and B is Before.

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APPENDIX A

Key to fabrics used in the trials described in Part 1

Part 1: Section A

2.1, 5, Reference 10

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	CK 169	single jersey	1/24	3.05	greige
2	CK 157	single jersey	2/50	3.02	greige

2.3, 3.1 Reference 13,14

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	IJDH	interlock	1/34	3.40	jet dye, CS
2	IMJDH	interlock	1/34	3.40	mercerise (1), jet dye, CS
3	RJDH	1x1 rib	1/30	3.50	jet dye, CS
4	RMJDH	1x1 rib	1/30	3.50	mercerise (1), jet dye, CS
5	SJ2G	single jersey	2/72	2.87	greige
6	SJ1G	single jersey	1/28	3.21	greige
7	IntG	interlock	1/38	3.40	greige
8	RibG	1x1 rib	1/30	2.85	greige
9	IMJDX	interlock	1/38	3.40	mercerise(1),jet dye, crosslink
10	IJDX	interlock	1/38	3.40	jet dye, crosslink
11	RMJDX	1x1 rib	1/30	2.85	mercerise (1), jet dye, crosslink
12	RJDX	1x1 rib	1/30	2.85	jet dye, crosslink
13	IMJDH	interlock	1/34	3.24	mercerise (1), jet dye, CS
14	IJDH	interlock	1/34	3.24	jet dye, CS
15	RJDH	1x1 rib	1/26	2.67	jet dye, CS
16	RMJDH	1x1 rib	1/30	2.67	mercerise (1), jet dye, CS
17	SJ1BRAZ	single jersey	1/28	3.06	overflow dye
18	SJ2BRAZ	single jersey	2/56	3.06	overflow dye
19	SJ2MBRAZ	single jersey	2/56	3.06	mercerise (1), overflow dye
20	SJ1MBRAZ	single jersey	1/28	3.06	mercerise (1), overflow dye

CS = compressive shrinkage on a Hunt and Moscrop machine; tubular mercerise (1) Omez; crosslink with DMDHEU at about 2% solids on weight of fabric; jet dye in a Thies R-95; overflow dye in a Brazzoli.

3.2, Reference 15

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	SJ2MBRAZ	single jersey	2/56	3.21	mercerise (1), overflow dye
2	SJ1MD	single jersey	1/36	2.87	mercerise (2), Gyrostock dye
3	RWB	1x1 rib	1/30	2.85	winch bleach
4	IWD	interlock	1/38	3.38	winch dye
5	IWB	interlock	1/38	3.38	winch bleach
6	IWD	interlock	1/70	2.36	winch dye
7	REJD	1x1 rib	1/34	3.26	jet dye, Ecosoft
8	SJ1RS	single jersey	1/16	3.44	jet dye, Rotostream
9	SJ1BRAZ	single jersey	1/28	3.06	overflow dye, Brazzoli
10	RMJD	1x1 rib	1/30	2.85	mercerise, Gyrostock dye

Tubular mercerise (1) Omez, (2) Dornier; overflow dye in a Brazzoli.

3.3, Reference 16

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	SJ1MD	single jersey	1/36	2.87	mercerise (2), Gyrostock dye
2	SJ2D	single jersey	2/56	3.21	Gyrostock dye
3	SJ2MD	single jersey	2/40	3.81	mercerise (2), Gyrostock dye
4	SJ1D	single jersey	1/28	3.21	Gyrostock dye
5	WDH	interlock	1/42	3.40	winch dye, CS
6	IMJDH	interlock	1/42	3.24	mercerise (1), jet dye, CS
7	IWDH	interlock	1/34	3.40	winch dye, CS
8	RWD	1x1 rib	1/30	2.67	winch dye
9	REJD	1x1 rib	1/26	3.26	jet dye, Ecosoft
10	REJD	1x1 rib	1/34	2.85	jet dye, Ecosoft

Tubular mercerise (1) Omez, (2) Dornier; CS = compressive shrinkage on a Hunt and Moscrop machine; jet dye in a Thies R-95.

3.4, 3.5.2, Reference 17

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	SJ Tight	single jersey	1/32	2.91	dyed
2	SJ Slack	single jersey	1/16	4.19	dyed
3	Rib Tight	1x1 rib	1/26	2.67	dyed
4	Rib Slack	1x1 rib	1/34	3.50	dyed
5	Int Tight	interlock	1/42	3.07	dyed
6	Int Slack	interlock	1/42	3.77	dyed

3.5.1, Reference 18

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	IWB	interlock	1/38	3.38	winch bleach
2	SJ2MD	single jersey	2/56	3.54	mercerise (2), Gyrostock dye
3	RWB	1x1 rib	1/30	2.85	winch bleach
4	SJ2MD	single jersey	2/56	3.21	mercerise (2), Gyrostock dye
5	RibG	1x1 rib	1/30	2.85	greige
6	REJD	1x1 rib	1/26	3.50	jet dye, Ecosoft

Tubular mercerise (2) Dornier.

4.1, Reference 19

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	SJ1D	single jersey	1/24	3.30	dye
2	SJ1D	single jersey	1/32	2.73	dye
3	RWB	1x1 rib	1/30	2.85	winch bleach
4	SJ1G	single jersey	1/36	2.59	greige
5	IWD	interlock	1/38	3.38	winch dye
6	IWB	interlock	1/38	3.38	winch bleach
7	SJ2MD	single jersey	2/56	3.54	mercerise (2), Gyrostock dye
8	SJ2MD	single jersey	2/56	3.21	mercerise (1), overflow dye
9	SJ2D	single jersey	2/72	2.59	Gyrostock dye
10	SJ2MD	single jersey	2/40	3.99	mercerise (2), Gyrostock dye

Tubular mercerise (1) Omez, (2) Dornier; overflow dye in a Brazzoli.

4.2.1, Reference 20

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	IWD	interlock	1/38	3.38	winch dye

4.2.2, Reference 21

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	IWD	interlock	1/38	3.38	winch dye

4.2.3, Reference 22

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	SJ2MD	single jersey	2/72	2.87	mercerise (2), Gyrostock dye

Tubular mercerise (2) Dornier.

4.2.4, Reference 23,24

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	RWB	1x1 rib	1/30	2.82	winch bleach
2	SJ2D	single jersey	2/72	2.87	Gyrostock dye

4.2.6.2, Reference 27

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	IWB	interlock	1/38	3.38	winch bleach
2	SJ2D	single jersey	2/72	2.59	Gyrostock dye
3	SJ2MD	single jersey	2/56	3.54	mercerise (2), Gyrostock dye
4	SJ2MD	single jersey	2/56	3.21	mercerise (1), overflow dye
5	SJ2D	single jersey	2/40	3.99	Gyrostock dye
6	SJ1G	single jersey	1/36	2.59	greige
7	RWB	1x1 rib	1/30	2.85	winch bleach
8	IWD	interlock	1/38	3.38	winch dye
9	SJ1JD	single jersey	1/32	2.73	jet dye, Rotostream
10	SJ1JD	single jersey	1/24	3.30	jet dye, Rotostream

Tubular mercerise (1) Omez, (2) Dornier; overflow dye in a Brazzoli.

Part 1: Section C

2.1.1, Reference 42

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	RibD	1x1 rib	1/30	2.80	dye

3,4 Reference 44

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
Singlets					
1	IJDH	interlock	1/38	3.40	jet dye, CS (1)
2	IJDH	interlock	1/42	3.77	jet dye, CS (1)
3	ICBT	interlock	1/38	3.24	continuous bleach, CS (2)
4	ICBT	interlock	1/42	3.07	continuous bleach, CS (2)
5	RJDH	1x1 rib	1/30	2.67	jet dye, CS (1)
6	RJDH	1x1 rib	1/30	3.06	jet dye, CS (1)
7	RJDH	1x1 rib	1/34	2.85	jet dye, CS (1)
8	RWDH	1x1 rib	1/26	3.06	winch dye, CS (1)
9	RWDH	1x1 rib	1/34	2.67	winch dye, CS (1)
10	RWBT	1x1 rib	1/30	2.85	winch bleach, CS (2)
11	RWBT	1x1 rib	1/34	2.67	winch bleach, CS (2)
12	RMJDH	1x1 rib	1/34	3.50	mercerise (1),jet dye, CS (1)
T-Shirts					
13	IJDH	interlock	1/34	3.07	jet dye, CS (1)
14	IJDH`	interlock	1/34	3.59	jet dye, CS (1)
15	IJDH	interlock	1/42	3.07	jet dye, CS (1)
16	IMJDH	interlock	1/34	3.77	mercerise (1), jet dye, CS (1)
17	IMJDH	interlock	1/42	3.77	mercerise (1), jet dye, CS (1)
18	IWDH	interlock	1/42	3.07	winch dye, CS (1)
19	RMWBT	1x1 rib	1/30	3.26	merc. (1), winch bleach, CS (2)
20	RMWBT	1x1 rib	1/34	2.67	merc. (1), winch bleach, CS (2)
21	RMJDH	1x1 rib	1/26	2.67	mercerise (1), jet dye, CS (1)
22	RJDH	1x1 rib	1/26	2.85	jet dye, CS (1)
23	RWBT	1x1 rib	1/26	3.06	winch bleach, CS (2)

Tubular mercerise (1) Omez; CS (1) = compressive shinkage on a Hunt and Moscrop machine, CS(2) = compressive shrinkage on a Tubetex machine; jet dye in a Thies R-95.

5.2, Reference 43

Fabric Reference		Fabric Type	Yarn (Ne)	S.L. mm	Finish
1	RibD	1x1 rib	1/30	2.83	dye

6, Reference 47

Fabric Reference		Fabric Type	Yarn (Ne)	S. L. mm	Finish
1	SJ1JD	single jersey	1/30	2.80	jet dye
2	SJ1JDX	single jersey	1/30	2.80	jet dye, crosslink

APPENDIX B

1. IIC Reference Relaxation Procedure

2. Determination of Dimensional Change

IIC REFERENCE RELAXATION PROCEDURE FOR 100% COTTON KNITGOODS

1. PRINCIPLE

A fabric is relaxed by being subjected to one cycle of washing and tumble drying followed by four consecutive cycles of rinsing and tumble drying, then conditioning in the standard atmosphere. At the end of the specified procedure the fabric is defined as being in its "Reference State".

2. APPARATUS

2.1 Front loading automatic domestic washing machine (e.g. Hoover).
2.2 Domestic tumble drier (e.g. Hoover).
2.3 Domestic automatic washing powder (e.g. Persil).
2.4 Scales.
2.5 Means for providing the standard atmosphere for testing textiles specified in B.S. 1051 and ISO 139; $65\pm2\%$ RH at $20\pm2^{\circ}C$

3. TEST SAMPLES

3.1 Samples for relaxation should be between 45 cm and 70 cm square and of single thickness. Selvedges and crease marks should be avoided.
Sufficient specimens of appropriate dimensions should be prepared from the sample to allow for those tests required to be made on Reference State fabric to be carried out according to the appropriate methods. Five specimens 70x70 cm are usually sufficient.

4. LAUNDERING

4.1 Washing Cycle

It is important to ensure that the first cycle of the relaxation procedure is a full length hot wash with detergent to ensure thorough wetting of the specimens and removal of loose dirt, waxes and grease.

For domestic automatic washing machines this is achieved by using the 60°C wash cycle, the International Textile Care Labelling symbol for this wash cycle is

4.2 Rinse Cycle

Subsequent cycles are designed to ensure thorough rewetting of the specimens before drying and this can be achieved conveniently by using the rinse only cycle.

4.3 Sample Load

It is important to maintain a standard load weight in the washing machine. Domestic automatic washing machines normally specify a recommended load for absorbent materials, e.g. 2.75 kg for Hoover.

4.4 Makeweights

Makeweights, if required, should be assembled from 100% cotton knitted fabric specimens of similar construction, weight, finish and dimensions as those specimens under test.

4.5 Washing Powder

A normal domestic automatic washing powder can be used in the first full washing cycle. Use the quantity recommended by the manufacturer. Do not use a detergent which contains softener or fabric conditioner.

5. DRYING

To achieve the Reference State with reliability and consistency it is essential that the test specimens are thoroughly dry, i.e. contain only a minimum amount of residual moisture ($<2\%$), on leaving the tumble drier. Cotton knitgoods continue to relax as residual moisture levels fall below normal regain. Therefore fabrics which have not been thoroughly dried may not have developed their maximum shrinkage potential and achieved their fully relaxed dimensions.

To ensure that this minimum moisture level is achieved it is necessary to determine the length of time required to bring the load to a constant dry weight prior to testing.

5.1 Drying Time

5.1.1 Weigh a standard conditioned load of specimens of either the same or similar construction to the sample load being tested and carry out a standard 60°C hot wash with long spin (Ref. 4.1).

5.1.2 On completion, transfer the load to the tumble drier and tumble dry at the hottest temperature setting for a nominal period of time, e.g. 60 minutes.

5.1.3 Remove load and weigh it.

5.1.4 Return load to the tumble drier and continue tumbling at the highest temperature for a further 10 minutes.

5.1.5 Remove load and weigh it.

5.1.6 Repeat 5.1.4 and 5.1.5 until the weight of the washed and tumble dried load remains the same.

5.1.7 Drying time is the length of time taken to reach the stable weight plus 10 minutes cool down period, i.e. continue tumbling for 10 minutes with the heat turned off.

6. TEST PROCEDURE

6.1 Prepare the specimens as described in 3.0.

6.2 Weigh the test specimens and where necessary make up the load to the standard weight (e.g. 2.75 kg) with makeweights as described in 4.4.

6.3 Place in the washing machine, add the recommended amount of washing powder to the dispenser and set the machine to wash at 60°C with long spin (e.g. final spin at 800 rpm for 4 minutes).

6.4 On completion of the washing cycle, transfer the load to the tumble drier and tumble dry at the highest temperature setting until dry (Ref. 5.1).

6.5 On completion of the first tumble drying cycle return the load to the washing machine and using the rinse-only cycle, (including final spin at 800 rpm for 4 minutes), thoroughly re-wet the load.

6.6 On completion return the load to the tumble drier and tumble dry for the same length of time as was established in 5.1 and used in 6.4.

6.7 Repeat 6.5 and 6.6 three more times.

6.8 After completion of the full 5 cycles, condition the test specimens in the standard atmosphere until they have reached equilibrium.

6.9 Test specimens are now defined as being in the Reference State.

7. REFERENCES

B.S. 1051: 1981; ISO 139 - 1973.

B.S. 4661: 1984; ISO 6330 - 1984, Method 2A.

Figure 1

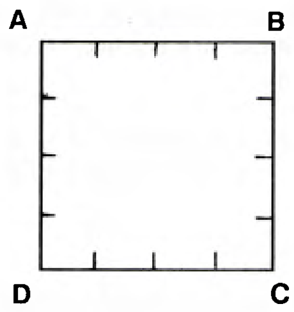
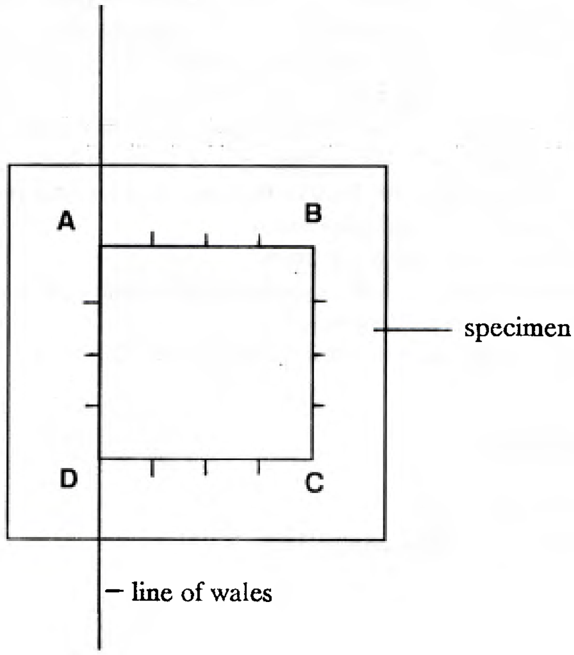


Figure 2



DIMENSIONAL CHANGES INDUCED IN 100% COTTON WEFT KNITTED FABRIC DURING A SPECIFIED WASHING PROCEDURE

1. PRINCIPLE

A fabric is subjected to a specified washing procedure, dried under the appropriate conditions and any changes in dimensions determined.

2. APPARATUS

2.1 Means for providing the specified washing and drying conditions.

2.2 Two Perspex templates:
a) 25x25 cm
b) 50x50 cm
both having equidistantly located measuring marks on all sides (Figure 1).

The markings on AD are opposite to those on BC (width measurement) and the markings on AB are opposite to those on DC (length measurement).

2.3 Ruler and indelible pen.

2.4 Means for providing the standard atmosphere for testing textiles specified in B.S. 1051 and ISO 139; 65±2% RH at 20±2°C.

3. TEST SAMPLES

Samples should be sufficiently large to enable five test specimens of single thickness to be prepared of 70x70 cm or six test specimens of 45x45 cm. They should be spaced to give a good representation of the sample avoiding selvedges and crease marks.

3.1 Specimen preparation

3.1.1 Condition the test sample in the standard atmosphere for testing textiles (Ref. 2.4) until it has reached equilibrium.

3.1.2 Lay the sample on a flat horizontal surface, removing wrinkles without stretching.

3.1.3 Prepare the test specimens from the sample, spaced to give a good representation, avoiding selvedges and crease marks. Each specimen should be a minimum of 20 cm larger in each direction than the required size of template, e.g. 25x25 cm template - specimen size 45x45 cm. 50x50 cm template - specimen size 70x70 cm. Prepare six test specimens if the smaller template is being used, five specimens if the larger template is being used. Where sample size permits the larger template should always be used.

3.1.4 Place the required size of template centrally on a specimen so that the edge follows a wale line.

3.1.5 Define the test area by drawing round the template, marking the position of the measuring marks. Remove the template and clearly define the measuring marks on each side of the square ABCD (Figure 2).

3.1.6 Measure and record the distance between the three pairs of measuring marks for width and the three pairs for length.

3.1.7 Repeat 3.1.4 - 3.1.6 for the remaining four or five specimens in turn.

4. TEST PROCEDURE

4.1 Prepare specimens as described in 3.1.

4.2 Subject specimens to the specified washing and drying procedure.

4.3 After completion of the specified washing and drying procedure lay the specimens on a flat horizontal surface, removing wrinkles without stretching.

4.4 Condition the specimens in the standard atmosphere for testing textiles (Ref. 2.4) until they have reached equilibrium.

4.5 Remeasure and record the distances between the three pairs of measuring marks for width and the three pairs of measuring marks for length.

5. CALCULATION OF RESULTS

5.1 For each of the three width measurements, calculate the change in width caused by laundering and express it as a percentage of the original width. Calculate the average of the three to two decimal places. For each of the three length measurements, calculate the change in length caused by laundering and express it as a percentage of the original length. Calculate the average of the three to two decimal places. Calculate the mean percentage changes in width and length by averaging over the five or six specimens.

5.2 Indicate an extension by using the prefix Ext.

5.3 Report the results correct to one decimal place and state the specified washing and drying procedure.

6. REFERENCES

B.S. 1051: 1981; ISO 139 - 1973.
B.S. 4931: 1986; ISO 3759 - 1984.
B.S. 5807: 1987; ISO 5077 - 1984

APPENDIX C

LOW SHRINK COTTON KNITS

Heap, S.A., Leah, R.D., Stevens, J.C.

(paper given to the Textile Institute Annual World Conference)

LOW SHRINK COTTON KNITS

S.Allan Heap, Robert D.Leah, Jill C.Stevens

1. INTRODUCTION

Cotton is still the world's most important single textile fibre with an annual consumption of more than 18 million tonnes. In spite of fierce competition from man made fibres, cotton consumption continues to grow steadily so that the present level of utilisation is more than 30% greater than that of 10 years ago (Fig 1). The required growth in production has been achieved without any increase in the area of farm land, which indeed has been almost constant since the 1950's, due to large increases in the productivity of cotton farming (Fig 2). There is every reason to believe that the rate of improvement in cotton yields can be maintained well into the next century.

Within this global trend of rising cotton consumption the key markets of Western Europe and Japan, where the International Institute for Cotton (IIC) has been most active, have witnessed the most significant shifts in demand during the 1980's. For example, according to the United Nations Food and Agriculture Organisation, between 1981 and 1987 the amount of cotton available for final consumption in the IIC programme area rose by some 1.22 million tonnes, or by 51.2%, while its market share grew from 35.9% to an estimated 43.5% (Fig 3).

When we think of the technical and quality control problems involved in the production, distribution, and processing of cotton compared to those of a synthetic substitute and, furthermore, when we consider the relatively massive amounts of highly focussed research, marketing, and technical service which are applied to competing fibres, the continued growth in consumption of cotton may be seen as rather surprising.

The explanation is very simple : **people prefer cotton.**

It is apparent that cotton has some outstanding attractions, of which the most important is generally said to be its comfort. This does not mean that there are no negative aspects to the fibre or to some of the fabrics and garments made from it. Indeed there are several and the one which is generally quoted by consumers in connection with cotton knitted fabrics is shrinkage. However, basic research and development work, carried out over the last decade and more by the IIC, has shown that there is, in principle, no good technical reason why consumers should be made to put up with high levels of shrinkage in cotton knits any longer.

2. THE CENTRAL DILEMMA

There is a central dilemma in the production of low shrink cotton knits which has been expressed recently by the typical demand of some retail stores to their suppliers and can be simplified into a statement such as the following.

> "*We want the shrinkage reduced by several percentage points but we want the weight and width to stay the same.*"

Now any cotton knitgoods finisher will tell you that he can improve the shrinkage of almost any existing fabric quality but that this can not be achieved whilst maintaining the same weight and width. Indeed it is self evident that, unless the basic knitting quality is changed, a reduction in length and width shrinkage can only be obtained by delivering the fabric shorter and narrower (unless resin finishing is used, which brings its own problems). However, the garment cutters are generally not prepared to accept the lower yield and the narrower width, and the retailers are apparently not prepared to pay the extra cost of such a fabric.

It therefore follows that the first requirement in developing a low shrink cotton product is that the basic knitting quality has to be changed. This is not as simple as it sounds if the development has to be based on the trial and error methodology which is typical of most of the knitgoods industry today. Fortunately, a computer programme is available which allows product development trials to be simulated for a wide range of standard fabric types within a short time and without the use of production resources. Thus the manufacturer can rather quickly and easily discover whether a given set of quality targets is actually attainable, and how to achieve them.

In the second place, it turns out that, when the required shrinkage levels are very low, then conventional finishing technology reaches its limits and new systems have to be considered which means new machinery investment. Fortunately again, a much better understanding has been acquired over the last few years of what is needed from finishing machinery in order to produce fabrics with very low shrinkage levels and the appropriate machinery and know-how is fast becoming available.

However, in order to maintain the width of low shrink fabrics at levels which suit the garment cutters, it may be necessary for the knitters to acquire wider knitting machines, or for the garment makers to develop new cutting lays to accommodate a different width. The garment makers may also have to change the sizing and grading of their garments to allow for the fact that shrinkage will be less and extensibility may be different. Finally, the knitters may find that the ideal yarn counts required for some of the new qualities are non standard ones which the spinners may be reluctant to produce in the relatively small quantities which are required at the beginning of such a development.

Therefore, it seems that a final solution to the problem of shrinkage in cotton knits does not depend on any one sector of the industry and, indeed can not be achieved without the cooperation of all, from the spinner to the retailer.

Within the scope of this paper it is neither possible nor desirable to go into all of the factors mentioned above, so attention will be focussed on three key questions, namely :-

1) What do we really mean by "Low shrink"?

2) How do we set about re-engineering our basic fabric qualities?

3) What kind of finishing technology will be required?

3. WHAT IS LOW SHRINK ?

A good place to start when trying to decide on performance standards is the requirements and the experiences of the ultimate consumers. However different consumers will experience different levels of shrinkage in a given product depending on their habits of laundering and care. A person who habitually uses a tumble dryer and does not iron will always see higher levels of shrinkage than one who dries the washing on a clothes line and then irons it. The amount of shrinkage which occurs in a tumble drier will be less if the garment is removed at slightly above normal regain than when it is overdried. With a mixed wash load it is often the case that some garments will emerge from the drier with a higher moisture content than others. For certain fabrics, the difference between line dry and tumble dry shrinkage can be very large but a garment which has been tumble dried will usually gain in length if it is subsequently washed and line dried (Fig 4). All of this tends to make it rather difficult to decide what is an appropriate level of shrinkage to set as a target for a low shrink product. It also implies that there may be several different testing standards for the measurement of shrinkage which have to be applied at different stages in the development, manufacture, and marketing of a new low shrink product.

For example there should be one standard which delivers information about the maximum shrinkage that a garment will ever experience at the hands of the consumers in any given market. If the given market is one where tumble driers are likely to be used, then the standard will have to include several cycles of laundering and tumble drying. This could be the method which we call our Reference Relaxation Procedure which uses five cycles. Such a lengthy procedure is obviously too expensive for use as a routine quality control test in the manufacturing industry, but it is important to establish what will be the ultimate shrinkage potential of the new product as early as possible during the development phase. There are many retailing companies and fabric purchasers who are still assessing the shrinkage potential of their products by using a single cycle wash and line dry or flat dry test. They are deluding themselves and they are holding back progress in the industry because a problem which is kept under the carpet is one which will never be solved.

In addition, an industrial standard is required for routine control of manufacturing targets. For such a standard, we also recommend that tumble drying should be included whether or not the product is intended for a market where tumble driers are expected to be used. This is mainly on the grounds of reproducibility but also for speed and convenience. Many companies have adopted an industrial QC test involving a single wash and tumble dry cycle, though quite a few companies are using two or even three cycles. It is important to note that tumble drying should be allowed to proceed until the fabric is dried to well below normal regain, not only to develop the full shrinkage but also to improve the reproducibility of the test method. Here again many companies have still not adopted the tumble dryer for routine QC testing and seem to be unaware of the fact that a line dry or flat dry test is usually much less reliable and reproducible than tumble drying.

It will of course be necessary to establish the relationship between the shrinkage as delivered by the industrial QC test and the ultimate potential shrinkage for any given low shrink product. For many markets, it may also be necessary to establish the ultimate shrinkage which results from a test which does not involve tumble drying. IIC has carried out a large number of trials comparing different shrinkage test methods on a wide range of fabrics so that we are in a position to offer advice on these relationships.

None of this tells us what the actual levels of the shrinkage targets should be in order to qualify for the description "Low Shrink". Here again, the situation is not simple. For example if a target of zero is set for the ultimate shrinkage then it is certain that the finisher will have extreme difficulty in actually delivering such a fabric. In addition, the fabric will tend to extend during garment manufacture and any consumer who does not actually use a tumble dryer will find that the garment will tend to grow in size during use. On the other hand, if a fixed positive level of ultimate shrinkage, say 5% in length and width, is set as a target for all fabric types then this would probably work perfectly well for plain jersey fabrics but not for interlock or lacoste.

A crucial question also is how the sizing of the garment relates to the actual body size of the (largest) person who will wear it. For a close fitting garment the relationships between fabric shrinkage, fabric extensibility and the reduction in length caused by extension in width should all be taken into account when deciding on the garment size for a given body size range. With a fabric which has a very high extensibility in the width, such as 1x1 rib, a somewhat higher width shrinkage can be accomodated without any complaint from the consumer.

A further, and most important consideration is whether the target shrinkage is to be specified as a maximum value or an average. It is an inevitable consequence of the normal random fluctuations in manufacturing parameters that there will be random variation in the final (fully relaxed) dimensions of the finished fabric. When the number of courses per cm and the width of the fabric are being controlled at more or less constant levels, as is normal in a well run finishing operation, then all of the random production variations - especially variation in yarn count and stitch length - will manifest themselves as variation in weight and shrinkage (Fig 5). In addition there is unavoidable variation in the shrinkage test itself which, depending again upon the fabric type and the finishing process, can be anything up to three percentage points even for a well controlled testing procedure (Fig 6). Thus a target of 5% average shrinkage means a probable range, over a long series of deliveries, of at least 3% to 8% and maybe more.

Therefore, there is no simple definition of "Low Shrink". What we at IIC take it to mean is that shrinkage levels have been brought down significantly from those disastrously high historical levels, which only a few years ago were commonly well over 10% in the length and often more than 20%. However we do not expect it to mean zero ultimate shrinkage, because of the problems mentioned earlier.

Depending on the fabric type, and sometimes the finishing process, we expect it to mean somewhere in the region of 5 to 8% average shrinkage to a two cycle wash and tumble dry test. Judging by the reports we have had from manufacturers and retailers, fabrics delivered with shrinkages in this range will perform well and will not generate complaints from consumers.

4. ENGINEERING THE FABRIC

Once the shrinkage targets have been set, it is necessary to decide on the basic knitting quality. Normally one will be working under the severe disability of having an existing fabric quality which the customer wants to match in weight and width but with reduced shrinkages.

In order to maintain the weight at lower shrinkage it will usually be necessary to have a finer yarn. In order to maintain the width, one needs a larger knitting machine diameter or a longer stitch length. In order to maintain the same tightness with a finer yarn, one needs to have a shorter average stitch length. Changes in yarn count and stitch length also change the number of courses and wales per cm in the relaxed state, which also changes the weight and width for a given level of shrinkage. They may also change the extensibility of the fabric and the amount of length contraction which occurs at a given level of width extension. For single jersey fabrics, a change in yarn count and fabric tightness will also change the spirality. Finally it should be noted that a change in tightness may affect the amount of difficulty that the finisher will have in meeting his targets - a tight fabric is generally easier to finish than a slack one. Every change has more than one consequence, so it is not always easy to predict what will be the result of a given change in the basic fabric design parameters.

There are some empirical equations in the literature (Fig 7), based on the so called dimensional constants or K factors, which will give a rough guide to the effects of changes in stitch length upon course and wale densities. As a rough guide these simple equations can be quite helpful but they do have serious limitations. For example they mostly refer to grey state fabrics made from average yarn counts knitted to average stitch lengths so that they are rather inaccurate for many practical finished fabrics. The K factors given in Figure 7 have been derived from our own early experimental work and they do account for some of the effects of wet processing. Nevertheless, the accuracy of K factor type calculations leaves a lot to be desired.

For this reason IIC has developed a new series of semi empirical equations for predicting the course and wale densities of relaxed fabrics, which can take account of changes in yarn count, stitch length, and wet finishing process, for a very wide range of single jersey, 1x1 rib, and interlock qualities. They have been derived from thousands of test data from hundreds of full scale knitting and finishing trials. What is more important from a practical point of view is that the equations have been built into a user friendly computer programme which can be used for rapid simulation of almost any fabric development project. This means that predictions for weight, width, and shrinkage can be obtained within minutes for any number of specified qualities within the three basic fabric types.

The early evolution of the STARFISH project has been well described in the literature and will not be repeated here. What should be mentioned, perhaps, is the fact that the basic STARFISH equations have undergone a third phase of development in the last couple of years so that they are no longer of the same form as those which were reported in the earlier literature. The new equations are much more accurate over a wider range of yarn counts and wet finishing processes and they allow some interesting new possibilities in terms of computer programming, not all of which have yet been explored. Preliminary equations are also available for a limited range of lacoste type fabrics and we have some prototype equations for predicting spirality and extensibility but none of these have yet been embodied in the computer programme. A new version of the programme is under development and will be available in 1990.

For the purposes of the present discussion we need only note that the re-engineering of the basic fabric quality, to arrive at an appropriate knitting specification for a low shrink product, is most conveniently carried out by recourse to the STARFISH computer programme. Within minutes it is possible to establish whether a particular set of targets can in fact be achieved in principle, or what compromises will have to be made by which sector of the production chain in order to arrive at something that is both acceptable and workable. The elimination of non-starters from the list of possible knitting qualities (and therefore from actual development trials) is probably the single most useful and cost effective aspect of the STARFISH programme. It has been calculated that, as a result of this feature alone, the cost of both computer and software can be saved after as few as three to six fabric development projects.

5. FINISHING TECHNOLOGY

Having set the targets and designed an appropriate knitting quality, it remains for the finisher to actually deliver the fabric at the desired weight and width. If the knitting quality has been properly specified, then the shrinkages will be correct when the target courses and width are achieved. However it should be borne in mind that the final weight (and maybe also the shrinkage) will be affected to some extent by variations in the dyeing and finishing route. For example, a fabric which receives a minimal scour followed by dyeing to a very deep shade will be heavier than one which is thoroughly scoured and bleached then dyed to a pastel shade. Moreover, a fabric which has been prepared and dyed by a high tension pad batch route will have different course and wale densities in the relaxed state than one which was dyed in a low tension jet machine. It therefore will exhibit different shrinkages even though it is finished to the identical number of courses per cm and the same width. Finally it must be appreciated that the finisher is critically dependent on the knitter actually maintaining the knitting specification to very close tolerances. Variations in the yarn count and the stitch length will translate directly into variation in shrinkage, as was pointed out earlier. Such considerations should have been foreseen and discussed with the customer in terms of the allowed tolerances for the final finished quality as a whole.

The finisher's targets are stated in terms of the final course density and the width because these two are the only practical parameters with which he can exert continuous quality control during production (as opposed to post mortem measurements). In order for the finisher to stand any chance of meeting his targets for low shrink cottons there is one basic guiding principle which must be remembered. It can be summed up in the phrase:

"Low shrink cotton knits are thick."

In other words, in order for the finisher to develop a product with low shrinkage, it will be necessary to develop the thickness of the fabric. This is not quite as simple as it may appear at first sight when we consider how many times in a conventional finishing line the cloth is pulled out in length or in width, and how the final process almost always involves passage through a pair of calender rollers whose function is to press (ie flatten) the fabric so that it presents a nice smooth appearance.

The most effective way to develop the thickness of a cotton fabric is by tumble drying and, furthermore, the thickness is developed most rapidly during that part of the drying process when the moisture content lies below about 35% (Fig 8). For some fabrics, eg interlock, lacoste, a single cycle of wetting and tumble drying is not sufficient to develop the full thickness which means that two or more tumblings at the sensitive moisture level may be required. The particular wet processing route which has been used can also have an influence upon how easy it is to develop thickness - the most extreme case of this being mercerisation. A good indication of how difficult it will be to develop the full thickness in a given fabric can usually be obtained by measuring the shrinkage of a conventionally finished sample after washing and line drying, compared with that obtained after a further cycle of washing and tumble drying, and again after five cycles of washing and tumble drying. If the differences between these three test conditions are more than about four percentage points, then the fabric may be difficult to finish to low shrink standards.

Tumble drying is of course not an option for bulk finishing but findings such as these have led to the development of commercial drying equipment which attempts to simulate the type of agitation which is achieved in a tumble dryer. Several drying machine manufacturers have been offering the so called relaxing dryers for some years and we have had direct evidence, as well as indirect reports that they do actually achieve more or less what is claimed for them. However, there are differences between the different makes so the choice of which machine is best for a particular finisher is not simply one of price and productivity.

One problem which remains is that the fabric still has to be calendered after drying. Conventional calenders, even if they are capable of some overfeeding, will inevitably push the fabric out again in the length due to the flattening effect of the nip rolls which must reduce the thickness. Compactors can of course be used as the final stage and this allows the course density to be maintained or even increased. This can be a perfectly good solution for non critical products like white underwear but some of the side effects of compacting, such as colour change, or differences in reflectance, or two-sided effects, or sensitivity to length tensions during garment making are not acceptable for some products. A much better solution for these more critical fabrics is to achieve the required development of thickness and course density at the drying stage followed by a final dressing on a compactor or one of the newer calender/ compactors whose settings are so light that only a bare minimum of the compacting effect is achieved - ie just enough to prevent the loss of courses but not enough that the disadvantages of compacting are manifested.

To be more specific, a typical low shrink finishing process for coloured outerwear might include the following features.

1) Avoid excessive back tension during opening and detwisting after bleaching or dyeing. If the fabric is to be fed to a nip at this stage, then there should be only a minimum of width spreading at the nip, for example by air injection, - just enough to be able to present the fabric neatly to the next stage. Excessive width spreading in front of a nip creates large length tensions and may produce edge creases which are difficult to remove later.

2) Wet spreading as a separate operation from drying because of the potentially large difference in their productivities. The wet spreader should be equipped with an efficient overfeeding device and should have the capability of controlled and uniform rewetting of a dry fabric with about 40% of added water. This is to allow for those difficult fabrics for which a second "tumble drying" may be desirable to develop the required shrinkage, but where complete rewetting is unnecessary and uneconomical. Width setting at this stage depends on fabric type and target finished width. For fabrics with low extensibility, spreading to 15% over the target finished width may suffice. For highly extensible fabrics 50% over finished width may be required. Feeding should be as accurate as possible with enough overfeed so that the length can be taken up without significant back tension developing.

3) A modern relaxing dryer which is set to deliver fabric at below normal regain and is designed so that maximum agitation occurs when the fabric moisture content is below about 40%. Maximum shrinkage is developed at about 2% moisture content so, if the full relaxation is required, the cloth should come out quite warm. The ability to vary the amount of agitation can be useful for finishers who have to cope with many different styles because sometimes the amount of agitation has to be compromised in favour of fabric surface appearance. However, it must be possible to develop enough relaxation so that the width can come in to just below the target finished width. This can only be achieved with a certain level of agitation. If two strands are to be passed through the dryer side by side, then they should be similar fabric types - or at least have similar weights - and have about the same initial moisture content.

4) A compactor or calender/ compactor which is set at close to its minimum compaction force so that almost no compaction occurs but the fabric is prevented from extending in length, while being delivered marginally over the target width.

6. CONCLUSION

A final and comprehensive solution to the problem of shrinkage in cotton knits requires the adoption by the industry of two separate, but interrelated sets of technologies. The first is to do with the capability for rapid prediction of fabric dimensions and performance so that new knitting specifications for low shrink cotton knits can be developed within a reasonable time and at reasonable cost. The second is to do with finishing machinery and techniques which place greater emphasis on the development of the fabric thickness and its maintenance through to the end of the finishing line. Some of the components of these two technologies are relatively new but they are readily available and are being taken up by the more enterprising companies.

However, new technology alone is not enough. There is also a vital requirement for a change in the attitude and the approach of the industry as a whole towards the problem of shrinkage and towards the rational specification of garments made from cotton knits. The fact is that no individual sector - knitter, or finisher, or garment maker, or retailer, can solve all of the problems alone because each action by an individual sector has ramifications up and down the line. Every link in the production chain, from spinner to retailer, must participate in the decisions and must bear its share of the load.

The popularity of cotton in the market, and the desire of the consumers for low shrink cotton knits presents a severe challenge to the cotton knitgoods industry collectively but it also presents opportunities for individual companies or groups within the industry to play a leading role in what ought to be a highly profitable development at the end of the day.

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Figure 1
World Cotton Consumption
Three year averages

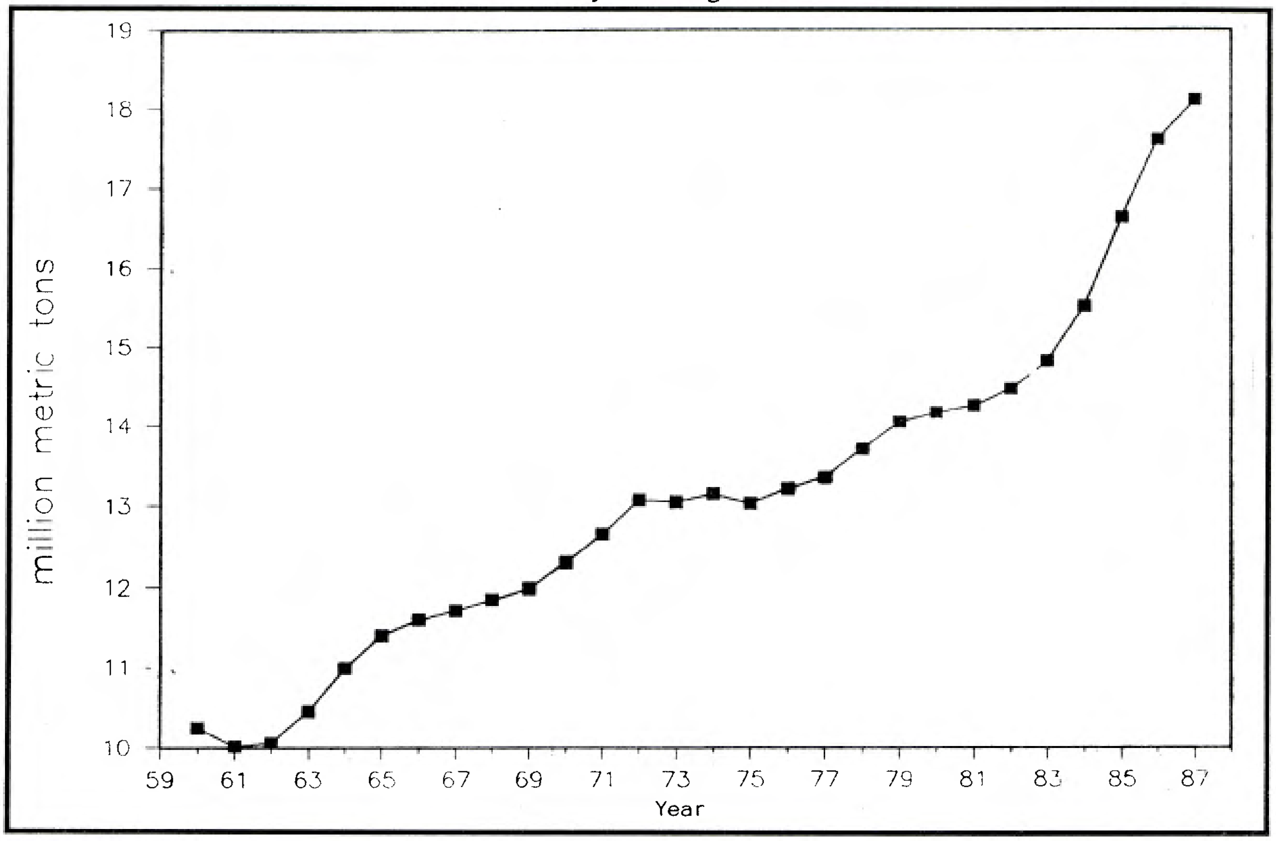

Figure 2
World Average Cotton Yield
Three year averages

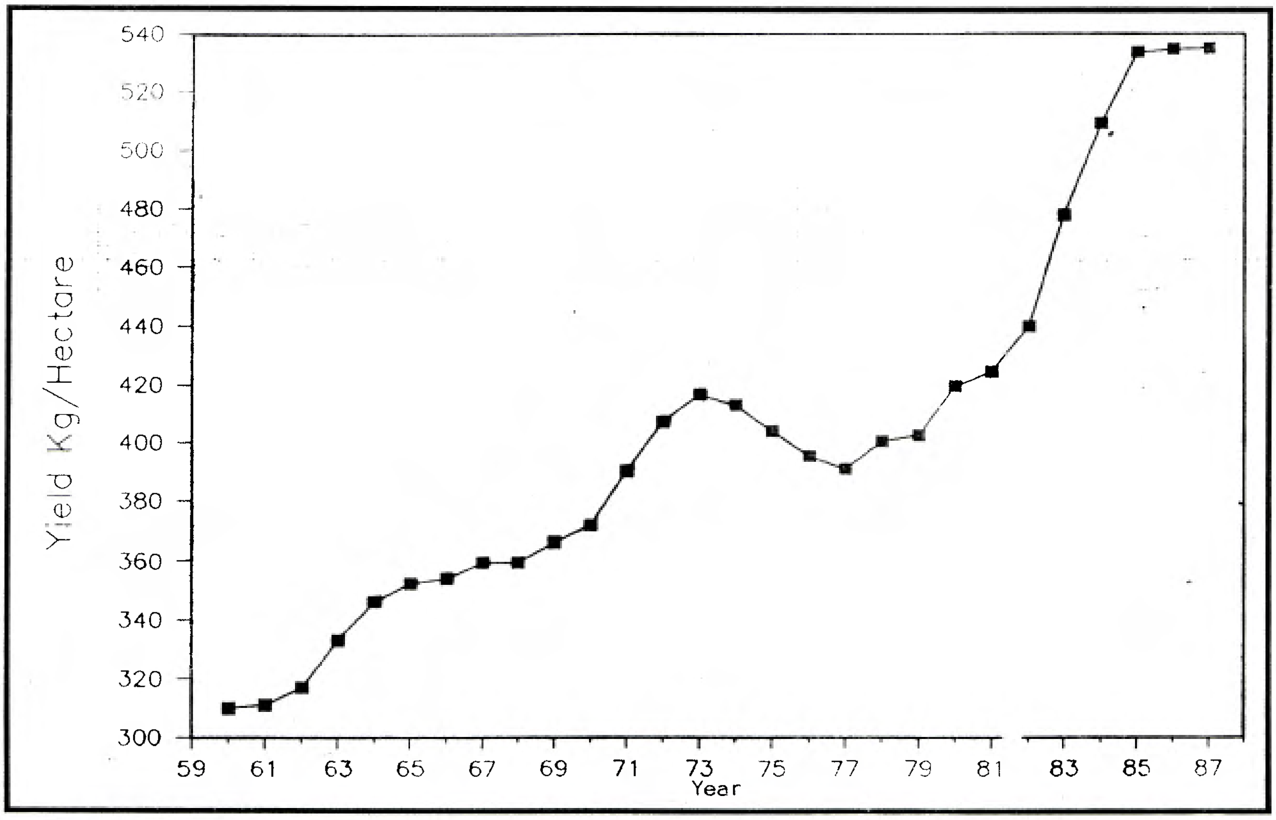

Figure 3
Availability of Cotton in the IIC Programme Area

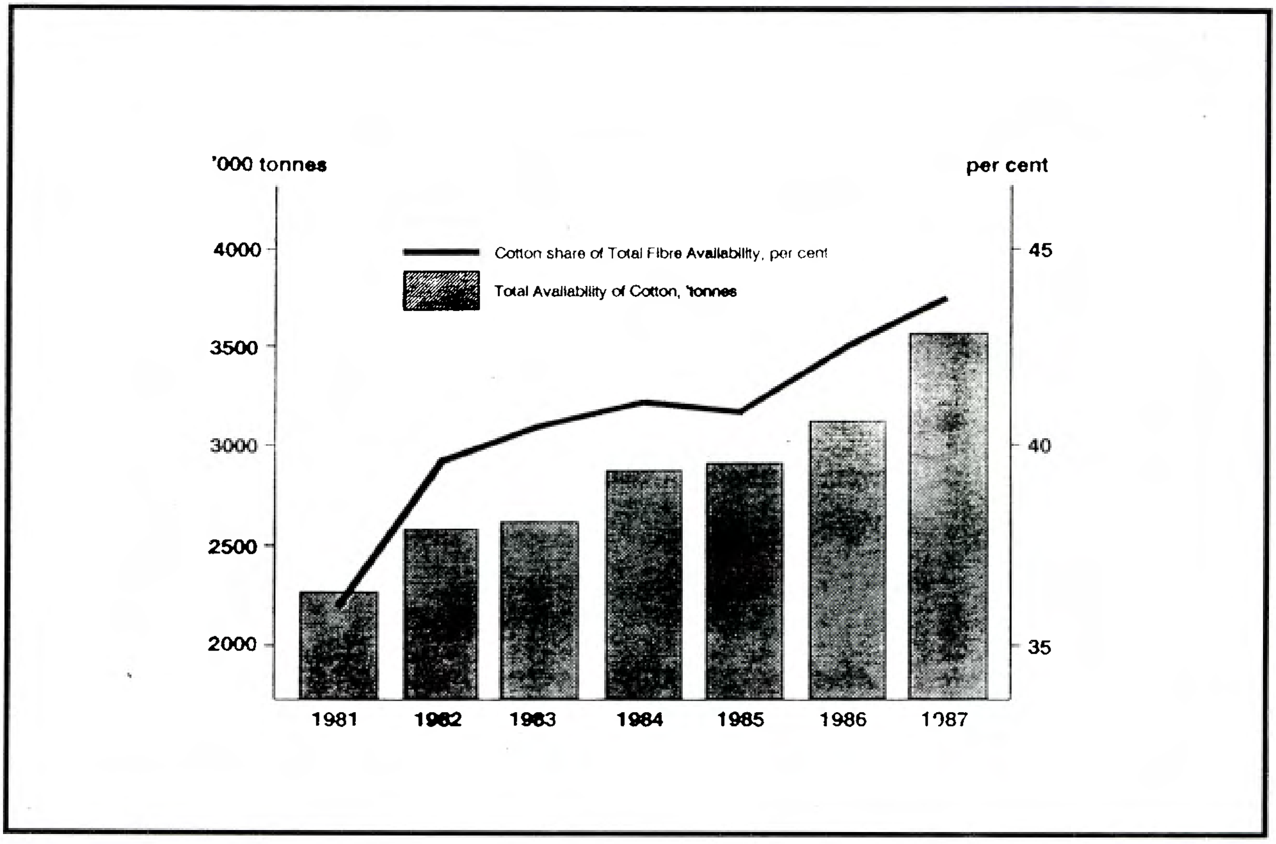

Figure 4
Shrinkage of 1x1 Rib Garments
Effect of Drying Method

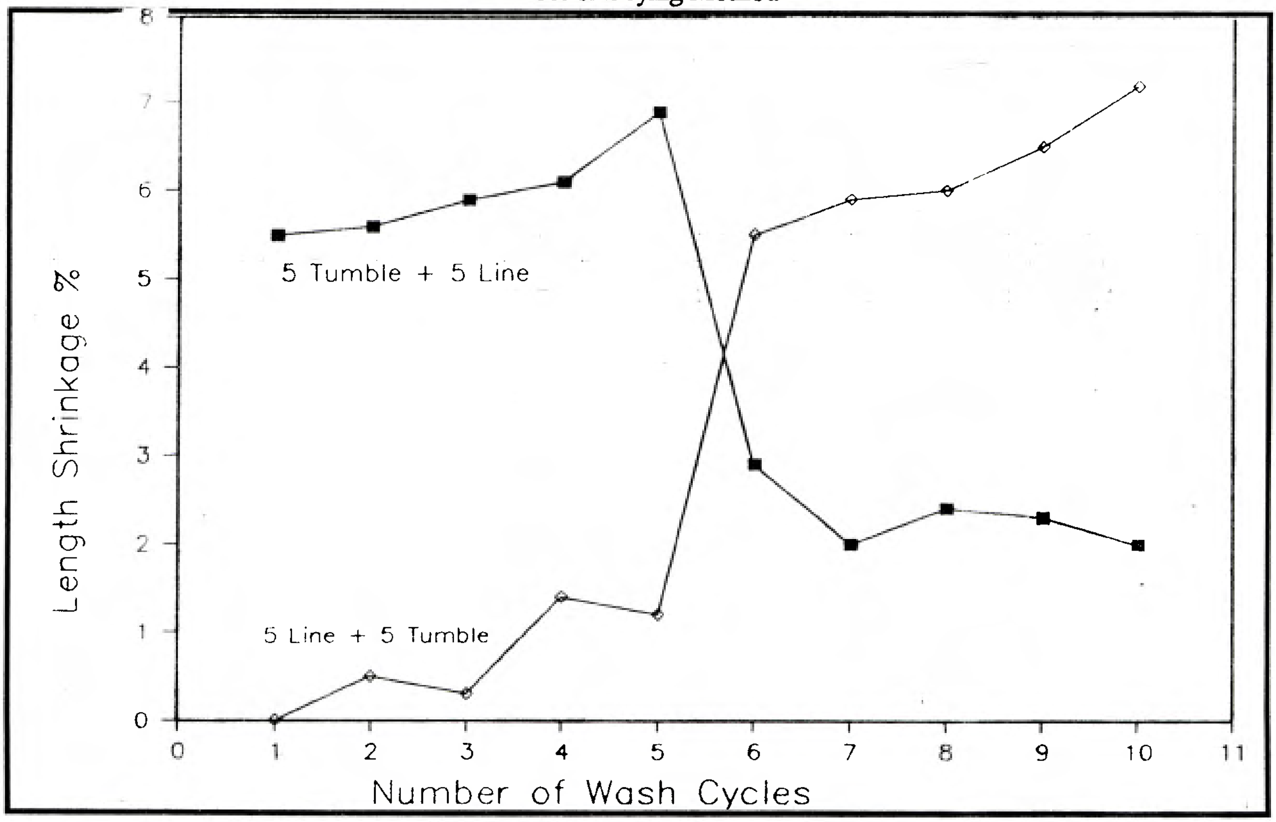

Figure 5

Variation in Shrinkage

Due to Knitting

Nominal quality

28g single jersey

30Ne ± 2.5% 2.82 mm ± 1.5%

Finishing targets

courses/3cm = 57

wales/3cm = 43

Performance	Ave	Min	Max
Length shr. %	5.0	3.0	7.3
Width shr. %	5.1	3.7	6.6
Weight gsm	145	138	151

Figure 6

Tumble-Dry Shrinkage Test

Distribution of 95% Confidence Limits

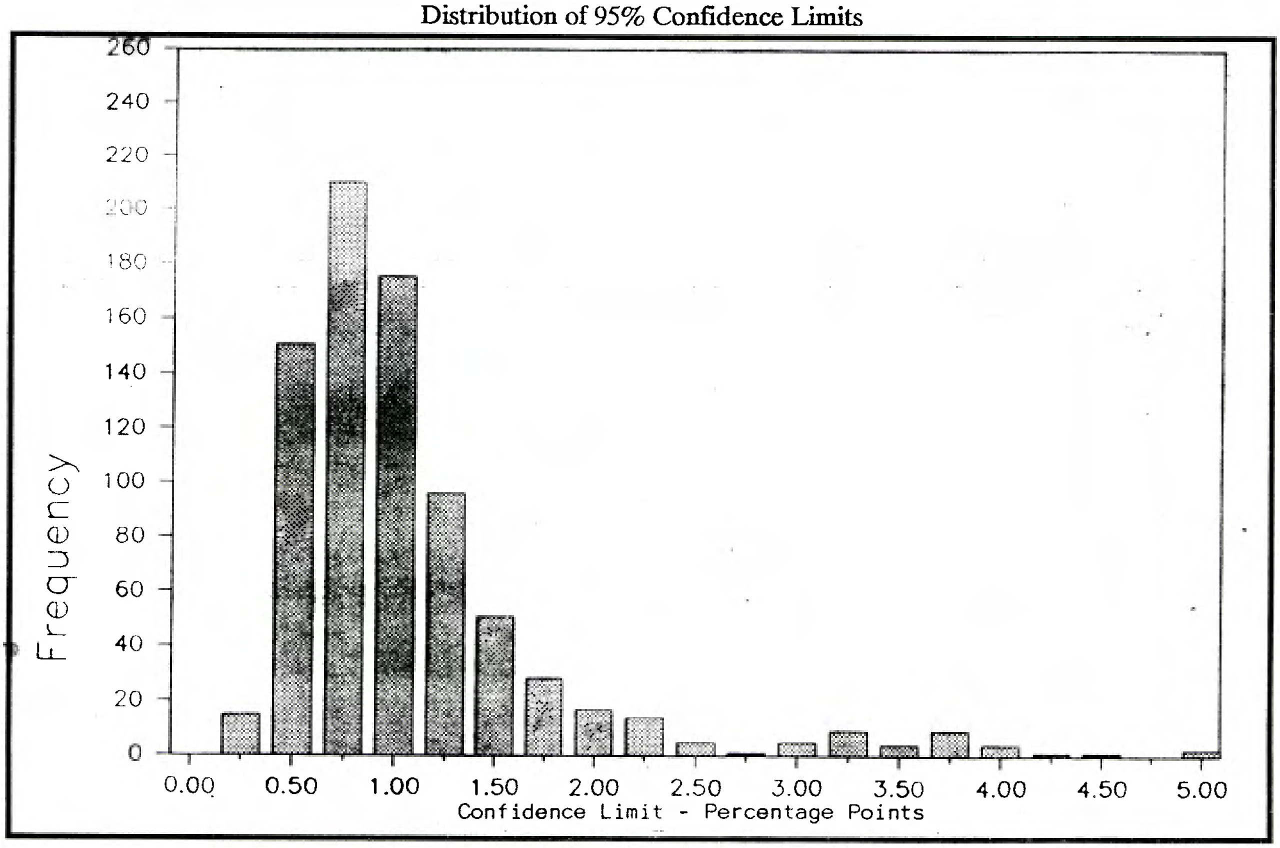

Figure 7

Fabric Engineering Equations

Courses = Kc/St Len   Wales = Kw/St Len

	Jersey	1x1 Rib	Interlock
Kc			
Grey	5.80	5.34	5.61
Dyed	5.44	4.97	5.13
Dyed + Resin	--	4.51	4.46
Mercerised	4.74	4.61	4.59
Merc + Resin	--	4.37	3.95
Kw			
Grey	4.40	3.26	5.02
Dyed	4.26	3.14	4.79
Dyed + Resin	--	3.23	4.90
Mercerised	4.95	3.51	5.29
Merc + Resin	--	3.61	5.41

Figure 8

Shrinkage During Tumble Drying

Bleached Interlock