# INFLUENCE OF THE SPINNER ON THE SHRINKAGE OF COTTON CIRCULAR KNITS

**S. Allan Heap & Jill C. Stevens, Cotton Technology International, Stockport, U.K.**

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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:

Length Shrinkage % = 100 * (Lo - Lr) / Lo [1]

Width Shrinkage % = 100 * (Xo - Xr) / Xo [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:

Length Shrinkage % = 100 * (Cr - Co) / Cr [3]

Width Shrinkage % = 100 * (Wr - Wo) / Wr [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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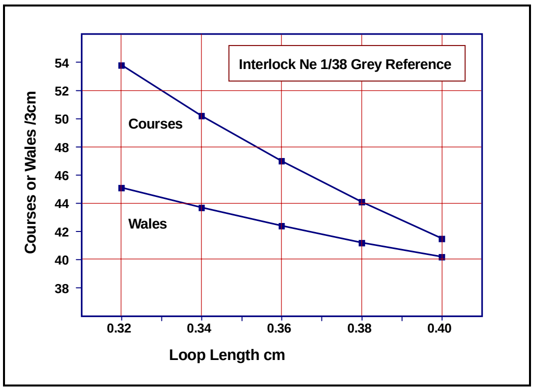
## FIGURES AND TABLES

### *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.

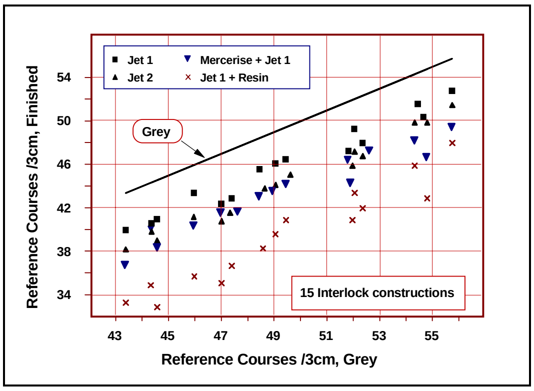
| Count | Origin | Courses | Wales |
|---|---|---|---|
| **Ne 22** | Texas | 12.82 | 10.42 |
| | Californian | 12.59 | 10.62 |
| | **Difference %** | **1.8** | **-1.9** |
| **Ne 26** | Texas | 14.09 | 11.44 |
| | Californian | 13.69 | 11.59 |
| | **Difference %** | **2.8** | **-1.3** |
| **Ne 30** |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

### *Figure 1*



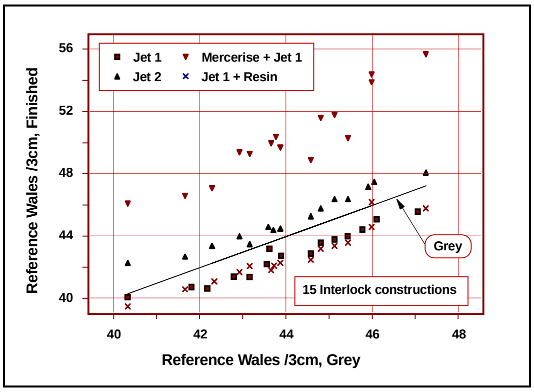
Effect of Loop Length on Course and Wale Densities in the Reference State

### *Figure 2*



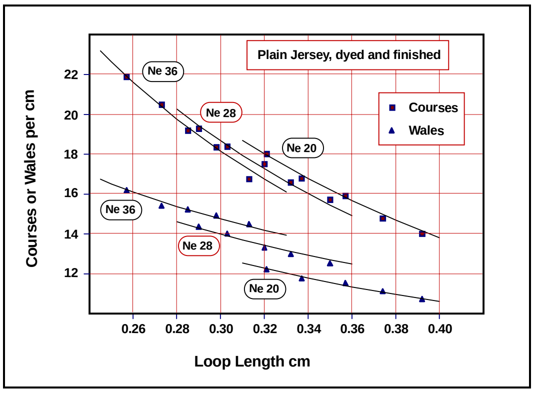
Effect of Wet Processing on Reference Courses

***Figure 3***



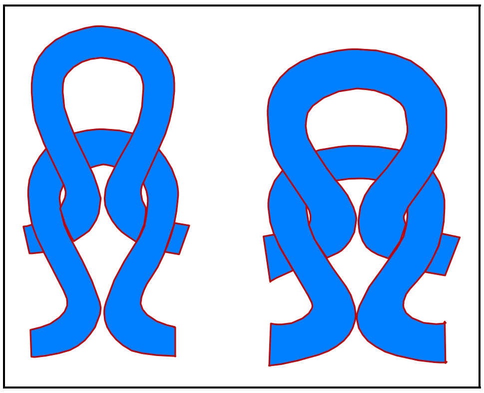
Effect of Wet Processing on Reference Wales

***Figure 4***



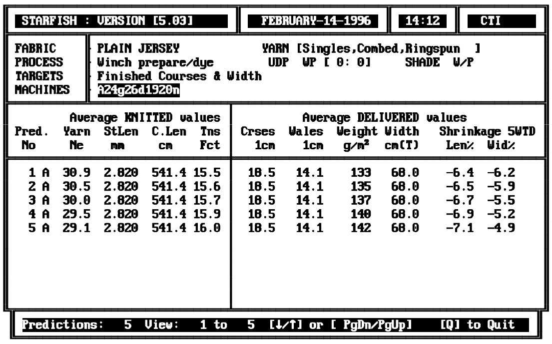
Effect of Yarn Count on Course and Wale Densities in the Reference State

***Figure 5***



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

***Figure 6***



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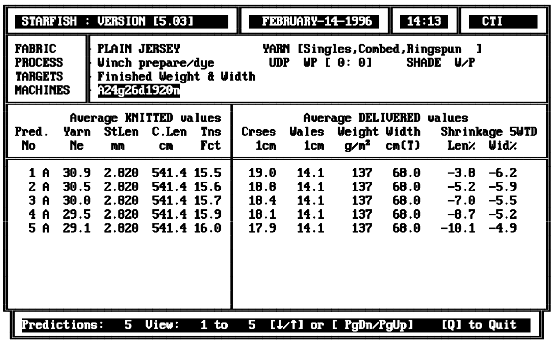
STARFISH Screen Shot - Plain Jersey. Delivery at Constant Length and Width

***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

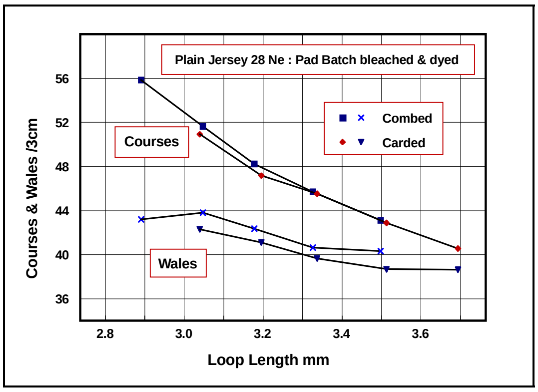
           Average KNITTED values         Average DELIVERED values
Pred.  Yarn  StLen  C.Len  Tns    Crses   Wales  Weight Width   Shrinkage 5WTD
 No     Ne    mm     cm    Fct     1cm     1cm    g/m²  cm(T)    Len%  Wid%

  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
```

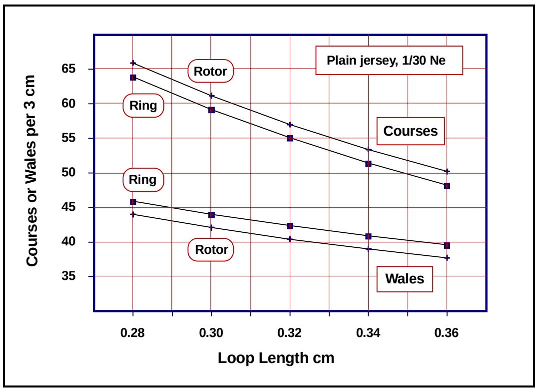
STARFISH Screen Shot - Plain Jersey. Delivery at Constant Weight and Width

***Figure 8***



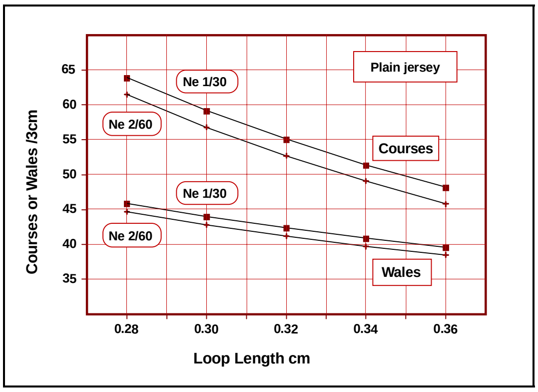
Carded vs Combed Ring Yarns

***Figure 9***



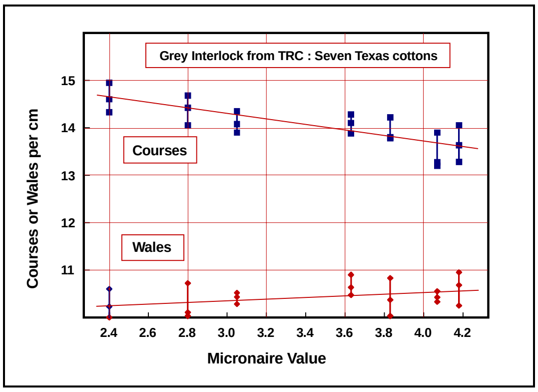
Combed Ring vs Carded Rotor Yarn

***Figure 10***



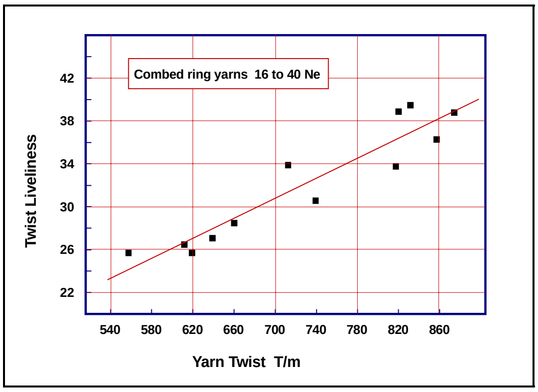
Singles vs Two-Fold Yarns

***Figure 11***



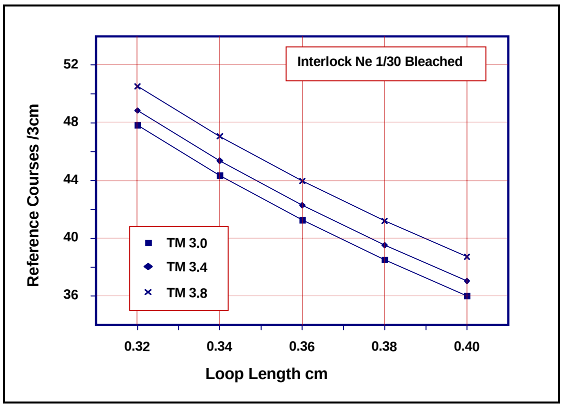
Effect of Micronaire Value on Course and Wale Densities in the Reference State

***Figure 12***



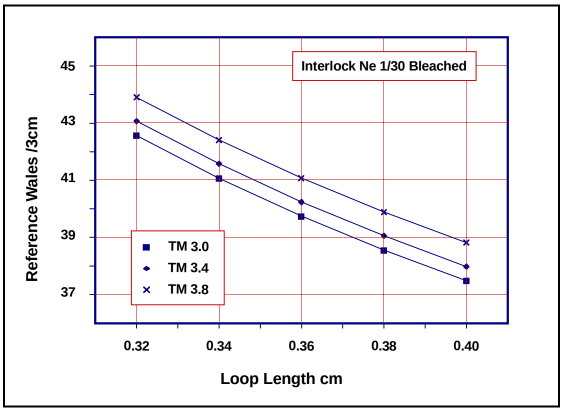
Twist Liveliness as a Function of Yarn Twist

***Figure 13***



Effect of Yarn Twist Multiple (TM) on Reference Courses

***Figure 14***



Effect of Yarn Twist Multiple (TM) on Reference Wales

**For further information, please contact:**

**Cotton Technology International**
27 Winnington Road, Marple, Stockport SK6 6PD, UK

Phone: + 44 (0)161 449 5593 : Fax: +44 (0)161 449 5594 : email: cotton.tech@virgin.net