Shrinkage and the Reference State

Introduction

Shrinkage is the change in dimensions of a sample of fabric brought about by some relaxation process, such as domestic laundering.

The fundamental structural unit of a knitted fabric is the loop. Any circular knitted fabric is composed of row after row of interlaced loops. Different types of fabric are made by different methods of interlacing the loops. Therefore, the gross 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 of fabric. Likewise, shrinkage is a reflection of a change in the average shape and size of the loops, caused by the laundering process.

There are four major sets of production variables that affect the average shape and size of the loops.

Knitting Variables

So far as the average dimensions of the loop are concerned, the most important knitting variables are: -

- The type and size of the yarn (yarn count, twist, spinning system). The type and size of the yarn governs the weight of each loop and also determines its shape (height/width/thickness).
- The average length of yarn in each loop (stitch length). The average length of yarn in the loop determines its weight and also the overall size of the loop (number of loops per unit area).
- In addition, 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.

Wet Process Variables

The effect of wet processing is to: -

- Change the **weight** of the yarn, by removing impurities and adding chemicals, such as dyestuffs and lubricants.
- Change the average **length** of yarn in each loop, through yarn shrinkage.
- Change the **shape** of each loop, mainly by changing the bulk, stiffness, and twist liveliness of the yarn.

Different types of wet processing Procedure change the weight, length, and shape of the loops by different amounts.

Stretching During Processing

During knitting, wet processing, and other handling operations, the fabric is subjected to tensions of varying degrees in both length and width directions at different times. The amount of stretching or contraction suffered by the fabric depends on the particular procedures used. These changes in gross fabric dimensions alter the length, the width, and the weight per unit area of the fabric and cause corresponding changes in the average shape of the loops. A fabric that has been pulled out in the length and allowed to contract in the width will contain very elongated loops, i.e. loops with a high ratio of height to width. It will consequently exhibit a high degree of length shrinkage.

Relaxation Treatments

A fabric which has been stretched during processing and handling contains potential energy which can be released during a wet relaxation treatment - such as home laundering - aided by swelling of the yarns. Shrinkage of cotton knitted garments is mainly the relaxation of strains, which have been imposed during manufacture. Some relaxation treatments are more effective at relieving strains than others. The most effective relaxation treatment is a vigorous (tension-free) wash followed by (tension-free) tumble-drying.

Therefore, 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.

But this simple statement conceals a more complicated question. What exactly is meant by "after shrinking"?

Different methods of testing for shrinkage will give different answers on the same fabric. The most obvious example is that when a tumble dryer is used as part of the test method, then the level of shrinkage recorded will be greater - sometimes much greater - than when a tumble dryer is not used.

In the case of a particular customer, obviously "after shrinking" means "according to the test method which the customer uses himself". But most manufacturers have more than one customer and these customers 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.

One thing that is certain is that, in order to be able to develop a system for predicting the dimensions of fabrics after shrinking, the shrinkage test to be used has to be very reliable and reproducible. It also should be one that will induce the maximum possible amount of shrinkage in a given fabric so that all different types of laundering conditions can be allowed for.

Over a period of several years, we have carried out very extensive studies of the shrinkage of cotton knits. From the results of this research it was concluded that the most representative and the most reproducible method of test was one which includes multiple cycles of washing and tumble-drying. We have therefore defined a REFERENCE RELAXATION PROCEDURE, which comprises five cycles of washing and tumble drying.

After a sample of fabric has been subjected to this Reference Relaxation Procedure, it is said to be in its REFERENCE STATE.

The STARFISH Reference State

The concept of the Reference State is fundamental to the use of the STARFISH technology. It is the foundation upon which the computer prediction program is built and it is the means by which the influence of the key production and processing parameters, and their effect on the final performance and dimensions of the finished fabrics can be quantified.

The Reference State is essentially a basis for making reliable and valid comparisons across different fabric types and qualities.

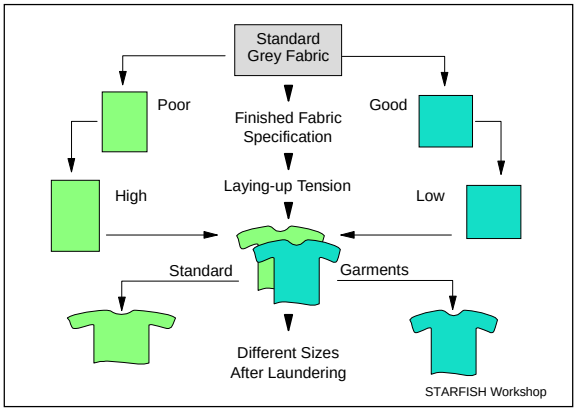
Most cotton knitted fabrics, which are encountered in the normal course of events, are distorted to some extent - this is the reason why they will shrink during laundering. The distortion begins at the knitting machine and continues all the way through the production chain. But different fabrics will be distorted to different degrees, at different times, depending on their basic characteristics and on their manufacturing history. Unless he takes deliberate steps to do so, a manufacturer or a retailer will never come across an undistorted fabric. The only person who ever sees a completely undistorted fabric (in the sense that it will not shrink significantly more) is the person who has purchased the garment and has laundered it for a sufficient number of times so that it is incapable of further shrinkage.

If we want to develop a rational system of fabric engineering and quality control then it is vitally important to be able to compare different fabrics, and different qualities of a given fabric type, at various stages of manufacture. It is also extremely important to be able to look at a given quality and be able to assess what total level of distortion is present in the fabric, because this is a true measure of its potential performance in the hands of our immediate customer and, more importantly, in the hands of the ultimate consumer.

In other words, for any given product at any given stage, we want to be able to establish its "Distortion Status".

These problems of making comparisons and assessing distortion levels are usually handled in practice by making shrinkage tests. Such tests are done frequently for routine quality control purposes at one or more stages in the manufacturing chain. Over a period of time the manufacturer or retailer should learn how to interpret the average results from his own shrinkage tests in terms of the expected performance of a specific product type and therefore be able to judge the degree of satisfaction of the ultimate consumer. But shrinkage tests are not very reproducible from time to time and from laboratory to laboratory, even when the basic test method is supposed to be identical. If the test methods at different times and in different laboratories are not identical, then the results can be very different indeed.

What is perhaps more serious from the manufacturer's, or the product designer's point of view is that every shrinkage test is, in a way, misdirected. What the shrinkage test reports is simply how much of the distortion present in the product was evident on that particular occasion. It says very little about how much further distortion remains in the product, or what the ultimate characteristics of the product will be after the shrinkage test has been carried out, or how to design and manufacture a better product which will shrink less.



An easy way to visualise this problem is to think about two batches of identical fabrics that are sent to different dyers and finishers. Both finishers have identical equipment but one delivers the fabric with high shrinkage levels, the other with low shrinkage. The two batches are now split into two, making four lots. One lot from each finisher is sent to each of two different garment makers, where the only difference is that one garment maker has tension-free

laying equipment and allows the lays to relax overnight before cutting, whilst the other has a high-tension laying machine and cuts the fabric immediately.

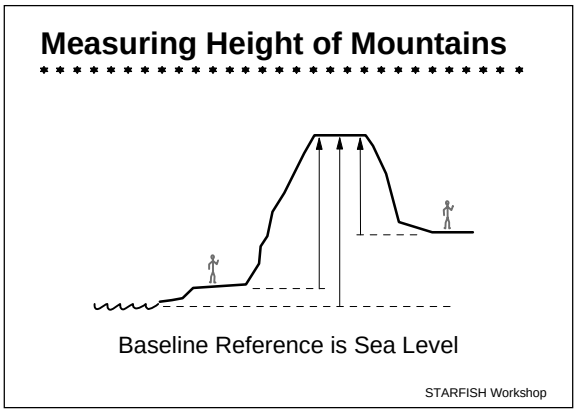
If garments made up from these fabrics are evaluated in the laboratory of a retailer, he will very quickly be able to place them in rank order, according to the results of his shrinkage test. The ones that shrink most will be labelled as "bad" products; the ones that shrink least will be labelled as "good" products.

From the retailer's point of view, of course, the assessment is reasonable, because it will be a reflection of ultimate consumer satisfaction with these particular garments. But the fabrics are, in fact identical with the sole difference of their Distortion Status. Simply reporting shrinkage values does not distinguish between what might be fundamentally different products on the one hand, or nominally identical products which just happen to have a different Distortion Status on the other. Furthermore, it does not identify where in the manufacturing chain the excessive distortion had been introduced.

The distinction is not important to the retailer, because he is interested only in the ultimate performance, but it is vital for the manufacturer who needs to be able to locate the source of the manufacturing problem and put it right. Therefore, in spite of its obvious value as an approximate indicator of ultimate performance, a shrinkage test is not, and can never be, a fundamental basis for comparison of different products because it is one-sided. However, if we were able to measure a product *after all of the distortions have been removed*, then we might have a better basis for comparison. This would be equivalent to setting the Distortion Status to zero.

For example, if the same garments had been subjected to a relaxation procedure that essentially removed all distortions, and then the *course and wale densities*, and perhaps the weight per unit area also, of the different garments had been measured after the relaxation procedure had been carried out, then it would have transpired that all had been made from the same basic fabric. If a similar procedure were also carried out on the fabrics as delivered to the garment maker then the source(s) of the problem would have been immediately obvious.

Looking at shrinkage in this way turns the conventional approach upside down. The conventional shrinkage test relates to the dimensions of the product *before* shrinkage. But these can be imposed more or less arbitrarily by distortions of varying degrees from various sources. The true nature of the fabric, from the point of view of the engineer, has much more to do with its dimensions *after* the shrinkage test. The properties of the completely distortion-free fabric, in particular the number of courses and wales per cm, are a much better representation of the fundamental nature of the product. In this "Reference State" all different products can be compared unambiguously, one with another.



The problem can perhaps be thought of in a similar way to that of expressing the heights of mountains measured in different parts of the world. From the "consumer's" point of view, the important measure of a mountain's height is how far one has to climb, from the valley floor, in order to get to the top. But if we want to be able to make valid comparisons of the true heights of mountains, we need to have a common datum height to use as a reference point. The convention is to use

sea level as the basis, because this is about the same all over the world, and is an unambiguous definition.

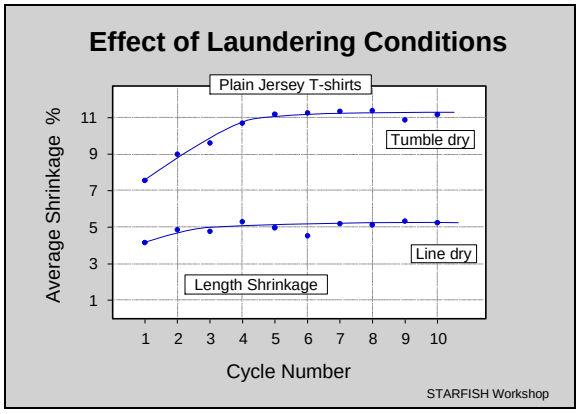
What we are suggesting here, is that the most appropriate and unambiguous reference point for the dimensions of cotton knitted fabrics is when all distortions have been removed. Then the Distortion Status of any knitted fabric is given by the number of courses and wales per cm compared to those that will be found in the Reference State. If we know in advance how many courses and wales will be found in the Reference State then we can simply calculate the shrinkage, without having to do any (unreliable) shrinkage testing.

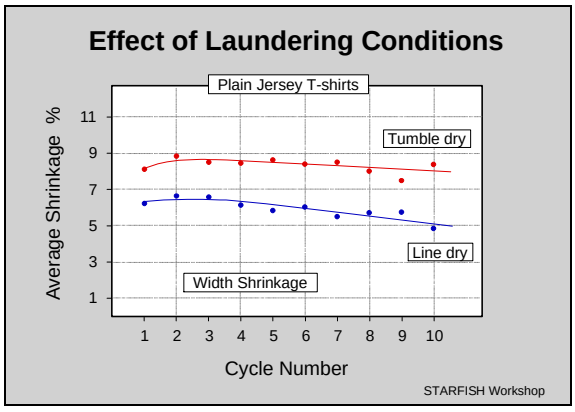
The difference between "Sea Level" and the "Reference Dimensions" of cotton knitted fabrics is that the latter are rather more difficult for a manufacturer to recognise and to measure because they seldom exist within the manufacturing environment.

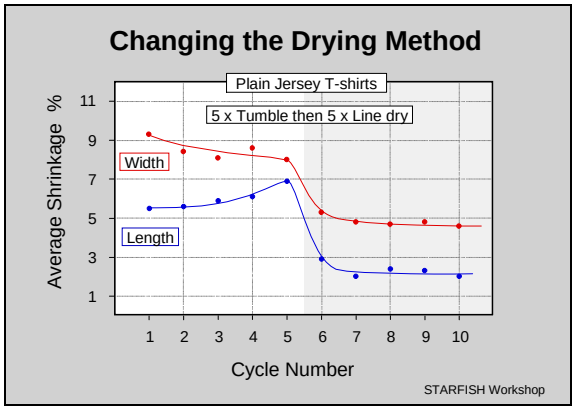
Development of a Reference Relaxation Procedure

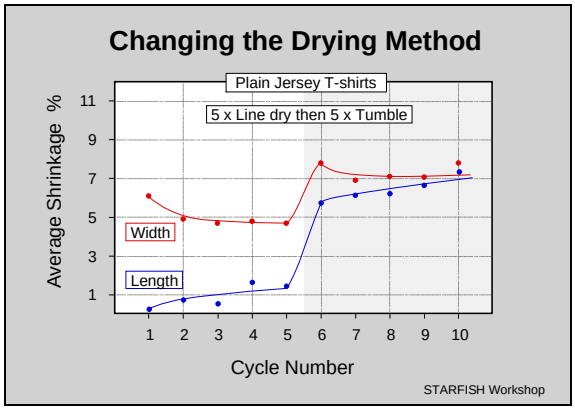
Since the condition of zero distortion is rare, it was necessary to develop a specific procedure in order to produce it at will in any given fabric quality.

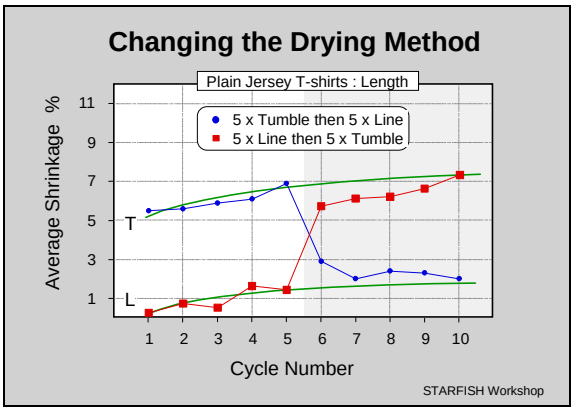
Accordingly, a large program of research was carried out which examined the various conditions of laundering and drying processes in order to be able to characterise a procedure which would be capable of generating the Zero Distortion State in cotton knits in a reliable and reproducible way. Zero distortion is defined as the most stable dimensions (course and wale densities) which are possible to achieve using domestic type laundering procedures.

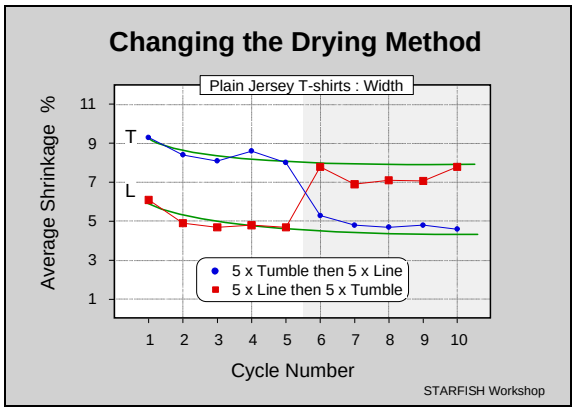


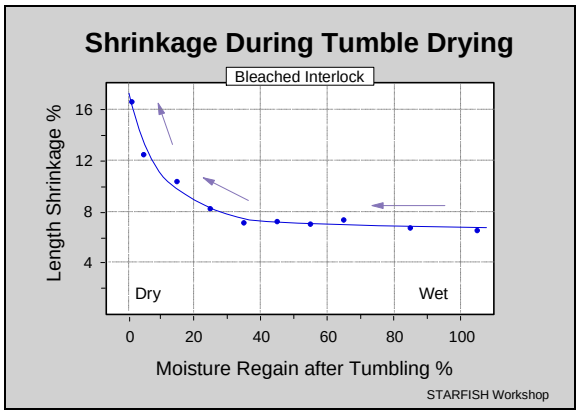


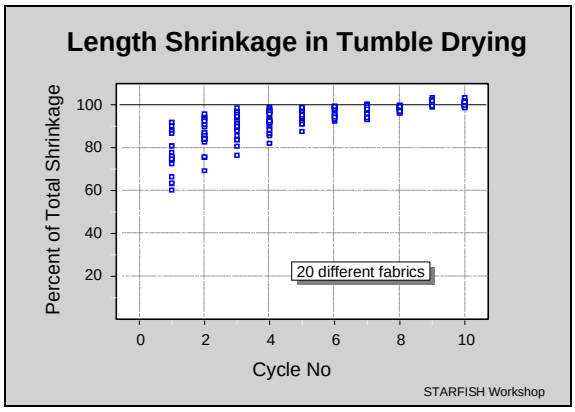












There were already clues in the technical literature that the required procedure would most probably include multiple cycles of washing and tumble drying, but many different aspects of relaxation treatments were actually investigated. For the purposes of the present discussion, it is sufficient to note the following points.

- The Zero Distortion State, which would be our true Reference State, is best achieved by using multiple cycles of washing, and tumble drying under certain defined conditions. Procedures which did not include tumble drying (such as line drying, flat drying) gave less, or less rapid relaxation and also led to higher levels of variability in the subsequent dimensional measurements.
- The number of cycles of washing and tumble drying which were needed to achieve the Zero Distortion State depended on the fabric type and its wet processing history.
- For a complete relaxation, there were some fabric qualities which required up to twenty cycles of laundering. These were generally fabrics which had been through a very drastic wet processing, such as mercerising, and/or had been delivered with very high levels of distortion. Certain fabric types (interlock, crosstuck) were found to relax over a larger number of cycles than others (plain jersey).
- Almost all fabrics investigated were very close to their ultimate level of relaxation after ten cycles and most fabrics were within about 95% of their ultimate relaxation after five cycles. Such fabrics could probably be compared as being equivalent in their degree of relaxation without too much loss of accuracy.
- After a single laundering cycle, there were pronounced differences between many fabric types in their degree of relaxation, so that it is not really acceptable to make comparisons between such fabrics.
- During tumble drying, the drying machine should not be overloaded and it is important to dry the fabrics completely (less than 2% Regain). The final moisture

content after drying affects the dimensions significantly. If the whole dryer load is not completely dry, then there is a good chance that some parts of some samples will still be damp. Ideally, the samples should then be allowed to cool and recondition properly before any measurements are taken, since the absorption of the natural moisture causes the dimensions to change.

- It is the tumble-drying part of the procedure, which produces the relaxation. The function of the washing is simply to have the fabric thoroughly wet. Therefore, the precise washing conditions are not critical when the fabrics are subsequently to be tumble-dried. It is advisable that the first wash should be a thorough one, say at 60 degrees with normal household detergent, so that the fabric is made absorbent. Subsequent "washes" may consist simply of wetting and spinning. The most convenient method is to use the rinse cycle of a normal domestic automatic washing machine.
- The type of detergent seems not to be important in the first wash but the use of fabric "conditioners", or softeners should be avoided. Although one may argue that a softener, or lubricant would aid in the achievement of zero distortion, it was found that they are unpredictable in their effects and serve mainly to increase the level of variability in the subsequent dimensional measurements.

After all of these results (and others) had been taken into consideration, a Reference Relaxation Procedure was defined as follows.

1. Wash in an automatic, domestic washing machine, using the 60°C wash programme, with domestic detergent, but no added softener or conditioner.
2. Tumble dry in a domestic tumbler, with a moderate load, until the samples achieve a constant weight.
3. Re-wet in the washing machine using the rinse cycle.
4. Tumble dry to constant weight.
5. Repeat steps 3 and 4 three more times, making five cycles in all.
6. Condition to normal regain.

This is the STARFISH Reference Relaxation Procedure. It does not achieve the ultimate Zero Distortion State for all fabrics but it comes very close for most and is a reliable basis for making comparisons. A fabric that has been subjected to this procedure is said to be in its Reference State, and its dimensional properties are the Reference Dimensions.

When developing new products, when evaluating new processes, or when establishing calibration factors of any type, the use of the STARFISH Reference Relaxation Procedure is to be recommended as a preliminary to establishing the Reference Dimensions. However, it is not recommended as a routine quality control test.