BACKGROUND PUBLICATIONS

P1 Low Shrinkage by Design

P2 Influence of the Spinner on the Shrinkage of Cotton Circular Knits

P3 Dimensional Properties of Cotton Fleece Fabrics

P4 Shrinkage – You don’t need to Measure it to be able to Control it.

P5 The Effect of Open-End Rotor Yarn Quality
on Dimensions and Shrinkage of Cotton Interlock Fabrics

P6 Shrinkage – If You Can Predict It Then You Can Control It.

LOW SHRINKAGE BY DESIGN
The New STARFISH Software for Cotton Circular Knits

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INTRODUCTION

Knitters, dyers and finishers of cotton circular knitted fabrics are faced with constantly-increasing global competition and ever-rising demands for better quality and reliability. One of the key demands is for fabrics and garments having consistently low levels of potential shrinkage.

Traditionally, cotton circular knitted products have been developed and optimised largely by trial and error methods but these methods will not be good enough for the future because they are too costly and too uncertain.

A modern quality assurance system requires firstly that product performance can be designed in advance by (more or less) exact calculations and, secondly that processing machinery can be regulated by reference to predetermined target levels of key product properties which can be measured continuously, on-line and used in feed-back loops to control some aspect of machinery settings.

For cotton circular knitted fabrics, there are three major requirements for achieving "low shrinkage by design".

1. The fabric has to be correctly engineered for the required performance (appropriate choice of yarn and knitting conditions).
2. Appropriate values have to be specified for the key fabric properties which will be used for process control (finishing targets).
3. The finishing machinery has to be provided with appropriate sensors and regulators.

This paper will discuss mainly the first two requirements from the point of view of the dyer and finisher, although the implications for knitters will be obvious.

In connection with item 3, it should be noted that appropriate sensors and regulators are now on the market, e.g. from Automation Partners (California) and Erhardt & Leimer (Germany). At the last ITMA such devices were being offered as options on a significant proportion of stenters and compactors.

ENGINEERING THE FABRIC

Fabric engineering in the modern sense implies that equations have to be available which can be used to calculate the fabric properties of interest, starting from the known manufacturing and processing conditions.

The known manufacturing and processing conditions comprise:

- The yarn (or selection of yarns) available for knitting.
- The knitting machinery characteristics (essentially, the number of needles).
- The knitting specification (essentially, the length of yarn fed for each revolution of the machine)
- The wet processing and finishing machinery characteristics.

CHECKING THE SPECIFICATION

Normally, the dyer and finisher does not participate in the fabric design and specification exercise. He has to accept whatever fabric is supplied, and he will usually be required to deliver the dyed and finished fabric at a certain weight and width and with certain maximum levels of shrinkage.

If the fabric has not been appropriately engineered, then there is no way that the dyer and finisher will be able to meet all of these requirements. Therefore, it is absolutely essential that the dyer and finisher should be able to check whether the fabric is correctly engineered before he puts it into work. If the dyer and finisher has access to the equations which are used for fabric engineering, then he is able to make such checks.

There are two sources for such equations.

- The so-called K values
- The STARFISH computer program

Calculations Based on K values

The K values were derived from observations made by research workers of more than two decades ago that there is a strong relationship between the number of courses and wales per cm in a relaxed cotton knitted fabric and the reciprocal of the loop length used in knitting (*Figure 1*). Relaxed means after the fabric has been subjected to an appropriate wetting and drying procedure (e.g. a shrinkage test). Loop length is the average length of yarn in each knitted loop. It is given by the length of yarn fed to the knitting machine per revolution (or per pattern repeat) divided by the number of needles which are knitting.

The two basic equations are:

$$\text{Courses per cm} = \text{Kc} / \text{loop length in cm} \qquad [1]$$

$$\text{Wales per cm} = \text{Kw} / \text{loop length in cm} \qquad [2]$$

It was said that Kc and Kw were constants for a given fabric construction and fibre type, and that these K values could be used to calculate the course and wale densities in any fabric, provided only that the knitted loop length is known.

Once we have found the course and wale densities for the relaxed fabric, then these can be used together with the yarn count, the knitted loop length, and the number of needles in the knitting machine to calculate the relaxed fabric weight and width.

$$\text{Wt} = \text{tex} * \text{loop length} * \text{courses} * \text{wales} * \text{F1} \qquad [3]$$

$$\text{Width} = \text{Number of needles} / \text{wales} * \text{F2} \qquad [4]$$

Where

F1 and F2 are scaling factors, depending on the units of measurement.

Courses and wales, weight and width in the unrelaxed fabric (i.e. as delivered to the customer) can then be derived by proportional scaling, according to the appropriate level of shrinkage.

$$\text{Length Shrinkage} = (\text{Cr} - \text{Cd}) / \text{Cr} \qquad [5]$$

$$\text{Width Shrinkage} = (\text{Wr} - \text{Wd}) / \text{Wr} \qquad [6]$$

Where

Cr and Wr are the relaxed courses and wales, Cd and Wd are the as-delivered values.

If the calculated as-delivered weight and width values do not coincide with what the customer has specified, then the fabric has not been correctly engineered, and this is a matter for serious discussion between the dyer and finisher and the customer.

If the calculated weight and width do coincide with the customer's requirements, then the calculated values for as-delivered courses and wales provide the dyer and finisher with his primary finishing targets. If he can hit these values in the delivered fabric, then the calculated weight and width, and the shrinkage values used in the calculation are guaranteed.

The finishing targets can be used as the basis for setting and operating control systems on stenters and compactors, which will aid the finisher in achieving his targets, and thus the required fabric performance. In practice the width will be used in preference to the number of wales per cm for control purposes, but there is no satisfactory substitute for courses per cm as the primary length control parameter.

Since the yarn count and loop length should be known from the knitting specification, it would seem to be a simple task for the dyer and finisher to check that a given grey fabric has been correctly engineered so that the weight, width and shrinkages required by the customer can actually be delivered. Kc and Kw values can easily be picked up from the literature, or can be determined on the grey fabric already to hand.

Limitations of K values

Unfortunately, it is now known that Kc and Kw are actually not constants. They are affected quite significantly by several factors including especially certain aspects of the yarn specification, and any wet processing which may have been carried out on the fabric. For example, K values for plain jersey fabrics which have appeared in the literature over the last two decades range from 5.1 to 5.8 for Kc and 4.1 to 4.95 for Kw. This range of variation is not some kind of experimental error. It is a reflection of real differences in K values, due to differences in the experimental conditions used by the various workers. It also represents approximately the range of K values which we have found in our own experimental work.

Some of these effects are illustrated by *Figures 2 and 3* which show the influence of the knitted Tightness Factor and wet processing on the values of Kc and Kw for a wide range of plain jersey fabrics, knitted from seven different yarns. Tightness Factor is given by the square root of the yarn count in tex divided by the Loop Length in cm. There are relatively large differences between the K values for grey fabric and those for the two sets of finished fabrics, and the wide scatter in the data, within a given wet process, is a reflection of the influence of the yarn properties upon the K values. In this context, it should be noted that a difference of only 0.1 unit in Kc represents a difference in length shrinkage of about two percentage points; a similar difference in Kw represents two and a half percentage points of width shrinkage.

Therefore, a dyer and finisher who wants to make use of simple K values to check for correct fabric design, or to develop finishing targets, should take care to use the appropriate values. Because the K values are affected by the wet process, he would be well advised to carry out determinations of courses and wales on his own finished fabrics. It is definitely not the case that he can determine K values on the grey fabrics and use these for making calculations. Indeed, the only value for the dyer and finisher in making measurements on grey fabrics is to ensure that the yarn count and loop length are exactly as specified.

Figures 4 and 5 show the dangers of using inappropriate K values for such calculations. The data behind these graphs comes from one of many STARFISH data base projects. In this case, six different yarns were each knitted at five different loop lengths, covering the normal commercial range of tightness factors, and a seventh yarn was knitted at three different loop lengths. Several rolls of all 33 qualities were produced, and the fabrics were processed, full scale, at several different dyeing and finishing plants. In other words, these are not small-scale laboratory trials, they are fully representative of commercial conditions. Results from only two of the wet processing routes are shown.

Kc and Kw were determined on the grey fabrics and their averages were computed. These averages were then used to calculate courses and wales for the dyed and finished fabrics using equations [1] and [2]. The graphs compare the calculated values with those actually measured on the finished fabrics. This is approximately what would happen if K values were taken from the literature or if they were determined on the grey fabric before putting it into work. The straight line on these graphs shows where Y = X, i.e. where calculated = measured and the error is zero.
It is clear that this is an unsatisfactory way to check a fabric specification, or to determine the correct finishing targets. Errors in estimation of more than ten percent are apparent. Since the dyer and finisher will be asked to deliver fabric with a shrinkage of less than about five percent, a potential error of ten percent is quite intolerable.

Figures 6 and 7 show the considerable improvement that can be gained by using Kc and Kw values which were determined on the finished fabrics rather than the grey. Separate estimations of Kc and Kw were made for each of the two different wet processing regimes. This amounts to a kind of calibration of the K values, so that they are representative of the dyer and finisher's own particular situation. However, even in this case there is still a fair amount of scatter in the data. Part of this will be due to measuring errors but still there is cause for concern, particularly in the case of the wales where errors of more than five percent are frequent.

THE STARFISH COMPUTER PROGRAM

The STARFISH computer program is founded on a database which, at the time of writing, comprises test data on more than 5,000 separate fabric qualities, and is still growing year by year. Almost all of the data come from fabrics which have been manufactured and processed at full scale. These data are mainly of two types. Firstly, there are the systematic series of fabric qualities, such as those reported here, which allow us to perform the basic mathematical analysis to develop the underlying equations. Secondly, there are the results from sets of serial samplings of individual qualities, taken over a period of weeks or months in dyeing and finishing plants. These serve to validate the predictions of the current program and also to establish the normal variation which can be seen in commercial production.

Using these data, we are able to model (amongst others) the average influence of different types of yarns and different wet processing regimes, so that these average effects are already built into the model.

Thus, with the STARFISH computer program, the average values for courses and wales, weight and width of an extremely wide range of dyed and finished fabrics can be estimated very rapidly and pretty accurately without the need for any physical knitting or finishing trials. The program will also calculate finishing targets for any desired level of shrinkage or any requested weight and width. It will also show whether a given set of customer demands can actually be met, in principle, using the yarns, knitting machines, and wet processing machinery which are actually available.

It should be emphasised that the equations used by STARFISH are not dependent in any way on K values. They include additional terms which allow for the yarn type, the yarn count, the wet process, and the depth of shade.

To get started with a basic simulation model, the user can select from a list of four standard yarn types, ten standard processes and eight depths of shade. Up to nine different yarn count values can be specified, as well as nine different knitting machines (to simulate a body-width range). *Figures 8 and 9* show the result of selecting the appropriate standard wet process on the calculated values of courses and wales, compared to those actually measured, for the same series of fabrics as in *Figures 6 and 7*. Clearly, the standard STARFISH equations are better able to cope with those additional effects which can not be allowed for by using K values.

However, just as the K values can be calibrated by making adjustments in the light of actual measurements, so too the STARFISH program provides a calibration facility. The user can enter his actual measured values which the program will then use to develop a calibration. This calibration can be saved to a file and used either as a standard model or whenever such conditions pertain again in the future. The effect of different yarn specifications can be allowed for as well as the wet process and the depth of shade.

In addition to fabric dimensions and shrinkages, the expected net weight loss due to wet processing, and the length and weight of the finished roll (based on a given grey roll weight) are calculated.

Figures 10 and 11 show the effect of calibrating the STARFISH model for the same yarns and finishes reported above. The agreement is now almost perfect. One could speculate that the scatter that remains must be due mainly to small "errors" in the measured values.

SUMMARY AND CONCLUSIONS

Demands on dyers and finishers to deliver low shrinkage on cotton circular knits will only grow more intense in an ever more competitive environment.

It is impossible for the dyer and finisher to deliver accurately to a given specification of weight, width and shrinkage if the basic fabric has not been correctly engineered.

Therefore, the dyer and finisher needs to be able to check that the fabric he has been given has been correctly designed for the performance he is expected to deliver. He also needs to be able to calculate the correct finishing targets, in terms of the courses and wales which he must strive to obtain in the delivered fabric.

The most effective means of checking performance specifications and developing correct finishing targets is by use of the STARFISH computer program, which can easily be calibrated to reflect actual commercial conditions within a given dyeing and finishing enterprise.

Figures

Figure 1

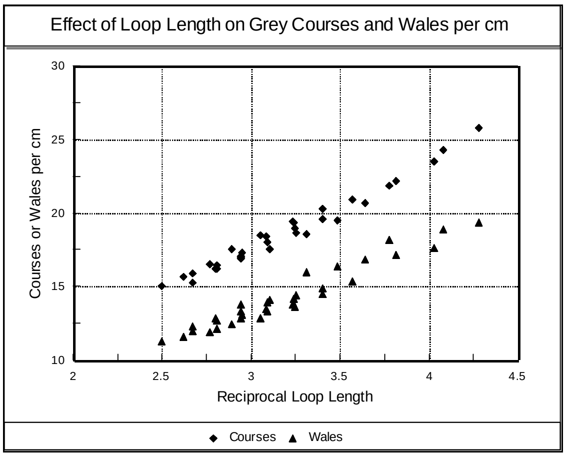


Figure 2

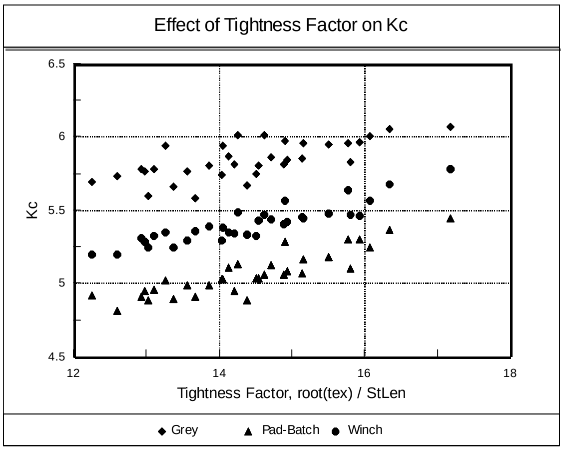


Figure 3

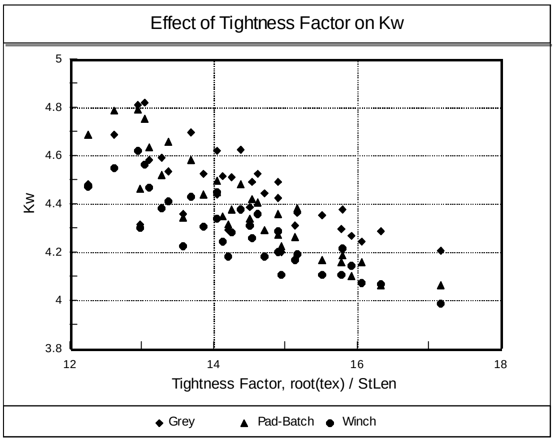


Figure 4

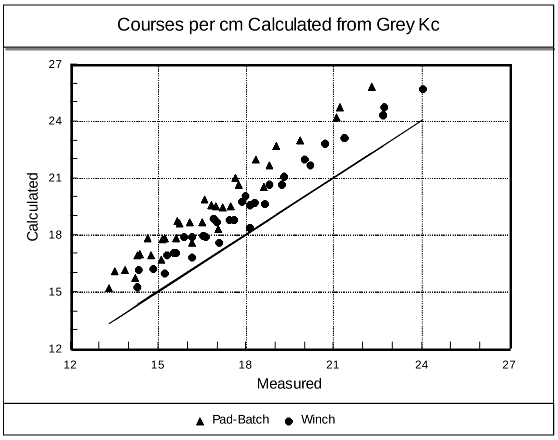


Figure 5

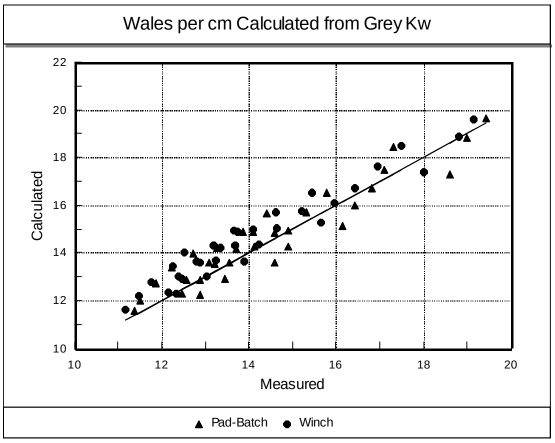


Figure 6

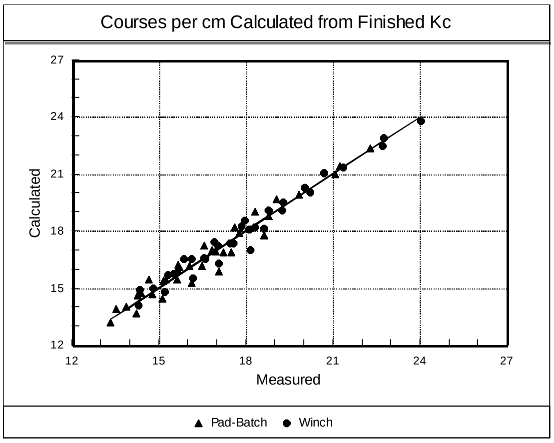


Figure 7

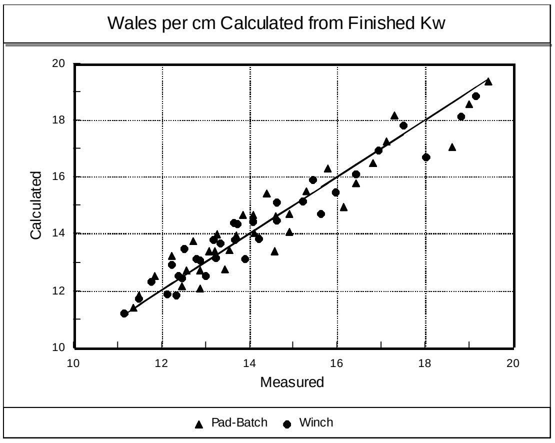


Figure 8

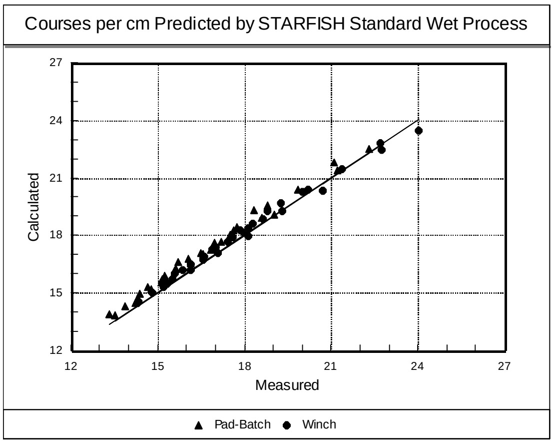


Figure 9

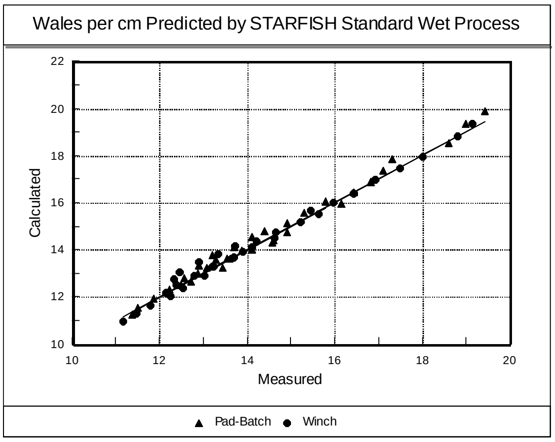


Figure 10

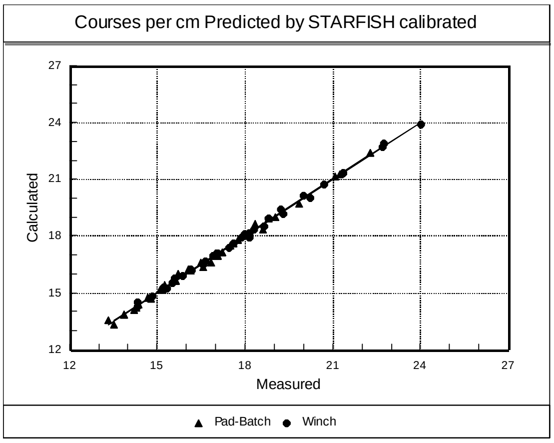
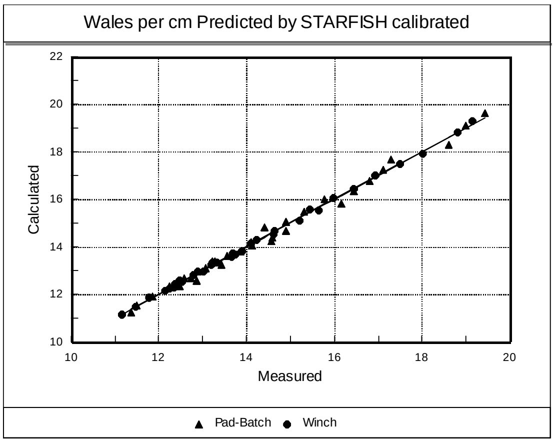


Figure 11



INFLUENCE OF THE SPINNER
ON THE SHRINKAGE OF COTTON CIRCULAR KNITS

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ABSTRACT

In an ideal world, the spinner would have no influence on the shrinkage of cotton circular knits, because knitters should engineer their fabrics taking account of the properties of the yarns that they purchase, and spinners should be delivering a consistent yarn. In the real world, knitters may use less sophisticated methods for fabric development and they may purchase yarns from a wide range of sources. In addition, there may be inconsistency in the yarns delivered by individual spinners over time. In these circumstances, it may be useful for both spinners and knitters to be aware of those features of yarn construction which can alter the "**Reference Dimensions**" of cotton circular knits, and hence their potential shrinkage.

INTRODUCTION

In principle, every yarn delivered to the market is unique. Each individual spinner has his own preference and sources for raw cotton, his own combination of preparation and spinning machinery, and his own recipes and techniques for machinery settings, process control and quality assurance. A modern, high quality spinner will develop a specific range of yarn qualities, based on secure sources of particular types of cotton and destined for specific groups of customers, for which he will attempt to maintain a strict technical specification, which is constant over time. Other spinners may be less able to control the source of their cotton, may have older equipment, and less experienced operatives, so that their yarns may have a less favourable technical specification and be less consistent from delivery to delivery.

Much as he would wish to, a knitter can not restrict his yarn purchases to a single, high quality supplier. Most knitters will have at least three yarn suppliers, often they may have more than six. It follows that the performance of the yarns that they purchase will vary more or less greatly from delivery to delivery and from supplier to supplier. Thus, the art of yarn purchasing, for a knitter, is to find a series of suppliers who are not only reliable and cost effective, but whose yarns perform roughly the same in his products.

For the strictly limited purposes of this presentation, we define "performance" only in terms of those aspects of yarn quality which affect the potential shrinkage of a cotton circular knitted fabric. This is not to deny the great importance of other yarn features which may affect, for example, the efficiency of knitting, the uniformity and yield in dyeing, and the fabric appearance and durability.

EVALUATION OF POTENTIAL SHRINKAGE

Before enumerating the factors of yarn quality which can influence the potential shrinkage of cotton knitted fabrics, it may be useful to define "potential shrinkage", and to describe how it may be evaluated unambiguously.

Shrinkage is the change in fabric dimensions, which is caused by some relaxation process. Usually, the relaxation process is one, which attempts to mimic household laundering procedures - such as washing in a standard domestic washing machine, followed by tumble drying. The resulting change in dimensions is expressed as a percentage of the original dimensions, thus:

$$\text{Length Shrinkage \%} = 100 * (Lo - Lr) / Lo \qquad [1]$$

$$\text{Width Shrinkage \%} = 100 * (Xo - Xr) / Xo \qquad [2]$$

Where:

Lo, Xo are the distances measured between benchmarks, placed on a sample of fabric before it is laundered,

Lr, Xr are the distances between the same benchmarks, after the relaxation process.

The shrinkage value is a useful indicator of the potential performance of an end-product in the consumer's hands, and is therefore a popular way of evaluating finished fabrics and garments. Unfortunately, it is almost worthless as a parameter for evaluating the fundamental constructional properties of the fabric, for two reasons. Firstly, the values of Lo and Xo are not controlled by the independent manufacturing variables (especially those relating to yarn quality) that we wish to study. Secondly, Lo and Xo are not a true reflection of the fabric length and width.

A moment's thought will reveal why Lo and Xo do not actually represent the length and width of the finished roll of fabric, as it is delivered to the customer (the garment maker). Lo and Xo are merely fixed distances, e.g. 50 cm, marked on a sample of fabric, cut from the piece. The actual length and width of the fabric roll are controlled by the tensions and distortions that are imposed upon the fabric by the mechanical handling, which is a necessary part of its manufacture and processing. A fabric piece that has been subjected to high processing tensions throughout will be relatively longer than one that has been through a relax-drying and compacting process. In other words, for a given basic fabric construction, even with strictly controlled values for the independent manufacturing variables, the relationships between Lo or Xo and the actual fabric length or width can vary over a wide range, according to the skill and experience of the finisher and the equipment at his disposal.

The difficulty of true representation can be overcome if, instead of the fixed lengths, Lo and Xo, we consider the number of courses and wales which lie between the benchmarks. In this case, the values obtained bear a strict relationship to the length and width of the fabric piece, because a roll of fabric is made from a definite number of yarn feeders and machine revolutions (courses), knitting over a fixed number of needles (wales).

Since the total length or width of a given roll of fabric is given by the reciprocal of the course or wale density (e.g. courses per metre, wales per metre), equations [1] and [2] can be rewritten thus:

$$\text{Length Shrinkage \%} = 100 * (Cr - Co) / Cr \qquad [3]$$

$$\text{Width Shrinkage \%} = 100 * (Wr - Wo) / Wr \qquad [4]$$

Where:

Co, Wo are the course and wale densities in the original sample, before laundering,

Cr, Wr are the corresponding values, after relaxation.

Co and Wo are a true representation of the actual length and width of the fabric roll, but this does not solve the problem that they are independent of the manufacturing variables that we wish to study. Co and Wo are still a reflection of the tensions and distortions which are imposed on the fabric by the finisher in his attempts to deliver a certain length and width (and hence a certain weight) of fabric, as demanded by his customer. They do not represent the fundamental characteristics of the (undistorted) fabric.

On the other hand, the values of Cr and Wr, the course and wale densities after relaxation, are indeed truly dependent variables. They are controlled by the basic manufacturing variables, namely stitch length, yarn count, yarn quality and wet process, and by the conditions of the relaxation procedure. Thus, provided that we have an effective and consistent relaxation procedure (and this is a large topic in itself), Cr and Wr can be used to evaluate the effect of changes in the manufacturing variables upon the potential shrinkage of the fabric.

The standard relaxation procedure that we have adopted for all of our extensive research work in this area since 1978, the STARFISH project [1,2,3], is based on a procedure which involves five cycles of "washing" and tumble drying under closely prescribed conditions. To distinguish it from similar relaxation procedures, used by other workers, we have termed it the STARFISH Reference Relaxation Procedure. A fabric sample, which has been subjected to this procedure, is said to be in its Reference State of Relaxation. Course and wale densities measured in the Reference State are termed Reference Courses and Reference Wales. In our terminology, these are Cr and Wr, in equations [3] and [4].

Thus, the problem of elucidating the effect of yarn quality variables upon the potential shrinkage of cotton circular knitted fabrics resolves into quantifying the effect of changes in these variables upon the Reference Courses and the Reference Wales.

If the effect of a certain change in a given yarn quality variable is to reduce the number of courses and wales in the Reference State, then (other factors being equal) the length and width shrinkages will also be reduced, in direct proportion. Thus, a two percent reduction in the Reference Courses will be directly translated into two percentage points lower length shrinkage.

THE MAJOR YARN QUALITY VARIABLES

The first point, which needs to be made, is that by far the most important manufacturing variable affecting the dimensional properties of cotton circular knits is the average stitch length (loop length) i.e. the average length of yarn which is knitted into each loop, *Figure 1*. It is given by the length of yarn fed to the knitting machine for each revolution, divided by the number of needles, which are knitting.

Another very important variable is the type of wet processing to which the fabric is subjected. In particular, the difference between the Reference Courses and Wales of the unprocessed grey fabric, and those found in bleached, dyed, and finished fabrics is striking, *Figures 2 and 3*. The reason is the very high strains which are imposed on fabrics by commercial wet processes, together with the setting (stress relaxation) effect of wet processes upon cotton fibres. These result in a permanent change in the yarn properties and, hence, a permanent change in fabric dimensions.

There are three obvious consequences:

- Any investigation carried out on grey fabrics, or on small samples of fabrics processed on laboratory equipment, will be misleading.
- Any investigation, which seeks to elucidate the influence of other variables, must either ensure a constant loop length in the experimental samples, or must be able to account for the independent effect of loop length.
- Likewise, the experiment must be conducted under full-scale, but well-controlled wet processing conditions.

In the course of the STARFISH project we have, naturally, concentrated on evaluating the effects of the most important variables, namely the loop length and the type of wet process. Nevertheless, our experiments, carried out in collaboration with institutes and companies in many different countries, have yielded data, which allow us some insights into certain yarn quality variables.

The findings can be encapsulated in the following, deceptively simple equations.

$$Cr = Sc / L + f(T) \qquad [5]$$

$$Wr = Sw / L + g(T) \qquad [6]$$

Where:

> Cr, Wr are the Reference Courses and Wales in the dyed and finished fabric,
>
> Sc, Sw are probably constants which depend mainly on the fabric construction (interlock, plain jersey, etc.),
>
> L is the Reference loop length
>
> f (T), g (T) are exponential functions of the Reference yarn tex, T, which depend on the yarn quality and the wet process type.

In addition to the yarn count, the features of yarn quality, which we have definitely identified as contributors to f (T) and g (T), are:

- the yarn type (ring, rotor, carded, combed, twofold)
- the raw cotton fibre characteristics
- the yarn twist level (twist liveliness)

Effect of Yarn Count

If a range of standard yarns, made from the same raw materials, spun on the same spinning equipment to the same twist multiple, and varying only in their tex, is knitted in a standard construction, and taken through a standard wet process, then the effect of an increase in the yarn tex (or reduction in Ne), is to increase the density of courses in the Reference State and reduce the density of wales, *Figure 4.* The effect is much larger for the wales than the courses and is assumed to be due to the combined influences of yarn bulk and twist liveliness.

A larger yarn diameter automatically means a larger distance from the centre of one wale to the centre of the next, because the space is (more-or-less) occupied by four yarn diameters, *Figure 5.* Since the loop length is constant, the course density must increase to allow the wale density to reduce.

However, for the same twist multiple, a heavier yarn has fewer turns per metre and is less twist lively. Normally, this has the effect of reducing the density of both courses and wales (see below).

Presumably, the effect of lower twist liveliness reinforces the effect of the larger diameter on the wales, but counteracts its effect on the courses, so that the overall effect of yarn count is greater on the wales than on the courses.

Of course, yarns with large differences in their tex value would not normally be knitted to the same loop length. The above conclusions have been deduced from experiments where yarns with a wide range of count were knitted with wide ranges of loop lengths. However, the results do allow us to simulate the effect of, for example, purchasing yarn supplies from different spinners, with slightly different average count values, or of taking yarn from a single spinner who happens to have relatively poor control of his average yarn count from lot to lot. An often-quoted value for the acceptable difference between deliveries is 3% and we have certainly seen differences in measured average tex values of this magnitude and more, when yarns of the same nominal count are purchased from different suppliers.

The practical effect upon the shrinkage, of a given fabric construction, of differences in yarn tex of ± 3%, depends on whether the finisher is attempting to deliver a constant length in the finished fabric, or whether he is attempting to deliver a constant weight per unit area. *Figures 6 and 7* are screen shots from the STARFISH simulation program which illustrate these two situations.

Figure 6 shows that, if a constant length and width are achieved in the finished fabric, then the weight per unit area will vary directly in proportion to the variation in yarn tex, i.e. by ± 3%, and length and width shrinkages will vary by only about one percentage point. Such variation will be accepted by most customers.

However, as *Figure 7* shows, if the finisher succeeds in delivering a constant weight per square metre, at constant width, then the consequence of variations of ± 3% in yarn tex between lots will be differences of up to six percentage points in length shrinkage between deliveries. Such variation is likely to prove unacceptable to demanding customers.

In fact, most finishers of cotton circular knits will be attempting to deliver a constant weight per unit area, because this parameter is the one most likely to be specified by their customers, but they actually fall somewhere between the two extremes simulated in *Figures 6 and 7*.

Effect of Yarn Type

If a combed ring yarn is taken as the standard, knitted into a standard fabric construction (constant loop length), and processed through a standard bleaching, dyeing, and finishing route, then the following effects have been found when yarns of different types are used.

Substitution of a carded ring yarn, of the same count and twist, makes very little difference to the Reference Courses and Wales, and hence to the shrinkage. What differences have been found suggest a slight reduction in both of these values, *Figure 8*.

Substitution of a carded OE rotor yarn causes a clear increase in the Reference Courses and a reduction in the Reference Wales; fabrics made from OE rotor yarns are shorter, but wider than those made from ring yarns of the same tex, *Figure 9.* A similar effect was found by Hunter, in 1978 [4]. The picture is complicated by the fact that rotor yarns made on modern spinning machinery tend to be less twist lively than combed ring yarns, even though they often have a higher nominal twist multiple. We have not recently had the opportunity to study fabrics made from modern combed rotor yarns.

For a standard fabric construction which is finished to the same length and width, a fabric containing a rotor yarn might shrink by up to five percentage points more in the length and five percentage points less in the width, compared to the corresponding combed ring-yarn fabric. The performance of the rotor-yarn fabric would be quite unacceptable.

In practice, of course, rotor-yarn fabrics should not be produced in exactly the same constructions as those made from ring-yarns - the fabric specification should be re-calculated so that the shrinkage values are acceptable whilst the delivered weight and width are still those demanded by the customer. This is quite a difficult and time-consuming exercise if the traditional trial-and-error development procedure is followed, but is accomplished rather easily with the help of the STARFISH computer program.

Substitution of a two-fold combed ring yarn produces a reduction in both Reference Courses and Reference Wales of the order of around 3 to 5%, compared to the same fabric construction made with a singles yarn*, Figure 10.* In addition to the more compact structure of a two-fold yarn, which maintains its integrity better through the wet processing, the effect can easily be visualised as a consequence of the extremely low level of twist liveliness in a two-fold yarn.

Effect of Fibre Type

It is well known that the relaxed dimensions of circular knitted fabrics are different for different fibre types - e.g. natural vs synthetic, or cotton vs wool [5,6,7,8,9], but very few authors have dealt with differences between cotton types or varieties [10,11]. Our own research contains one such study, in which two identical sets of interlock fabrics were made, from OE rotor yarns of different counts and twist levels, using two different cottons [12]. *Table 1* shows some summary data from that study, where it can be seen that substitution of a Californian cotton for a Texas cotton resulted in an average decrease of about 2% in the Reference Courses, and an average increase of about the same proportion in the Reference Wales. We presume that the important fibre properties are those which, for a given count and twist, affect the bulk, stiffness, and twist liveliness of the yarn. If this is a reasonable assumption, then candidate fibre properties for investigation would be fineness, maturity, and micronaire.

There is one other relevant set of data in the STARFISH project data base. This concerns a set of OE rotor yarns, made from a group of seven cottons with widely different Micronaire values, each spun to the same count at three levels of twist, and all knitted into interlock fabrics with approximately the same stitch length [13, 14]. The data do not conform strictly to our requirements, since they refer only to grey fabrics and the twist multiples were not quite identical for each cotton. In fact, it is the differences in twist multiple between cottons which is largely responsible for the scatter in *Figure 11*. However, the data do imply very strongly that a reduction in Micronaire value of the raw fibre stock will result in an increase in the Reference Courses and a reduction in the Reference Wales. Over the range of Micronaire from 2.8 to 4.2, the changes in courses and wales were about 5% and 2%, respectively.

These two sets of data together suggest that the influence of the cotton fibre properties alone could easily amount to two percentage points on the shrinkage, with length and width shrinkages moving in opposite directions for a given change in cotton.

Effect of Twist

Twist in a yarn causes twist liveliness, which leads to snarling. This can easily be seen if a piece of yarn is held extended, one end in each hand, and the hands are slowly brought together. The yarn will snarl, and twist up around itself. This effect has been embodied in a simple piece of laboratory apparatus so that the number of snarling turns per unit length can be measured under controlled conditions. When measured in this way, twist liveliness is found to be directly related to the number of turns per unit length in the original yarn, *Figure 12*. Similar results have been reported in the literature [15,16]. Whilst following the same, or a similar general relationship, different sources and different types of yarn (ring, rotor, dyed, mercerised) show different average levels of twist liveliness. Modern rotor yarns are significantly less lively than ring yarns. Dyed yarns have low twist liveliness. Yarns, which have been extracted from dyed and finished fabrics, usually show lower values for twist liveliness than the original grey yarn. This can be understood in terms of the setting (stress relaxation) effect of wet processes on cotton fibres.

Twist liveliness causes the shape of a knitted loop to be distorted; the higher the twist, the greater the distortion [17,18,19]. This is the main source of the problem of spirality in plain jersey fabrics made from singles yarns; spirality is virtually absent from plain jersey fabrics made from balanced two-fold yarns.

Distortion of the loops also alters the density of courses and wales in the Reference State of Relaxation, and this is true not only for plain jersey but also, so far as we know, for all cotton fabrics, *Figures 14 and 15*. In general, an increase in yarn twist will result in an increase in the density of both courses and wales. The effect is usually much larger for the courses than for the wales [12]. Over a very wide range of twist multiples in several separate, overlapping studies, we have found differences in the Reference Courses of the order of 3 to 6% and in the Reference Wales of 1 to 3%. For the much narrower range of variation in twist levels which are likely to be found in commercial knitting yarns, the potential differences are expected to be not more than about 2% for courses and 1% for wales.

SUMMARY AND CONCLUSIONS

Changes in yarn type (e.g. ring vs OE rotor), or variations in certain components of yarn quality from lot to lot (especially the average yarn count, the twist, and the type of raw cotton), can lead to significant variations in the density of courses and wales which will be found in relaxed cotton circular knitted fabrics. These variations will be manifested as variations of potential shrinkage in the delivered fabrics, and in made-up garments. The magnitude of these variations could easily amount to five percentage points of shrinkage.

A knitter who obtains his yarns from a single, high quality spinner, and who has taken the trouble to engineer and to calibrate his basic fabric specification, for example using the STARFISH technology, should have few problems with variations in shrinkage caused by variations in yarn quality.

A knitter who is obliged to obtain his yarns from several different sources, must evaluate each yarn in terms of its compatibility with his particular fabric specification, and must monitor the incoming yarn properties, as well as the Reference Courses and Wales in the dyed and finished fabrics on a routine basis, to ensure consistency of yarn and fabric quality from lot to lot.

It follows that product development in the knitting industry should be based on the actual yarn, which will be used, and a careful assessment of Course and Wale densities in the Reference State of Relaxation.

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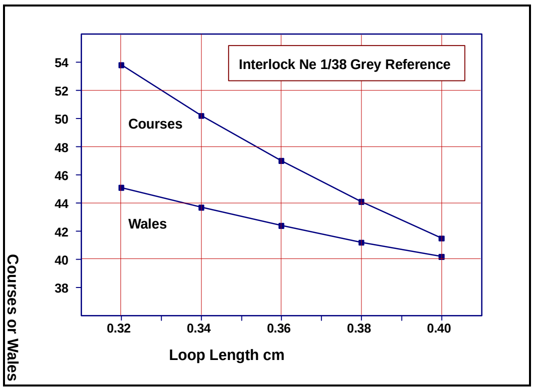
FIGURES AND TABLES

Table 1

Reference State Courses and Wales per cm., for 54 Rotor Yarn Fabrics averaged over Twist Multiple and Stitch Length, within Fibre Origin and Yarn Count.

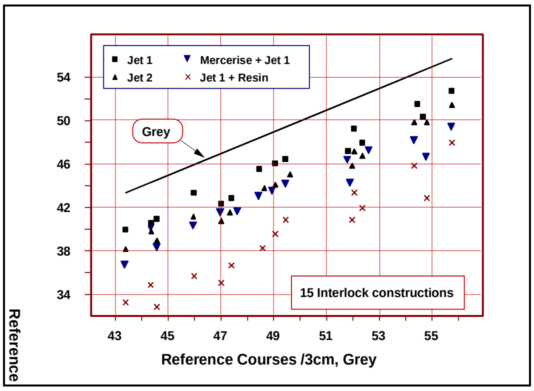
Count	Origin	Courses	Wales
Ne 22	Texas	12.82	10.42
	Californian	12.59	10.62
	Difference %	**1.8**	**-1.9**
Ne 26	Texas	14.09	11.44
	Californian	13.69	11.59
	Difference %	**2.8**	**-1.3**
Ne 30	Texas	15.03	12.20
	Californian	14.88	12.48
	Difference %	**1.0**	**-2.3**
	Mean Difference %	**1.9**	**-1.8**

Figure 1



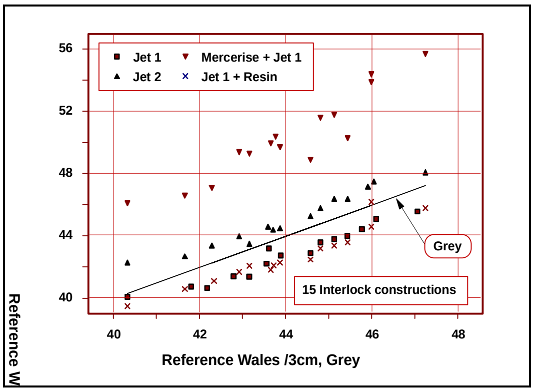
Effect of Loop Length on Course and Wale Densities in the Reference State

Figure 2



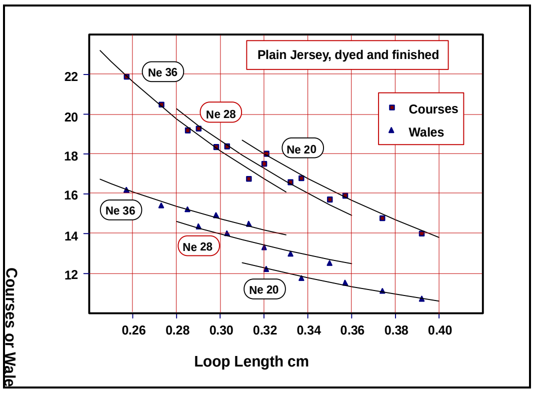
Effect of Wet Processing on Reference Courses

Figure 3



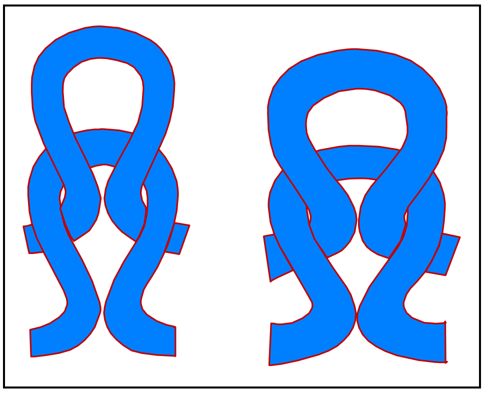
Effect of Wet Processing on Reference Wales

Figure 4



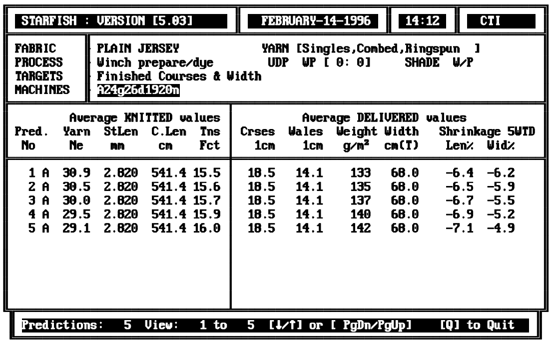
Effect of Yarn Count on Course and Wale Densities in the Reference State

Figure 5



Schematic interpretation of the Effect of Yarn Count on Course and Wales Densities (not to scale)

Figure 6



```
STARFISH : VERSION [5.03]   FEBRUARY-14-1996   14:12   CTI

FABRIC     PLAIN JERSEY              YARN [Singles,Combed,Ringspun  ]
PROCESS    Winch prepare/dye          UDP  WP [ 0: 0]     SHADE  W/P
TARGETS    Finished Courses & Width
MACHINES   A24g26d1920n

           Average KNITTED values            Average DELIVERED values
Pred.  Yarn  StLen   C.Len  Tns     Crses  Wales  Weight Width   Shrinkage 5WTD
 No     Ne    mm      cm    Fct      1cm    1cm    g/m²  cm(T)    Len%   Wid%

  1 A  30.9  2.820  541.4 15.5      18.5   14.1    133   68.0    -6.4  -6.2
  2 A  30.5  2.820  541.4 15.6      18.5   14.1    135   68.0    -6.5  -5.9
  3 A  30.0  2.820  541.4 15.7      18.5   14.1    137   68.0    -6.7  -5.5
  4 A  29.5  2.820  541.4 15.9      18.5   14.1    140   68.0    -6.9  -5.2
  5 A  29.1  2.820  541.4 16.0      18.5   14.1    142   68.0    -7.1  -4.9

Predictions:   5  View:   1 to   5  [↓/↑] or [ PgDn/PgUp]    [Q] to Quit
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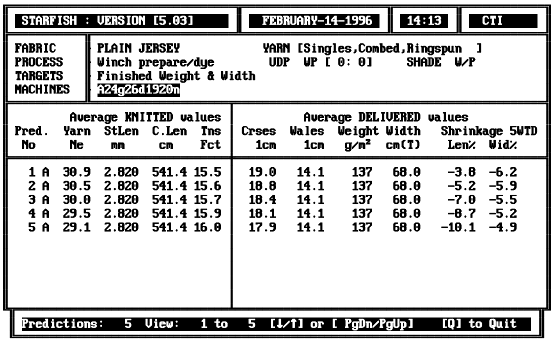
STARFISH Screen Shot - Plain Jersey.
Delivery at Constant Length and Width

Figure 7



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STARFISH : VERSION [5.03]   FEBRUARY-14-1996   14:13   CTI

FABRIC     PLAIN JERSEY              YARN [Singles,Combed,Ringspun  ]
PROCESS    Winch prepare/dye          UDP  WP [ 0: 0]     SHADE  W/P
TARGETS    Finished Weight & Width
MACHINES   A24g26d1920n

           Average KNITTED values            Average DELIVERED values
Pred.  Yarn  StLen   C.Len  Tns     Crses  Wales  Weight Width   Shrinkage 5WTD
 No     Ne    mm      cm    Fct      1cm    1cm    g/m²  cm(T)    Len%   Wid%

  1 A  30.9  2.820  541.4 15.5      19.0   14.1    137   68.0    -3.8  -6.2
  2 A  30.5  2.820  541.4 15.6      18.8   14.1    137   68.0    -5.2  -5.9
  3 A  30.0  2.820  541.4 15.7      18.4   14.1    137   68.0    -7.0  -5.5
  4 A  29.5  2.820  541.4 15.9      18.1   14.1    137   68.0    -8.7  -5.2
  5 A  29.1  2.820  541.4 16.0      17.9   14.1    137   68.0   -10.1  -4.9

Predictions:   5  View:   1 to   5  [↓/↑] or [ PgDn/PgUp]    [Q] to Quit
```
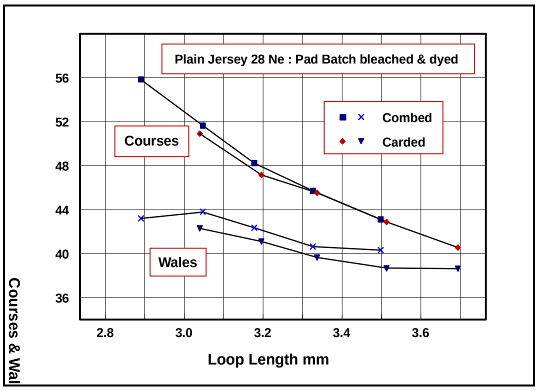
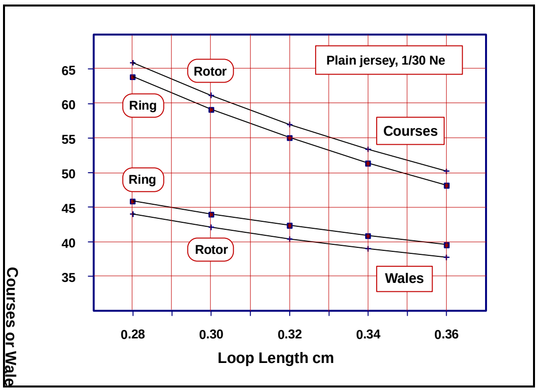

STARFISH Screen Shot - Plain Jersey.
Delivery at Constant Weight and Width

Figure 8



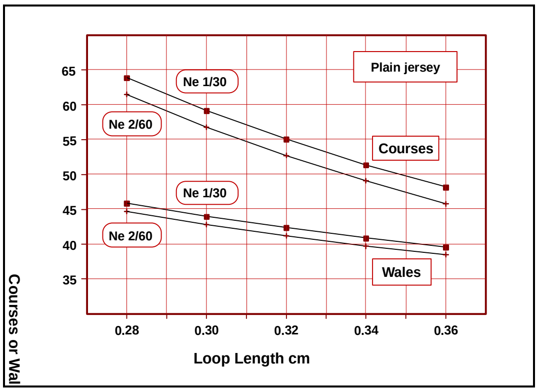
Carded vs Combed Ring Yarns

Figure 9



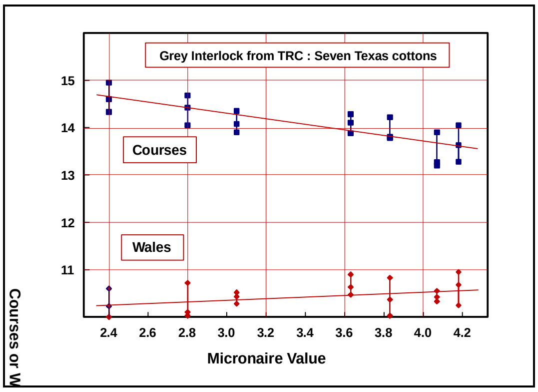
Combed Ring vs Carded Rotor Yarn

Figure 10



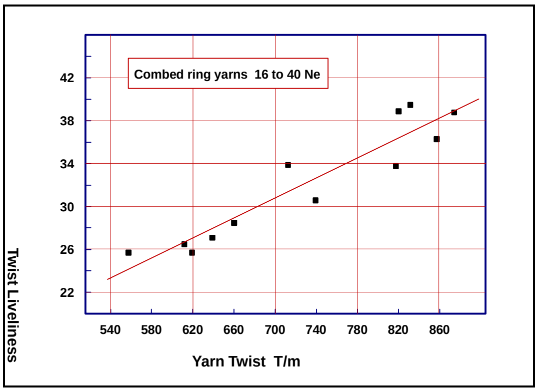
Singles vs Two-Fold Yarns

Figure 11



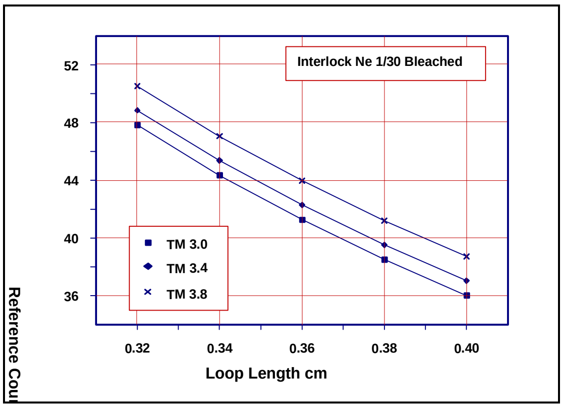
Effect of Micronaire Value on Course and Wale Densities in the Reference State

Figure 12



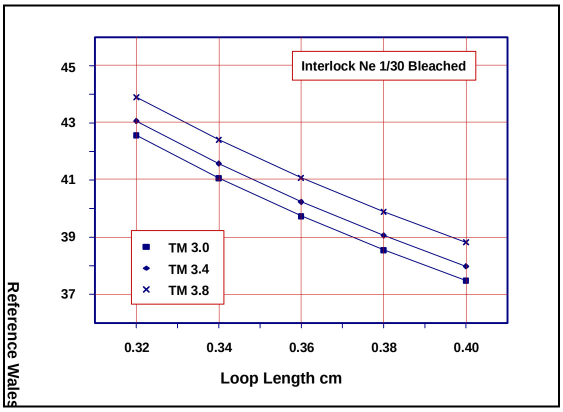
Twist Liveliness as a Function of Yarn Twist

Figure 13



Effect of Yarn Twist Multiple (TM) on Reference Courses

Figure 14



Effect of Yarn Twist Multiple (TM) on Reference Wales

DIMENSIONAL PROPERTIES OF COTTON FLEECE FABRICS

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and

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Presented at the Cotton Textile Processing Conference, January 11th 1996, Nashville, TN, USA

ABSTRACT

To enable rational fabric engineering for end-use performance, and to allow focused process control, it is necessary to be able to predict fabric dimensions as a function of knitting and wet processing input variables. In particular it is necessary to predict the course and wale densities of the dyed and finished fabric in its Reference State of Relaxation. A wide range of two-thread cotton fleece fabrics, together with the corresponding plain jersey controls, has been knitted, processed, sampled and tested. The results have been analysed to derive the necessary prediction equations. The equations have been included in a new version of the STARFISH computer program for simulating the manufacture and processing, and for predicting the end-use performance of cotton circular knits.

INTRODUCTION

One of the fundamental tasks of a manufacturer of cotton circular-knitted fabrics is to provide materials having specified values of weight per unit area and width, together with minimal levels of potential shrinkage, using available yarns, knitting machinery, and processing equipment. It follows that a rapid and reliable system for calculating the dimensions of dyed and finished knitted fabrics, starting from the raw yarn, knitting, and processing variables is a necessary requirement for rational fabric engineering. To our knowledge, there is only one such system which is generally available to cotton knitted fabric manufacturers world-wide. This is the STARFISH computer program (1, 2, 3). The current version of the program does not encompass two very popular cotton circular knitted fabrics, namely two-thread and three-thread fleece. Research has been carried out over the past two years in an effort to elucidate the dimensional properties of these fabrics, with a view to developing the simulation equations which will allow them to be included in a future version of the program. This report summarises some of the results obtained from one section of the research on two-thread fleece.

EXPERIMENTAL

Three separate sets of fabrics have been knitted. Each set was based on a different ground yarn, either 18/1 Ne, or 24/1, or 30/1. Each set contained a plain jersey control (no inlay yarn) and four two-thread fleece fabrics with inlay yarns of 12/1 Ne, 14/1, 16/1, or 20/1. All yarns were carded OE rotor spun, purchased in North Carolina. All of the different basic yarn combinations were knitted, at four different levels of average ground stitch length, on an 18 cut, 20 inch diameter machine having 1156 needles. The inlay stitch length was held (more-or-less) constant. Thus each set comprised 20 different qualities, for a total of 60 different fabric rolls in all. The rolls were sewn together in sets and processed in a commercial plant on a continuous peroxide bleach range, using a standard prepare-for-printing recipe, followed by extraction, softening, wet spreading and relax drying with overfeed.

Samples for testing were cut after discarding at least six yards from the ends of the rolls. Four sub-samples from each roll were measured for yarn count, stitch length, course and wale densities and weight per unit area, using standard methods, both before and after being subjected to the STARFISH Reference Relaxation procedure. This procedure comprises one hot wash and tumble dry followed by four cycles of cold rinsing and tumble drying, followed by conditioning. An essential aspect of the relaxation procedure is that tumble drying must continue until all of the samples are bone dry, followed by a short period of cold tumbling. For this report, data from the four sub-samples have been averaged, and only the Reference State data are discussed.

RESULTS AND DISCUSSION

The basic equations of knitted fabric dimensions are as follows:

$$\text{Weight} = T * L * C * W * F \tag{1}$$
$$\text{Width} = N / W \tag{2}$$
$$\text{Length Shrinkage} = 100 * (C - Cr) / Cr \tag{3}$$
$$\text{Width Shrinkage} = 100 * (W - Wr) / Wr \tag{4}$$

Where:

Weight = weight per unit area
T = yarn number in tex units
L = average stitch length
C = course density
W = wale density
F = a scaling factor
Width = fabric width (circumference for a tubular fabric)
Length Shrinkage = length shrinkage, percent
Width Shrinkage = width shrinkage, percent
Cr = course density in the Reference State
Wr = wale density in the Reference State

For a fleece fabric, equation [1] is modified in so far as separate calculations are made for the weight of the ground fabric and the inlay yarn. The two are then added to give the weight of the whole fabric.

In a hypothetical fabric development exercise, a particular yarn (or maybe two) might be chosen and knitted on a given machine at a range of stitch lengths. All of the resulting samples might then be processed through a given wet process route and the final finished samples tested to see which performs closest to the specified performance targets. In such cases, most of the variables contained in equations [1] to [4] are known: either they are selected as knitting inputs (yarn number, stitch length, number of needles) or they are given as primary performance targets (weight and width), or they are a direct consequence of fixing other variables.

For example, if the target weight per unit area has been specified and a yarn number and stitch length have been selected, then the product of courses and wales is known from [1]. Likewise, once the knitting machine (number of needles) has been decided and the required finished width has been specified, then the wale density in the finished fabric is known from [2].

Note, however, that after the knitting inputs have been selected and the primary performance targets have been specified, then the shrinkage values are also determined since, although Cr and Wr may be unknown at this stage, they do have specific values which depend on the knitting inputs and the type of wet process which is used. Thus, the shrinkage of a given fabric can not be specified independently of weight and width (or vice versa) unless the values of Cr and Wr are known.

The problem of rational fabric engineering by simulation then resolves itself into the problem of predicting Cr and Wr, for a given set of knitting inputs and wet processing conditions. From a vast quantity of experimental data, we have concluded that Cr and Wr are determined, with sufficient accuracy for practical purposes, as follows.

$$Cr = Sc / L + Ic \tag{5}$$

$$Wr = Sw / L + Iw \tag{6}$$

Where Sc and Sw are probably constants depending mainly on the fabric construction, whereas Ic and Iw are probably determined mainly by the fibre type, the yarn type, the yarn number, and the type of wet processing which is used. In order to develop simulation equations, Sc and Sw have to be estimated empirically for each different fabric type; Ic and Iw have to be estimated for the different types of yarn and wet processing. This requires an enormous quantity of detailed experimental data, gathered from fabrics which have been manufactured and processed under very closely controlled, but nevertheless fully commercial conditions. In particular, it may be noted that data based upon laboratory-scale wet processing of short lengths of fabric have proved to be of only marginal value in attempts to model full-scale operations.

Figure 1 shows the course and wale densities, as a function of stitch length and yarn number, for the plain jersey control fabrics. *Figure 2* shows the corresponding data for the two-thread fleece fabrics of the Ne 24 series. The dotted lines on this graph indicate the plain jersey controls. It is clear that the introduction of an inlay yarn has the effect of reducing the density of both courses and wales, but especially the wales. The heavier the inlay yarn, the greater is the reduction in stitch density. The differences between control and fleece fabrics were even greater in the Ne 30 series, but less in the Ne 18 series - reflecting the greater or lesser differences between the ground and the inlay yarn numbers - but the general pattern was the same

As a first approximation, we can smooth these data by assuming a constant slope for all of these lines. For this report, we have assumed that the grand averages for Sc and Sw for the two-thread fleece fabrics are the same as for the plain jersey controls. When this is done, average values for the intercepts, Ic and Iw can be computed and the effect of yarn number can be derived. Since the effect of the ground yarn number is already known, the independent influence of the inlay yarn can be established. *Figure 3* shows the resulting values for Ic and Iw for the three sets of fabrics, as a function of the inlay yarn number. Plain jersey controls are allocated an inlay yarn number of zero.

Having deduced the values for the main parameters of equations [5] and [6], it is possible to construct prediction equations for Cr and Wr, which can then be used to simulate product development trials for two-thread fleece fabrics having any set of knitting inputs and primary performance targets within the range of the data base (and a short distance outside it).

Figures 4 and 5 show the results of such predictions for the three series of fabrics, plotted against the actual measured values. Correlation coefficients for these predictions against measured values are very good for the courses and tolerably good for the wales. In both cases, the slope of the regression line is very close to 1.00 and the standard error of the predictions is consistent with normal variation in measurements of course and wale densities. Correlations may improve after several obvious anomalies (outliers) in the data have been scrutinised carefully.

There is more work to be done, particularly in industrial validation trials which are proceeding among the STARFISH users. Industrial case studies are used to sample and test the products from factories producing similar fabrics, both inside and outside the basic research data base. The resulting data allow the robustness of the predictions to be tested, and also allow the influence of different yarn types and wet process procedures to be deduced. Data are already available from several such case studies but these have not yet been analysed fully.

As a result of this research, and the parallel industrial case studies, we have a working model for simulating the dimensions of cotton two-thread fleece fabrics which will be incorporated into the forthcoming upgrade to the STARFISH computer program. At the same time, the opportunity will be taken to add several important new features to the program.

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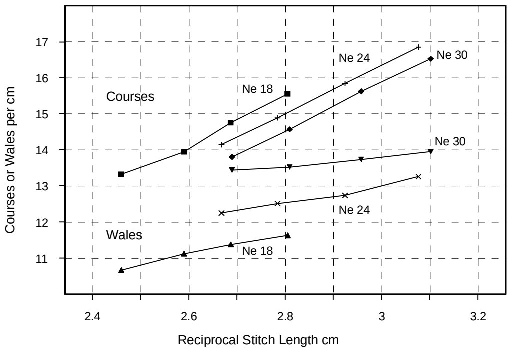
[3] Heap, S. A., and Stevens, J. C. Shrinkage: You Don't Need To Measure It To Be Able To Control It. Proceedings 36th Congress, International Federation of Knitting Technologists, 1994, 107-117.

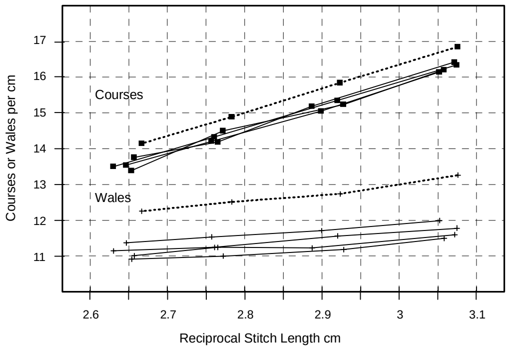
FIGURES

Figure 1



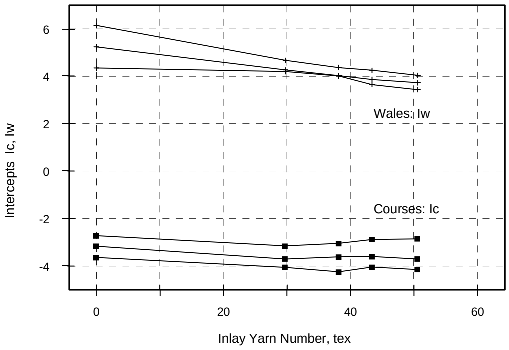
Plain Jersey Controls. Finished, Reference State Courses and Wales.

Figure 2



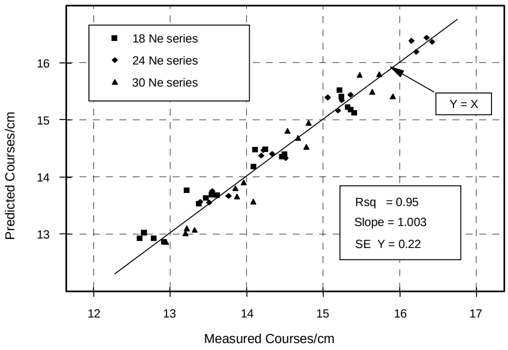
Two-Thread Fleece: Ne 24 Series. Finished, Reference State Courses and Wales.

Figure 3



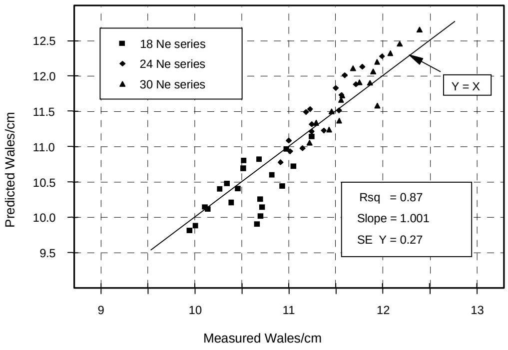
Two-Thread Fleece: Finished. Intercepts Ic, Iw versus Inlay tex

Figure 4



Two-Thread Fleece: Finished. Predicted versus Measured Courses per centimetre.

Figure 5



Two-Thread Fleece: Finished. Predicted versus Measured Wales per centimetre

SHRINKAGE
YOU DON'T NEED TO MEASURE IT TO BE ABLE TO CONTROL IT

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Presented at the 36th Congress of the IFKT, Ghent, Belgium, September 1994

INTRODUCTION

Cotton knitters and finishers are faced with constantly-increasing global competition and ever-rising demands for better quality and reliability. One of the key demands is for circular knitted fabrics and garments having consistently low levels of potential shrinkage. Therefore, a great deal of time and money is expended, especially by the finishers and garment retailers, in making routine tests for shrinkage. Unfortunately, the shrinkage test often is not very reliable (*Figure 1*) but, what is worse, it is not very informative.

For a large garment retailer, a shrinkage test may be a reasonable pass/fail criterion because, provided that he has been keeping good records (and provided that his testing is consistent), he can obtain some idea of the level of complaints that he may expect from his customers as a function of the average level of shrinkage in the products that he offers.

For the fabric manufacturer and finisher, the shrinkage test is of very limited value. A poor shrinkage result will indicate that something about the fabric is not right but it gives no information about where the fault lies. There are (at least) three major reasons why a given fabric may exhibit unacceptably high shrinkage.

1. The fabric was not properly engineered for the required performance (inappropriate choice of knitting conditions).

2. The finishing targets were inappropriate (incompatible values for weight, width, and shrinkage).

3. The finisher has failed to hit the finishing targets.

Thus, the shrinkage test has little or no diagnostic value for the manufacturer - it can not tell him how to improve the product, merely that improvement is needed. Furthermore, the shrinkage has no value as a production control parameter. Its result is available only after the fabric has been finished so it can not be utilised to make short-term adjustments to production conditions.
In passing, it may be noted that the shrinkage measured on a fabric (using the usual routine test methods) is not a very reliable guide to the shrinkage which will be measured in a garment made from that fabric - still less to the shrinkage which will be experienced by the ultimate purchaser of that garment after it has been worn and laundered several times (Figure 2).

In fact, it is our impression that there are two main reasons why finishers test for shrinkage. Firstly, because their customers demand a certain (maximum) level of shrinkage and secondly because they are not able confidently to predict what will be the actual level of shrinkage in a given fabric on a given day. In short, they need to know the level of shrinkage in their fabrics and the only way that they can know it is to measure it.

AN ALTERNATIVE SYSTEM

Shrinkage is a measure of distortion in a fabric. Shrinkage is the result of relaxation of manufacturing and processing strains. It is defined as the difference in dimensions between the fabric as delivered and the fabric after some relaxation process. The amount of shrinkage that will be measured in a given fabric depends firstly on by how much it had previously been distorted and secondly on how efficiently it is relaxed during the shrinkage test. Different shrinkage test methods (and different aftercare regimes by consumers) involve different relaxation treatments and therefore deliver different results.

The reason that we can not predict shrinkage is that we can not predict the effect of the relaxation treatment. After all, we always know what are the dimensions of the as-delivered fabric before we carry out a shrinkage test (or the dimensions of a garment at the point of sale). What we do not know is what will be the dimensions of the fabric (or garment) after the test (or after the consumer has worn and laundered the garment several times).

If we could predict what would be the dimensions of a given fabric after the shrinkage test, then we would not need to measure shrinkage because we could calculate it easily from the known as-delivered dimensions. What is more important, we would also be able to calculate what should be the as-delivered dimensions in order to have a certain level of shrinkage. This would then have a very important consequence. Once we are able to calculate the required as-delivered dimensions for a given level of performance, then we have a vital process control tool which can be used to adjust the processing conditions, on a short-term basis, to guarantee the required level of potential shrinkage in the as-delivered fabric.

Shrinkage can be calculated about as reliably as it can be measured from the density of courses and wales in the fabric, before and after relaxation (*Figures 3 and 4*).

Thus:

Length Shrinkage = $100\,(CA - CB) / CA$

Width Shrinkage = $100\,(WA - WB) / WA$

Where:

CB, WB are the courses and wales per unit distance, before relaxation,

CA, WA are the courses and wales per unit distance, after relaxation.

Therefore, provided that we can define a reliable and reproducible relaxation process, and provided that we can predict the number of courses and wales that the fabric will attain after such relaxation process, then we will be able to use the courses and wales, measured in the as-delivered fabric both to calculate potential shrinkage and to use as process control parameters. It is an advantage if the relaxation treatment is one that produces (close to) the maximum possible relaxation.

It is relatively easy to define a standard relaxation process. The one that we (and others) have used consists of five cycles of washing and tumble drying, followed by conditioning. To obtain the best reproducibility, the detailed relaxation conditions (especially of tumble drying) have to be rigidly standardised. To distinguish our particular set of conditions we have named our relaxation treatment the "Reference Relaxation Procedure". Fabrics which have been subjected to this treatment are said to be in their "Reference State". In the two equations above, we would substitute the "Reference courses" and the "Reference wales" for CA and WA.

For any given fabric, which is available to the finisher on a regular basis, it is relatively easy to establish what are the Reference courses and wales. All that is necessary is to sample the finished fabric on several different occasions, subject the samples to the Reference Relaxation Procedure, and count the courses and wales in the Reference State. If the fabric is being knitted consistently, from piece to piece, from machine to machine, and from day to day, then only five to ten separate determinations of Reference State dimensions will be needed to establish a good average.

> *If the fabric is not being knitted consistently, then serial measurements of the Reference courses and wales will reveal this important fact. This is a matter for serious discussion between knitter and finisher because the finisher has no chance of producing a reliable*

> *finished fabric from unreliable grey goods (though he will probably take the blame from the customer). It can be argued that, especially for commission finishers, this aspect alone will justify significant investment in monitoring Reference courses and wales.*

Once the average Reference State courses and wales are known, then it is a simple matter to calculate what should be the as-delivered courses and wales in order to have the required level of shrinkage. These values can then be used as finishing targets for process control purposes. Provided that the finisher can hit the targets, and provided that the knitting conditions remain constant, then the desired (average) level of shrinkage is guaranteed. It does not change merely by being measured.

The same principle can be applied to any new fabric that is supplied to a finisher. For such an unknown product, the finisher must first take the fabric through the preparation and dyeing process. He then samples the fabric before the final drying and calendering or compacting operation to determine the Reference courses and wales. Once these are known, then targets for courses and width can be calculated for the final finished fabric, as delivered to the garment maker. The main difficulty here is the amount of time it takes to carry out five cycles of washing and tumble-drying. In practice, a decision will be made based on only one cycle - though the full five cycles should ideally be carried out and the result filed for future reference.

> *The careful commission finisher will carry out this procedure in any case for any new quality. Not only does it allow him to determine the correct finishing targets for a given level of shrinkage but also it allows him to check whether the weight and width specifications he has been given by the customer are actually achievable at the desired level of shrinkage. If not, then the customer can be advised of the findings, warned that the fabric has not been correctly engineered for the stated performance requirements, and asked to choose whether he prefers the target weight and width or the target shrinkages.*

PRODUCT DEVELOPMENT

Of course, this approach only works really well when we have a standard, long-running, and basically satisfactory product. What is more important, it also works only if the calculated finishing targets produce not only the desired level of shrinkage but also the weight and width, which are requested by the customer.

The real difficulty comes when we are faced with a product which is too heavy and too narrow when the shrinkage is correct, but shrinks excessively when delivered at the target weight and width; in other words, a product which has not been correctly designed for the end-use requirements. Such products are very common. They are an inevitable by-product of the demand for improved performance from our customers; they are a consequence of a change in end-use requirements.

In such cases, we need to know more about how to re-engineer the fabric so that all of the desired finishing targets are mutually compatible. In brief, we need to be able to predict the Reference courses and wales of an unknown fabric.

It is already well known that the fully-relaxed courses and wales of grey circular knitted fabrics are determined only by the knitting variables - especially the knitted stitch length but also the yarn count and the yarn construction. However, it is another matter actually to calculate Reference courses and wales of grey fabrics accurately from information available in the literature and, moreover, the properties of the grey fabrics are not a sufficient guide. The Reference courses and wales are significantly different in the finished fabric from those in the grey. Furthermore, the effect of preparation, dyeing and finishing upon the Reference Dimensions depends on the type of wet processing to be used (*Figures 5 and 6*).

In general, wet processing will usually cause a permanent lengthening of the fabric (fewer courses per cm in the Reference State). Wet processes, which embody very high tensions (e.g. continuous rope preparation), cause greater permanent elongation than those that have low tensions (e.g. overflow jets). High processing tensions also will tend to cause a permanent narrowing of the width (more wales per cm in the Reference State). However, at the same time there is a countervailing tendency in the width direction, due to a reduction in yarn twist liveliness and an increase in yarn specific volume, both of which can cause growth in the width. Processes which result in greater yarn bulking, such as long dyeing cycles in high-impulse jet machines will give greater gains (or smaller losses) in width. Processes, which tend to preserve the integrity of the yarn structure, such as pad-batch preparation and dyeing, may result in significant width reductions. In the length direction, the reduction in twist liveliness works to reduce the number of courses in the Reference State. This can reinforce any tension effects.

Because of the countervailing effects in the width and reinforcing effects in the length, net permanent changes in the width direction as a result of different wet process routes are generally of smaller magnitude than changes in the length. A notable exception is certain types of tubular mercerising process which can cause large reductions in the Reference width. For an old-fashioned winch prepare and dye process, the Reference width in the finished fabric is usually not much different from that in the grey. This may be one reason why the grey width was traditionally used as a guide to finished width with reasonable success. Unfortunately, with modern processing equipment (which may differ in different finishing plants), and with modern demands for lower levels of shrinkage, the old guide-lines are no longer good enough.

Nevertheless, for given types of fabric, within a narrow range of qualities and processed over a standard wet processing line, there will tend to be a more or less constant relationship between the Reference courses and wales in the grey fabric and those which will be found after finishing. It follows that there also will be a more or less constant relationship between two different types of wet processing (*Figures 7 and 8*).

For those knitters and finishers who are still using the trial and error system of fabric development this knowledge allows a considerable saving in time and cost. If the relationship between grey and finished (Reference State) fabrics can be established empirically, then it is not necessary actually to dye and finish the fabric in order to know what will be the (approximate) values of Reference courses and wales after dyeing and finishing, and hence to determine whether the result of a given knitting trial is likely to yield a satisfactory finished fabric.

THE STARFISH APPROACH

With the STARFISH computer program, the average values for Reference courses and wales of a very wide range of dyed and finished fabrics can be estimated fairly accurately without the need for any physical knitting or finishing trials. The program will also calculate finishing targets for any desired level of shrinkage or any requested weight and width. It will also show whether a given set of customer demands can actually be met, in principle, using the yarns, knitting machines, and wet processing machinery which are actually available.

From the description of the effect of wet processing given above, it will be appreciated that, within certain limits, a pretty wide range of effects can be found in practice. In other words, for a given grey fabric construction, the Reference courses and wales in the finished fabric may be found at any point within the range which represents the total spread of possible results for different types of wet process. For a single process type (e.g. overflow jets), this range is actually quite narrow but, even so, it can represent differences in calculated shrinkage values of the order of several percentage points. Particular combinations of wet processing conditions might extend the range even further.

In the early version of the STARFISH program, the choice of wet processing options that could be simulated was rather limited, and was restricted to specific types of machinery. The user was obliged to select the process which most closely matched his own and to observe the systematic offsets in the predicted performance, compared to that actually achieved. Once the offsets were established, then they could be accommodated in the (re-calculated) finishing targets.

In the latest version of the program (Version 5), two changes have been introduced. These were made possible by a significant broadening of the STARFISH database, followed by a complete new mathematical analysis.

Firstly, instead of specific machinery, *average process types* have been defined. In the data base, all of the process lines of the same general type - e.g. winches, jets, continuous prepare, etc. - were grouped and their average effect was established. This means that when, for example a winch type process is selected, the STARFISH predictions will be based on the average effect of such processes. In other words, the predictions will tend to lie close to the centre of the natural spread of results that will be found for winch type processes; the different effects of different designs of winch and different methods of operation will tend to cluster around the STARFISH prediction. Note that many modern jet-dyeing machines are very similar in their basic operating characteristics to modern winches.

Secondly, a so-called process calibration routine has been included. If a finisher can establish the true Reference courses and wales for one standard quality, processed through his standard wet process route(s), then these can be used to modify the output of the STARFISH program so that all qualities of the same fabric type can henceforth be predicted more accurately. Thus, for example, the average STARFISH winch process can be made to conform to the specific conditions of a particular dyeing and finishing plant, (which actually may include overflow jets) thereby improving the accuracy of its predictions.

SUMMARY AND CONCLUSIONS

1. The measurement of shrinkage may serve as a (very) rough guide to retailers to establish the approximate performance of a given product in the consumer market, but it is of very limited help to a knitter or finisher. In particular, a shrinkage value has no diagnostic power and can not be utilised as a process control parameter or a tool for product development.

2. There is no need to measure shrinkage if it can be calculated.

3. Calculation becomes possible once we can predict what will be the average values for the courses and wales per cm for any given finished fabric in its Reference State. These are determined primarily by the knitting conditions (yarn and stitch length) but also are significantly affected by the type of wet processing used in preparation and dyeing, and the processing conditions.

4. Once the Reference courses and wales are known, they can be used for process control to deliver fabrics with predictable levels of weight, width and shrinkage.

5. For individual, established, reliable, long-running products, the average values for Reference courses and wales can be determined easily enough by measurements made on a series of deliveries of the finished fabrics. For a standard wet process, they can also be estimated approximately from the values determined on grey fabrics, provided that the effect of the wet process has been established carefully in advance, and a reliable sample of the grey fabric is available.

6. For new product development it is necessary (and highly cost-effective) to use the STARFISH computer program to estimate the Reference values of courses and wales for candidate development fabrics in advance of any knitting and finishing trials.

7. STARFISH predictions of Reference courses and wales refer to averages for given types of wet process. These predictions will generally be pretty close to the values which will be found in practice, but the finisher has the facility to "calibrate" his wet process, and hence to modify the output of the computer program so that it refers not to the average process but to his own specific situation.

POSTSCRIPT

We have pointed out, both here and elsewhere, that the average Reference values for courses and wales are fixed primarily by the knitting variables and that, for a constant wet processing route, the effect of the wet process on the average Reference dimensions is also constant. It follows that ***for a constant wet process***, the Reference courses and wales in the finished fabric are fixed by the knitter.

In many if not most cases, the final as-delivered dimensions of the finished fabric are also fixed (within certain tolerances), by the customer in terms of his specifications for the weight and width which must be delivered by the finisher.

Since the Reference dimensions are fixed by the knitter, and the as-delivered dimensions are fixed by the customer, and since the difference between the two is the shrinkage, it follows that, in principle, the finisher who succeeds in delivering exactly the required weight and width has no control over shrinkage.

This fact has been taken by some finishers to mean that, provided they meet the customer's specifications for weight and width, then they have no responsibility for the level of shrinkage that they are constrained to deliver.

Whilst this is a reasonable and understandable (and often a true) interpretation, it is justified only when the finisher is really able to guarantee a truly constant wet process. Such perfection must be rare (probably about as rare as a knitter who is able to guarantee truly constant knitting conditions). In particular, we have seen examples of nominally identical finishing plants (sometimes side-by-side in the same factory) where small, but nevertheless significantly different results are obtained.

The fact is that machinery and operating conditions are seldom absolutely constant. Machinery builders are always improving (changing) the detail of their designs and some of these changes are bound to affect tension and other conditions during processing. Preparation conditions, dye recipes and dyeing cycles are seldom identical from batch to batch. Maybe one day, when automatic controls for machinery and chemical recipes are fully developed, standardised, and universally installed, then finishers will run their processes identically from batch to batch and from month to month: but that day has not yet arrived.

Therefore, it is important that finishers should not be complacent about their apparent lack of influence on shrinkage. They should constantly be monitoring the effect of their particular processes upon the Reference Dimensions so that they are aware of the average effect, the variations in the effect, and any drifts, which may be occurring.

This mild warning to finishers does not invalidate the basic conclusion of the general argument, of course, which is that a modern, reliable, reproducible product, conforming to the customer's demands and expectations can scarcely, if ever be developed without the active, close, and informed participation of all three parties, knitter, finisher, and customer, to the product design exercise. In our view, ***informed*** implies having access to the STARFISH system of product design and process control.

FIGURES

Figure 1

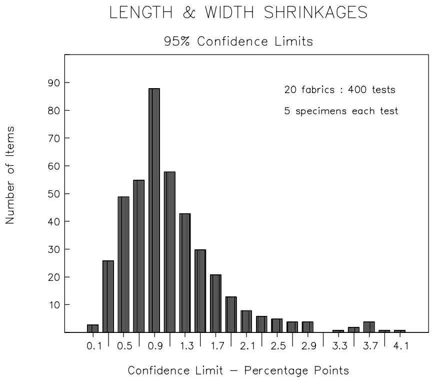


Figure 2

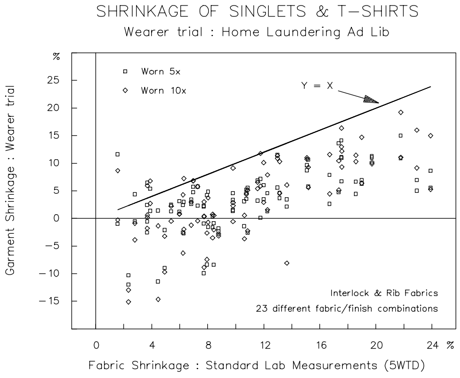
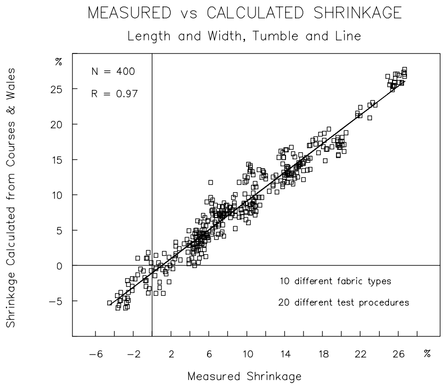


Figure 3



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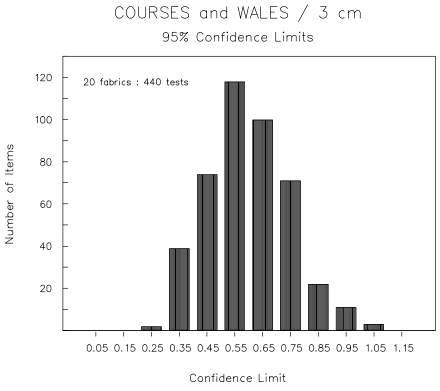


Figure 5

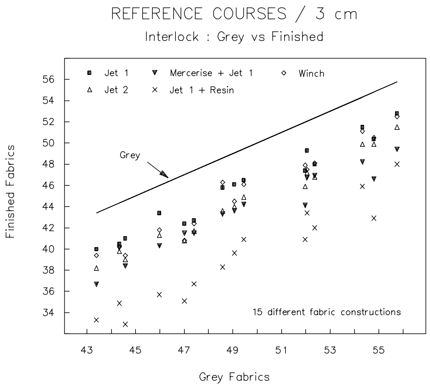


Figure 6

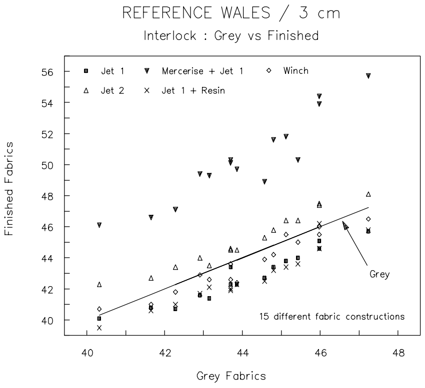


Figure 7

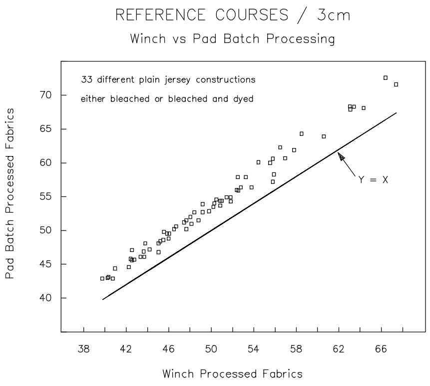
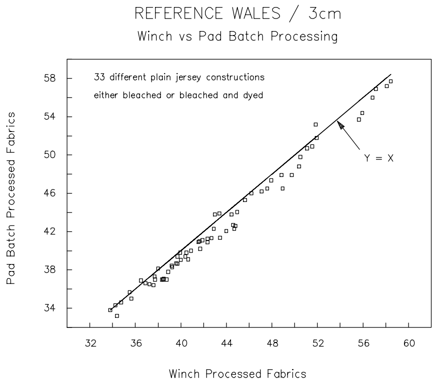


Figure 8



THE EFFECT OF OPEN-END ROTOR YARN QUALITY ON DIMENSIONS AND SHRINKAGE OF COTTON INTERLOCK FABRICS

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and

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Presented at the Annual Congress of the International Federation of Knitting Technologists, 1993

INTRODUCTION

Two of the important new concepts of recent years are those of "Quick Response" and "Total Quality Management". These are both large and complex subjects which, for practical implementation in a knitting factory, require the adoption of many new technical and organisational procedures and, perhaps more importantly, some fundamental changes in attitudes. Among these new procedures and attitudes are:

- The ability to develop new products, or improve the performance of existing products very rapidly and **according to the specific requirements of the customer** (rather than according to what we have always made before).

- The ability to **predetermine product quality and reliability** through the identification and continuous positive control of key raw material and process parameters (rather than by trial and error processing) so that product quality is guaranteed by making it "right first time and every time".

A feature of modern quality assurance systems is that they rely to a large extent on more or less exact numerical solutions to development and control problems, rather than trial and error solutions based on past experience plus manual tuning. In modern production situations, trial and error development and control systems are simply too expensive and too unreliable. In other words, when we want to develop a new product, we have to be able to calculate exactly what are the raw materials which must be used and the control settings of the key machines which must be maintained.

Probably the most obvious and widespread example of this approach is computer-based dye recipe selection combined with automated dyebath preparation and metering (together with strict quality control of water and chemicals) to allow one-shot dyeing for the majority of dyelots with no need for shading additions. Although the cost of such equipment is very high, it can easily be justified in terms of savings in time, reductions in reprocessing, and improvements in quality and reliability.

A further example, in the field of circular knitted cotton fabrics, is the need to guarantee that the weight per unit area and especially the shrinkage of the fabric shall conform to particular customer requirements reliably and consistently. In this case, the computer software which models the fabric manufacturing, dyeing, and finishing processes is the **STARFISH** system and the raw material which has to be closely controlled is the yarn. The main yarn quality parameters, which affect the weight and shrinkage of knitted fabrics, are the yarn type (ring, rotor, carded, combed), the yarn count (yarn weight and diameter), the yarn twist, and the basic fibre quality (especially fibre fineness and maturity). Other yarn properties are of course important for manufacturing efficiency and fabric appearance but they do not affect the weight and shrinkage.

In the **STARFISH** software, the separate effects of these four different aspects of yarn quality are modelled by only two parameters, namely the yarn type and the yarn count. This is partly because of the enormous time and expense, which would be required to develop a comprehensive data base to properly take account of variations in twist and fibre quality. However, it is also the case that, in practice, only a narrow range of twist factors is actually used for knitting yarns and, moreover, the quality of fibre used tends to be related to the yarn type and the yarn count. Therefore, the practical range of influence of twist and fibre quality is much less than the potential range.

In spite of this reasoning, it is fairly important for the knitter to monitor the twist of his yarns and to ensure that the fibre quality stays more or less the same from lot to lot if he wants to guarantee a consistent product. In addition, we would like eventually to be able to include the yarn twist as a separate input parameter in the **STARFISH** computer software because twist is important in determining the spirality of plain jersey fabrics. Spirality is a fabric performance property that we have studied extensively and that we would like to be able to predict in a future version of the **STARFISH** software.

Therefore, from time to time, we do carry out studies of the effect of twist and fibre quality on the dimensions and shrinkage of circular knitted cotton fabrics. This report summarises a part of the results from some experimental work which was carried out on interlock fabrics made from open-end rotor yarn fabrics made from two different cotton fibre qualities spun to different yarn counts at different twist levels.

EXPERIMENTAL

Bales of cotton from two separate origins were available. The main fibre quality parameters were as follows.

Origin	**West Texas**	**California**
Staple Length, mm	25.9	27.9
Micronaire value	4.0	4.3
Tenacity, g/tex	22.4	27.1

The bales were prepared over a hopper feeder, step cleaner, chute feed, card at 25 Kg/hour, followed by two passages drawing to 3.9 Ktex sliver. Spinning was on a Schlafhorst Autocoro rotor frame fitted with a G33D rotor running at 90,000 rpm. and a KN4 navel with twist-stop device. From each cotton type, three yarn counts were spun, each at three twist levels, as follows.

Yarn Count, Ne	**22**	**26**	**30**
Twist Multiple	3.50	3.75	3.97
Twist Multiple	4.01	4.27	4.50
Twist Multiple	4.51	4.74	5.00

Each of the yarns was knitted into interlock fabrics, on a 30" diameter, 18g Mayer machine, at three separate levels of tightness factor, namely 11.0, 12.0 and 13.0. Tightness factor is the square root of the yarn count (tex) divided by the stitch length (cm). Fabrics were alkali scoured and peroxide bleached in several lots in a Burlington winch beck, then hydroextracted by centrifuge and dried in a Huebsch tumble drier.

The finished fabrics were all tested using standard methods for the main parameters, namely yarn count, stitch length, course density, wale density and unit weight. Fabrics were tested both dry relaxed and also after the **STARFISH** Reference Relaxation procedure (five cycles of washing and tumble drying in automatic domestic laundering equipment).

RESULTS

Preliminary Considerations

It is an unfortunate fact of knitted fabric geometry that one can learn little or nothing about the effect of variation in yarn quality (or any other manufacturing variable) upon the shrinkage performance of circular knitted cotton fabrics merely by measuring shrinkages. Shrinkage for a given fabric quality can take on a wide range of values depending on the tensions which have been applied to the fabric during processing. Furthermore, shrinkage is a very unreliable test parameter so that its results can be quite different from day to day and especially from laboratory to laboratory. In fact, it is our opinion that knitters and finishers spend altogether too much time and money measuring shrinkage which is an almost worthless parameter for purposes of product design and quality assurance.

The only fixed reference points are the number of courses and wales in the fabric **after all shrinkage has been removed** and, in general, the results of our research and development trials can only be interpreted rationally by considering the fully relaxed (Reference) dimensions of the fabrics. For the present case, therefore, we are interested in the effect of the yarn quality parameters upon the level of courses and wales measured in the fully relaxed (Reference State) finished fabrics.

The effect of variation in stitch length is well known. *Figure 1* shows the graph of courses and wales plotted against the reciprocal of stitch length for all of the 54 fabrics. Apart from experimental error, the scatter in this graph is due mainly to the variations in yarn count, twist multiple and fibre type.

To separate the independent effects of these yarn quality variables, it is first necessary to manipulate the data in such a way that the dominant influence of the stitch length is removed. This can be done by reference to the fact that, for a given yarn quality, there is a close straight-line relationship between the Reference State courses or wales per cm and the reciprocal of the stitch length. The difference between the different yarns is the intercept that this straight line makes with the axis of courses or wales. If these intercepts are different, then the number of courses and wales in the Reference State will be different and, hence (for a given target finishing specification) the shrinkages of fabrics, as delivered to the garment maker, will also be different in the same proportions.

Figure 2 shows the effect of the yarn count and twist multiple on the reference courses and wales, for each yarn count, averaged over the two cotton types and independent of the stitch length. The ordinate for this graph is the absolute value of the (normalised) intercept of the straight-line relationships between courses or wales per cm and reciprocal stitch length. They are in units of courses and wales. Absolute values are shown because the intercept for courses is actually negative. For a given yarn count and stitch length, increasing the yarn twist will increase the number of both courses and wales in the Reference State, though the effect on the level of courses is apparently much greater than on the wales. From these data it is possible to develop regression equations which predict the independent effect of twist multiple on the courses and wales. Correlation coefficients for such regressions are generally better than R = 0.98.

Effect of Twist level

From these regression equations we can easily calculate the effect of twist multiple on fabric shrinkage by comparing the differences to the average values of Reference courses and wales at some arbitrary base level of twist multiple for each yarn count. The result is shown in *Figure 3,* where the base value for the twist multiple is taken as 3.6.

The additional shrinkage caused by increasing twist multiple, over the range 3.6 to 4.4, is about three percentage points for the length and about one-and-a-half percentage points for the width. This is, of course, a much wider range of twist multiples than would normally be allowed by knitters so the practical consequences of twist variation in yarn supplies are likely to be less than half of the effect shown here.

Effect of Fibre Quality

In general, cottons from California tend to be longer, finer, stronger, and more mature than those from Texas. The fibre test data given earlier are consistent with this expectation. Since the yarns from the two different fibre types were spun under the same conditions, to the same nominal counts and twist multiples, and were knitted at the same nominal tightness factors, we can deduce the average effect of fibre quality from the Reference State courses and wales after averaging over twist and stitch length, within yarn counts. These data are shown in *Table 1.*

The differences are not large but, nevertheless, they imply that if a yarn which was normally made from this particular Californian cotton were to be substituted by one made from the Texas cotton, and the fabric was delivered with exactly the same unit weight and width, then the length shrinkage would be about two percentage points greater and the width shrinkage would be about two percentage points less. Among the world's cotton varieties and origins there are larger differences in basic fibre quality than those which have been investigated here.

Comparison with Typical Ring-Yarn Fabrics

We can make a rough comparison by establishing the level of courses and wales which would be expected for a typical combed ring yarn of the same average yarn count and knitted stitch length, by reference to the output of the **STARFISH** computer prediction program. These data are shown in *Table 2.* They refer to ring yarns with twist factors of about 3.6 and a typical winch bleaching process. The rotor yarns in the table are the ones of this experiment, averaged over stitch length and twist factor within yarn counts. The average twist factors of the rotor yarns are significantly higher than those of the ring yarns and, moreover, the wet processing was also somewhat different. Both of these facts are reflected in the differences which are found in the fully relaxed courses and wales for the two types of fabric.

For a given yarn count and stitch length, the differences in the levels of courses and wales in the Reference State do not look very large but they can have serious consequences for the shrinkages of the corresponding fabrics. The figures in the last two columns show that, if these particular rotor-yarn fabrics were to be delivered by the finisher at the same weight and width as the typical ring-yarn fabrics then, on the average, their length shrinkages would be five to nine percent greater and their width shrinkages would be three to four percent less.

CONCLUSIONS

In addition to the yarn count, it seems that cotton fibre type and yarn twist multiple probably have a significant effect on the fully relaxed dimensions of interlock fabrics made from open-end rotor spun yarns.

This means that, for a given nominal quality of fabric (made from a given yarn count, knitted to a given stitch length, dyed and finished in a given way to fixed targets of unit weight and width), if significant variations are allowed in the fibre quality and the yarn twist multiple, then there will be corresponding variations in the average levels of length and width shrinkage.

For the yarns and fabrics of this investigation, it was found that an increase in the yarn twist multiple from 3.6 to 4.0 would cause the average shrinkage to increase by about one and a half percentage points in the length and by about one percentage point in the width.

Independently of the effect of twist, substitution of a different cotton fibre type could cause length and width shrinkages to change by about two percentage points each, but in opposite directions.

The results presented here refer to a specific set of fibres, yarns, fabrics, and processing conditions. Therefore the absolute differences found for the effects of yarn quality on fabric shrinkages can not necessarily be taken as typical. Nevertheless, it seems reasonable to suppose that similar trends will exist for the generality of interlock fabrics. In fact, we have previously found similar trends in two separate series of experiments with interlock fabrics made from ring yarns.

Although the range of yarn twist and fibre quality found in practice should not be as wide as that presented here, it is clear that knitters should keep a careful watch on the average level and the consistency of yarn quality. Most knitters do not routinely monitor the twist of the yarns that they buy and have only a vague idea of the fibre quality that is used to spin them.

TABLES & FIGURES

Table 1

Reference State Courses and Wales per cm, for 54 Rotor Yarn Fabrics averaged over Twist Multiple and Stitch Length, within Fibre Origin and Yarn Count.

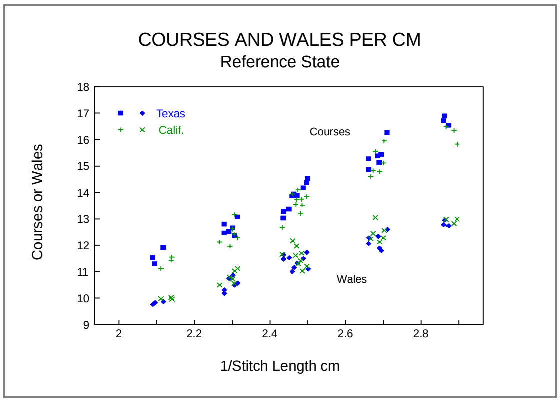
Count	Origin	Courses	Wales	Weight
Ne 22	**Texas**	12.82	10.42	310.7
	California	12.59	10.62	304.6
	Difference %	1.8	-1.9	2.0
Ne 26	**Texas**	14.09	11.44	284.8
	California	13.69	11.59	280.1
	Difference %	2.8	-1.3	1.6
Ne 30	**Texas**	15.03	12.20	264.6
	California	14.88	12.48	262.7
	Difference %	1.0	-2.3	0.7
	Mean Difference %	1.9	-1.8	1.4

Table 2

Reference State Courses and Wales for 54 Rotor Yarn Fabrics, averaged over Fibre Origin, Twist Multiple and Stitch Length within Yarn Counts, compared to the output of the STARFISH model for Ring Yarns.

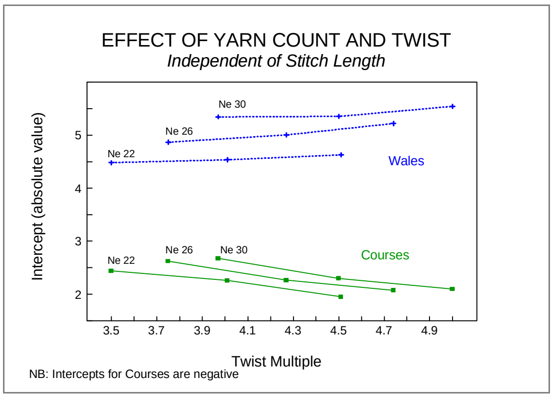
As Knitted		**Finished Reference State**								
		Ring Yarns			**Rotor Yarns**				**Difference**	
Ne	**SL mm**	**C/cm**	**W/cm**	**gsm**	**TM**	**C/cm**	**W/cm**	**gsm**	**Len%**	**Wid%**
21.9	4.43	12.0	10.8	295	4.01	12.7	10.5	307	5.5	-2.8
25.8	4.08	13.0	11.9	272	4.25	13.9	11.5	283	6.5	-3.4
29.8	3.82	13.7	12.8	252	4.49	15.0	12.3	264	8.7	-3.9

Figure1:



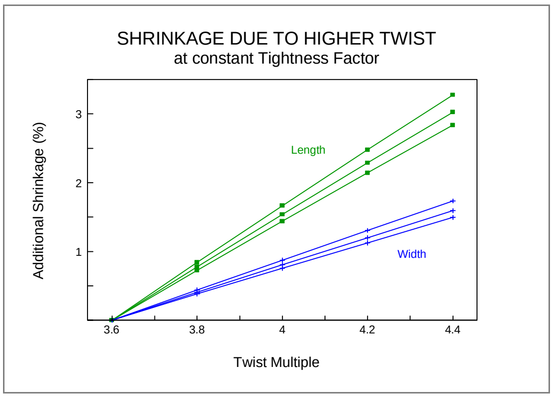
Effect of Stitch Length on Reference State Courses and Wales

Figure 2:



Effect of Yarn Count and Twist Multiple independent of Stitch length on Reference State Courses and Wales

Figure 3:



Effect of Twist Multiple on Fabric Shrinkage at constant Tightness Factor

SHRINKAGE: IF YOU CAN PREDICT IT THEN YOU CAN CONTROL IT

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Based on a presentation to the Knitted Textile Association, Raleigh NC, USA, September 1992

INTRODUCTION

We start from the following assumptions:

a. In the developed consumer markets of Japan, Western Europe, and the USA, there is a large demand for cotton circular knitted goods together with a strong desire for wider choice and higher quality.

b. The demand for wider choice means that frequent changes in basic fabric types, styles and colours have to be made. It is no longer the case that a single range will suffice for a whole season.

c. This means that new products have to be continually evolved at a much faster rate than before, and consumer response to poor quality will be felt more rapidly. It also means that the size of individual orders will be smaller.

d. The consequence is that reputable, high volume multiple retailers in advanced consumer markets are becoming more interested in those suppliers who can guarantee to have the quality right first time at reasonable cost and can respond rapidly to requests for new and improved products. Such customers are prepared to develop long-term relationships based on mutual profitability.

e. There will always be competition from low cost, low quality suppliers but they will suffer from low profit margins, stiff competition from producers in less well-developed economies, slow response times, poor customer service, and customers who are not very interested in long-term relationships.

Thus, one of the keys to a long-term future in supplying the advanced consumer markets is to be able to develop the appropriate technical performance in the appropriate range of fabrics and to do this very rapidly and at a reasonable price.

PROBLEMS IN UPGRADING THE PERFORMANCE OF COTTON KNITS

The most important performance attribute, which has to be improved, is the shrinkage. This is the message, which always comes back from consumers and from retailers when they are asked what are the disadvantages of cotton knits.

Many finishers of cotton knitgoods will tell you that it is often not too difficult to improve the shrinkage of a given existing fabric quality but, in order to achieve such an improvement, the fabric has to be delivered with a heavier weight and a narrower width. However, the garment cutters are not always prepared to accept a narrower fabric, and the customers are not always prepared to pay the extra cost of the heavier material.

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 so simple as it sounds if the development has to be based on the trial and error methods, which are typical of the knitgoods industry today.

For example:

- In order to maintain the weight at a lower shrinkage, a finer yarn is required.
- In order to maintain the width, a larger knitting machine diameter or a longer stitch length is necessary.

- In order to maintain the same knitted tightness factor, or cover factor (square root of tex divided by stitch length) with a finer yarn, a shorter average stitch length must be knitted.
- Changes in yarn count and stitch length also change the stitch density which again changes the weight and the width for a given level of shrinkage. Changes in the tightness factor will change the extensibility of the fabric and will also affect the amount of spirality (fabric twisting) which may be developed.

It should also be noted that a change in the knitted tightness factor will affect the amount of difficulty that the finisher may have in meeting his weight and shrinkage targets and the garment maker may have in the cutting and sewing operation - a tightly knitted fabric is generally easier to finish and to make into garments than a slack one.

Every change that we make to the manufacturing process 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 design parameters upon the final performance of the fabric. For this reason, it is very common for knitters and finishers to carry out a number of sample trials when they have to develop a new product. These sample trials can consume significant amounts of time and raw materials, and cause considerable disruption to production schedules, before a satisfactory solution is found but they are essential to ensure that a customer's wishes can actually be met.

Finally, it is as well to recognise that the demands of customers are often based largely upon wishful thinking rather than solid experience of the product that they have in mind. In the case of a new product, this is almost inevitably the case and is to be accepted as a fact of life - part of the process of product evolution and improvement in response to market opportunities.

We are left with a few simple conclusions about the problems of upgrading the performance of cotton circular knits.

1. Developing a new fabric quality which is supposed to have a specified level of performance is a very tricky business because there is no way to predict exactly what will happen as a result of changing the different manufacturing parameters.
2. Therefore, the only methods that most companies can use to develop new qualities, or to upgrade existing qualities are "past experience", "guess-work", and "trial and error".
3. Trial and error development is not only expensive in itself - because it consumes valuable time and production resources - it is also very risky because there simply may not be enough time or resources to get it right.
4. There is very little time or opportunity to check whether the product performance that a particular customer is asking for can actually be achieved. It is not at all unusual for customers to ask for a combination of, for example weight, width, and shrinkages, which are quite impossible to obtain from the existing selection of yarns and manufacturing equipment.

COST IMPLICATIONS

Some of the cost implications of the problems inherent in developing new products with good performance are immediately obvious. For example, the cost of trial and error development is not too difficult to establish. In the UK it has been calculated that every sample piece costs in the region of GB Pounds 400 to produce. If it were possible to predict in advance exactly how a new quality should be made, then only one development trial would have to be made before the new fabric was ready for bulk production. With a trial and error system we may be lucky the first or second time but more likely we would have to spend money on buying in different yarns, knitting them up with several different stitch lengths and processing and testing all of the trial qualities with different settings at the dryer and calender before we would have a good idea of what the best compromise might be.

Even after all that effort, the final quality may still not be quite right but time and money would not allow any further trials to be made before a commitment was made to bulk production. In earlier days, when long runs of standard qualities were the norm, it was expected that further development to refine the performance would continue on the bulk production but such a luxury is less and less common in the modern market environment.

Several companies have reported to us that the cost of such development trials can run into tens of thousands of dollars each year.

A second cost, which is relatively easy to quantify, is the cost of wasted fabric, reprocessing, customer complaints, rejects, and even compensation on account of the performance not being as specified. Every manufacturer who is dealing with quality-sensitive customers can show examples of lost orders, returned goods, goods which had to be sold off at second grade prices, or actual claims for compensation because the performance did not conform to the original specification. Often these rejections will have arisen because an order was accepted by the salesman when neither he nor the production department had appreciated that the customer's wishes could not actually be met by the installed equipment. These amounts can also run into tens of thousands of dollars.

There are other cost penalties, which are not quite so easy to quantify. There is the cost of lost opportunity and lost reputation. If a sample is submitted which does not attain the customer's requirements then, not only does he not place the order for that product but he is less likely to request samples again for other products. If a delivery is accepted which arrives late, or does not perform up to standard, the customer may not necessarily complain or claim compensation but he is less likely to come back for more. Good suppliers can gain a reputation, which extends beyond their immediate customers and will generate business from unexpected sources.

DEVELOPMENT OF A PREDICTIVE SYSTEM

Many of these problems in upgrading the performance of cotton circular knits could be solved if we had a method of predicting what would be the performance of a particular proposed fabric quality before we ever started to make it. If we could make such predictions then:

1. We would know immediately whether our particular production equipment would allow the proposed quality actually to be produced. If the customer's request did not coincide exactly with what was physically possible, then we could offer a close compromise, which we could guarantee to produce.
2. We could dispense with guesswork and trial-and-error methods. When a new or improved quality was required, we could simply calculate how to make it and proceed directly to pre-production trials with a single target quality, or a couple of options.

The consequent savings in time and cost of development and the corresponding improvement in customer service would be enormously beneficial to the profitability of our business.

The first problem, which has to be faced in the creation of a predictive system for product development, is the question of exactly what to predict.

In order for a manufacturer to be able to deliver a fabric with guaranteed low levels of shrinkage, he first has to know what will be the dimensions of that fabric after it has been shrunk. When the dimensions after shrinking are known, then it is relatively easy to calculate the dimensions which must be delivered to the garment maker.

As a simple example:

- If the garment maker must have a width of 100 cm and the width shrinkage must be 5%, then the width after shrinking must be 95cm.
- If the same fabric has to have a finished weight of 150 grams per square metre (gsm) and the length shrinkage must also be 5%, then it can be calculated that the weight after shrinking has to be about 165 gsm.

- Therefore, the manufacturer has to be able to predict what combination of manufacturing conditions will result in a width of 95cm and a weight of 165 gsm after shrinking.

Thus, the problem of predicting performance can be solved if only we are able to calculate the dimensions that the fabric will have after shrinking.

It turns out that there are just four major variables, which affect the dimensions after shrinking of cotton circular knitted fabrics. The effects of these four variables are most easily understood by thinking about the shape and size of each knitted loop in the fabric. Any circular knitted fabric is composed of row after row of interlaced loops. Different types of fabrics are made by different methods of interlacing the loops. Therefore, the dimensions of any knitted fabric are simply a reflection of the average shape and size of the individual loops, summed over the total number of loops in a given area.

The four major variables are:-

1. **The Yarn**

   The type and size of the yarn (yarn count, twist, spinning system) governs the weight of each loop and also determines its shape (length/width ratio).

2. **The Stitch Length**

   The average length of yarn in each loop (stitch length) determines its weight and also the overall size of the loop (number of loops per unit area).

3. **The Knitting Machine**

   The size of the knitting machine (number of needles) determines the number of loops across the width of the fabric, and hence the fabric width.

4. **The Wet Process**

   The effect of wet processing is to change the shape of each loop, mainly by changing the stiffness, the specific volume, and the twist liveliness of the yarn. In addition, wet processing will change the weight of the yarn, by removing impurities and adding chemicals (such as dyestuffs), and will change the average length of yarn in each loop, through yarn shrinkage.

   Different types of wet processing procedure will change the shape, the weight, and the length of the loops by different amounts and, therefore, they affect the length, width, and weight of the fabric by different degrees.

From this simple analysis, it now becomes clear that, in order to set up a system for predicting the dimensions and shrinkage of cotton knit fabrics, the first requirement is that we must be able to calculate the average dimensions of the loops from a knowledge of the knitting parameters and the type of wet processing. In other words, it is necessary to have a set of equations which link the dimensions of a given fabric after shrinking to the yarn type and size, the knitting machine used, the average stitch length, and the wet process route. Comparison of these dimensions with the specification demanded by the customer will then yield the values for weight, width and shrinkages in the "as delivered" cloth.

It is also necessary to define more closely what we mean by "after shrinking".

In the case of a particular customer, obviously "shrinkage" means "according to the method that the customer uses himself". But most manufacturers have more than one customer and they will not all use the same test methods. In addition, if the final shrinkage performance is to be guaranteed, then it is necessary to consider what will be the largest possible shrinkage that the fabric will ever experience in the hands of the ultimate consumer. How can we know what this will be and how can we relate it to the customer's definition of "shrinkage"?

For the purposes of making predictions about shrinkage, the test method that we use for this definition is one which involves five cycles of washing and tumble drying. We call the the

Reference Relaxation Procedure and after a fabric has been subjected to this procedure, it is said to be in its **Reference State**.

The reason that we use this very intensive relaxation procedure is that it removes essentially all of the shrinkage in nearly all knitted cotton fabrics. In this way, we achieve two important objectives.

The first is that we gain a knowledge of the ultimate shrinkage of any given product. This is a value, which is very seldom seen by manufacturers or retailers, but it is what the ultimate consumer may actually experience in practice under the worst conditions. If we can accommodate the worst conditions, then we know that our product can give satisfaction in the market.

The second is that it reduces all different fabric types and qualities to a common, comparable state. It is only when we have such a common state - a Reference State -that we can make reliable comparisons and develop reliable prediction equations for the final fabric dimensions.

In fact, the only two-dimensional properties for which prediction equations are needed are the number of *courses per unit length* and the number of *wales per unit width* in the fabric after shrinking to its Reference State. This is because all of the other properties that are of interest can be derived from these and from the target "as delivered" specification.

Thus:-

- Width is given by the number of needles and the number of wales per unit width,
- Weight per unit area is given by the product of yarn count, stitch length, courses per unit length, and wales per unit width.
- Shrinkage is given by the differences in courses and wales between the target "as delivered" state and the Reference State.

DEVELOPMENT OF THE PREDICTION EQUATIONS

The prediction equations which allow us to calculate the course and wale densities in the Reference State for any given quality of fabric have taken a great deal of time and an enormous quantity of money to discover. In order to do this, we have had to produce more than two and a half thousand different qualities of fabrics, subject them all to commercial wet processing procedures of many different types, and carry out extensive laboratory testing on the fabrics both "as delivered" and after relaxation to the Reference State. This yielded a very large data base which was then subjected to comprehensive mathematical analysis in order to discover the underlying relationships.

Once these underlying relationships were known, then it was possible to build a special computer program, which would allow the dimensions after shrinking for any fabric within the original database to be calculated very rapidly. The computer program, and the technology for upgrading the performance of cotton circular knitted fabrics which has been built up around it, have been called "**STARFISH**".

In the first phase of the project, we collected and analysed a wide range of data on plain single jersey, 1x1 rib, and interlock fabrics made with combed ring yarns. These fabrics were all incorporated in the first commercially released computer program, which was called **STARFISH VERSION 4**. About 50 copies of this first program are in use all around the world on IBM - compatible personal computers.

In a second phase, additional data was collected including, for example, data on plain jersey fabrics made from open-end rotor spun yarns and from carded yarns, and also on single jersey crosstuck (pique) fabrics. In addition, a brand new analysis of the larger database was carried out. This has resulted in a new set of equations with a significant improvement in reliability and also has allowed us to increase the range of wet processing treatments which can be modelled by the program.

Therefore, we have been able to develop a new, upgraded computer program - called **STARFISH VERSION 5.0** - which was announced officially for the first time in Japan, in July 1992, and is now being made available world-wide.

The collection of data and the analysis and interpretation of the database is still continuing. We are currently examining plain jersey and interlock fabrics made from open-end rotor yarns and we are looking at the effect of twist and twist liveliness on fabric dimensions and spirality. We also have extensive data on the effect of crosslinking (resin finishing) on several fabric types and we are beginning to collect data on single jersey loopback (fleecy) fabrics. These new data will be analysed and the results will be incorporated into future upgrades of the system.

Three further points should perhaps be mentioned in connection with the collection of the **STARFISH** database. The first is that almost all of the fabric samples have been manufactured and processed under fully commercial conditions, so that the results are a realistic representation of practical large-scale operations in the industry.

The second is that, we have been fortunate in securing a very broad measure of support from the industry in preparing these samples. In order to carry out the necessary trials, co-operating mills were required to disrupt their normal production by setting up knitting machinery and wet processing equipment to produce and finish large quantities of non - standard as well as standard qualities, and at the same time to allow our technical staff to closely monitor all aspects of the production and processing.

The third is that the validity of the **STARFISH** equations has been extensively checked by means of case studies carried out in the industry. This is done by taking random samples over a period of time from the standard production of individual fabric qualities. When enough samples are available, we can obtain a good idea of the normal random variation to be expected in commercial production. If we calculate the mean and standard deviation from the measurements for each property of interest for a given quality, then we can say that, to a first approximation, the difference between the mean value and the value predicted by **STARFISH** should be less than one standard deviation most of the time. About 95% of the measured values should be within two standard deviations of the predicted value. Several sampling exercises of this type have been undertaken and it has been found that the **STARFISH** predictions are in fact usually contained within the normal production variations.

The original research, together with the validation exercises, has required the development of a tremendous level of co-operation and trust with several manufacturing companies as well as a large degree of foresight and quite some investment in time, facilities and lost production efficiency by those companies involved. The work has been carried out over a very wide geographical area, including companies and research institutes in Brazil, Denmark, Germany, Italy, Japan, Portugal, Sweden, Switzerland, USA, and Great Britain.

THE STARFISH COMPUTER PROGRAM

The name **STARFISH** is contracted from the phrase "**START** as you mean to **FINISH**". It embodies the principle that, in order to know how to produce a knitted fabric with the desired dimensions and performance, we must first have an accurate knowledge of the final finished product. For example, we must be able to calculate in advance what will be the consequences, in terms of final fabric performance, of finishing a given quality of fabric to specified targets of weight and width using a specified wet processing regime.

Once the equations of the Reference State are available, they can be used to calculate the Reference Dimensions of any conceivable fabric quality within the range of the database. When the Reference Dimensions are known, it is easy to find out what the gross, "as delivered" dimensions must be in order to guarantee a given level of weight and width, and to calculate what will be the corresponding shrinkage. Conversely, if the target finished weight and width are specified, then it is easy to discover what fabric quality has to be knitted in order to be able to guarantee a given level of shrinkage.

In effect, the **STARFISH** computer program is a simulator; it models the key elements in the production and processing of circular knitted cotton fabrics and calculates their expected performance. This means that in the space of a few minutes, a yarn and knitting machine can be selected, the fabric tightness specified, an appropriate wet finishing process selected, the desired "as delivered" finishing targets indicated, and the weight, width, and shrinkage of the finished fabric discovered without spending a penny on materials and processing.

If the simulation does not match the desired performance, then the key production elements can be altered repeatedly until a suitable fabric quality is found. In this way, large scale product development exercises can be carried out in a very short time and at very little cost. In addition, the desires and demands of customers can very quickly be checked out against what is really possible, so that orders which are bound to give production problems can be avoided or can be amended during discussion with the customer.

With the **STARFISH** computer program available, the central problem of defining a proper production specification to achieve particular performance targets has been solved in a very effective and satisfying manner, at least for plain jersey, single jersey crosstuck, 1x1 rib, and interlock fabrics. However, this knowledge alone is not sufficient to guarantee consistent performance levels for two reasons.

The first reason is that the **STARFISH** predictions refer to *average* performance values and they assume that the specified production conditions are being strictly maintained. In practice, there is always some variation in control of production conditions and this means that there will be variation in performance. Therefore, the first essential component of the introduction of the **STARFISH** system into any manufacturing regime must be an increased awareness of quality assurance and quality control and much closer attention to the key factors in production which lead to avoidable variations in the product. This aspect of the **STARFISH** system is summarised in the Reference Manual which accompanies the software, but it is treated in greater depth in the special **STARFISH** training courses.

The second reason is that, although the computer program is able to help in the setting of proper targets for the finisher - for example in terms of the length and width which must be delivered in order to achieve specified performance targets - it does not tell the finisher how to achieve these targets in practice. Therefore, the second essential component which accompanies the introduction of the **STARFISH** system is the latest finishing technology and know how. If a really good performance (i.e. low shrinkage) is required, then it will be found that the traditional finishing technology may not be adequate - especially for some of the more difficult fabrics such as interlock and single jersey crosstuck. It goes without saying, of course, that additional attention to certain aspects of quality control is also necessary in the finishing plant. The question of finishing technology, as well as quality control in the finishing plant is also covered in the **STARFISH** Reference Manual and training courses.

Thus, we see that upgrading the performance of cotton circular knitgoods in general requires three main elements, each of which is dependent upon the other.

1. A rational system of fabric engineering based on the ability to predict the dimensions of the fabric in its Reference State.
2. The introduction of specifically targeted Quality Assurance and Quality Control systems.
3. The installation of the latest finishing technology and the application of the corresponding technical know-how.

Item 1 is supplied by the **STARFISH** computer program. Items 2 and 3 are summarised in the Reference Manual and are treated in depth by the **STARFISH** training courses.