STARFISH Reference State

Introduction

The concept of the Reference State is fundamental to the use of the STARFISH Technology. It is the foundation upon which the STARFISH software is built and it is the means by which the influence of the key production and processing parameters, and their effect on the properties of the finished fabrics can be quantified.

To develop (and to utilise) a rational system of fabric engineering and quality control it is necessary to be able to compare different fabrics, and different qualities of a given fabric type, at various stages of manufacture, in an unambiguous way.

It is also important to be able to look at a given fabric (or garment) and be able to assess what total level of distortion is present, because this is a true measure of its potential performance in the hands of the ultimate consumer.

Most cotton knitted fabrics that 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. However, 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.

This is a curious oversight on the part of the fabric manufacturer since it is the distortion-free state of his fabrics upon which his competence ultimately will be judged.

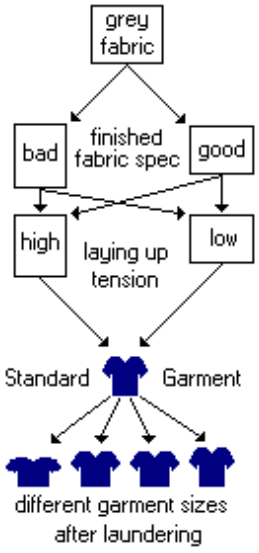
The Reference State provides the manufacturer with the basis for making reliable and valid comparisons across different fabric types and qualities since it represents the nearest approach to a distortion-free fabric that can be attained economically by practical testing procedures.

The concept of the Reference State as a condition of zero distortion is a more fruitful one for the fabric manufacturer than a shrinkage-based way of thinking about product design and performance.

Distortion Status and Shrinkage

The problem of making comparisons and assessing distortion levels in fabrics and garments is 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 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.



However, 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, nor what the ultimate characteristics of the product will be after all of the distortion has been removed. Furthermore, it does not provide any information about how to design and manufacture a better product that 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-up 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 four fabric lots are evaluated in the laboratory of a retailer, they can quickly be placed in rank order, according to the results of the retailer's 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 basic 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, or identical products that just happen to have a different Distortion Status. Furthermore, it does not identify where in the manufacturing chain the excessive distortion has been introduced.

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

The distinction is not important to the retailer, because he is interested only in the ultimate performance of the garments, but it is vital for the manufacturer who needs to be able to locate the source of the manufacturing problem and put it right.

Distortion Status and the Reference State

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, or the same product at different stages, because it is one-sided.

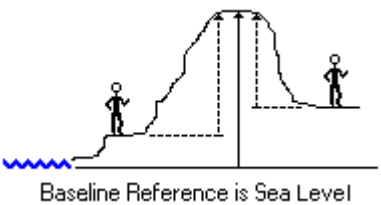
The shrinkage test simply reports how much distortion is present in a fabric or garment on the particular occasion that the test was carried out. It says very little about how much further distortion remains in the product, nor what the ultimate characteristics of the product will be after all of the distortion has been removed.

On the other hand, if the product is measured after all of the distortions have been removed, then it is possible to make a better comparison. This would be equivalent to setting the "Distortion Status" to zero.

Looking at shrinkage in this way turns the conventional approach upside down. The conventional shrinkage test relates to the dimensions of the product before relaxation. But these dimensions 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 unit length, 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 concept 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 to be able to make valid comparisons of the true heights of mountains, a common datum height is required 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.

The suggestion is that, by analogy, 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 unit length compared to those that will be found in the Reference State. If the number of courses and wales that will be found in the Reference State are known in advance then the full extent of any potential shrinkage can simply be calculated, 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.

Predicting the Reference Dimensions

It is important to distinguish between those factors that influence only the gross dimensions of the fabric and those that affect the Reference Dimensions. Factors that alter the Reference Dimensions are those that cause a permanent change in the shape and size of the loops whereas those that alter only the gross dimensions cause only temporary or reversible distortions.

For practical purposes, it can be said that the Reference Dimensions are affected only by the major knitting variables – Yarn Quality and Stitch Length - and the type of Wet Processing that is used.

In other words, once the knitting machine, the Yarn Type and Size, the Stitch Length and the type of Wet Process have been fixed, then for all practical purposes the Reference Dimensions have been fully determined. There is nothing that can be done to change the dimensions that this particular quality of fabric will have after relaxation (e.g. after a shrinkage test).

The effect of stretching (or relaxation) during processing is to determine the Distortion Status i.e. how far the gross dimensions of the fabric (as delivered to the garment maker) will be from its Reference Dimensions.

The difference between the gross, "as delivered" dimensions and the Reference Dimensions is the total amount of shrinkage that the fabric is capable of.

For a given quality, the finisher does not have much choice in the type of wet process that he will use. He is constrained by the equipment at his disposal and the colour and the fastness properties required. This leads to a very important conclusion.

For a given fabric quality and wet processing route, i.e. under normal circumstances, the Reference Dimensions are determined by the knitter - there is nothing that the finisher can do to alter them.

What the finisher controls is the gross, "as delivered" dimensions.

If the "as delivered" dimensions are rigidly fixed by the customer, in the form of a specification for weight and width, with very close tolerances, then the finisher can have very little influence upon the shrinkage of the final fabric.

From this simple analysis, it now becomes clear that, in order to set up a system for predicting (and therefore controlling) the dimensions and shrinkage of cotton knitgoods, the first requirement is to be able to calculate the Reference Dimensions, starting 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 that link the dimensions of a given fabric in its Reference State to the yarn type and size, the knitting machine used, the average stitch length, and the wet process route. Comparison of the Reference Dimensions with the specification demanded by the customer will then yield the values for weight, width and shrinkage in the "as delivered" cloth.

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 in the STARFISH Reference State. This is because all of the other properties that are of interest can be derived from these and from the target 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 "as delivered" specification and the Reference State.

The equations that predict Course and Wale densities in dyed and finished fabrics have been discovered, for certain types of fabrics, after a very extensive research program that has lasted more than 30 years and is still running. They are called the STARFISH Reference State Equations.

Developing a Reference Relaxation Procedure

To develop (and to utilise) a rational system of fabric engineering and quality control it is necessary to be able to compare different fabrics, and different qualities of a given fabric type, at various stages of manufacture, in an unambiguous way.

It is also important to be able to look at a given fabric (or garment) and be able to assess what total level of distortion is present, because this is a true measure of its potential performance in the hands of the ultimate consumer.

To do this it is necessary to know what will be the dimensions of the fabric when all of the distortions have been removed. In other words when the fabric is in a state of Zero Distortion. If the number of courses and wales that will be found in this Zero Distortion State are known in advance then the full extent of any potential shrinkage can simply be calculated, without having to do any (unreliable) shrinkage testing.

Since the condition of Zero Distortion is rare it was necessary to develop a specific procedure in order to produce it (or at least to approximate it) at will in any given fabric quality.

To this end, a large program of research was carried out that examined the various conditions of laundering and drying processes in order to be able to characterise a procedure that would be capable of generating the condition of Zero Distortion in cotton knits in a reliable and reproducible way.

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.

Research Summary

The major findings of the background research that lead to the development of the STARFISH Reference Relaxation Procedure can be summarised as follows:

- The Zero Distortion or true Reference State, is best achieved by using multiple cycles of washing, and tumble-drying under certain defined conditions.
- Procedures that do not include tumble-drying (such as line drying, flat drying) give less, or less rapid relaxation and also lead to higher levels of variability in the subsequent dimensional measurements.
- The number of cycles of washing and tumble-drying that are needed to achieve the Zero Distortion State depends on the fabric type and its wet processing history.
- For a complete relaxation, there are some fabric qualities that require up to twenty cycles of laundering. These are generally fabrics that have been through a very drastic wet processing, such as mercerising, and / or have been delivered with very high levels of distortion.
- Certain fabric types (Interlock, Crosstuck) 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 only a single laundering cycle, there are 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 that produces the relaxation. The function of the washing is simply to have the fabric thoroughly wet. The precise washing conditions are not critical when the fabrics are subsequently to be tumble-dried.
- It is advisable that the first wash is a thorough one, say at 60 °Celsius with normal household detergent, so that the fabric is made absorbent. Subsequent "washes" can 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 it can be argued that a softener, or lubricant can aid 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.

STARFISH Reference Relaxation Procedure

The STARFISH Reference Relaxation Procedure is defined as follows.

1. Wash in an automatic, domestic washing machine, using the 60 °Celsius 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.
6. Condition to normal regain.

The STARFISH Reference Relaxation Procedure 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.

It is not recommended as a routine quality control test.

Shrinkage and the Reference State

In STARFISH, shrinkage is defined as the change in fabric dimensions brought about by means of the Reference Relaxation Procedure.

The Reference Relaxation Procedure is both time consuming and relatively costly. Therefore it cannot really be used (and is not intended as) a routine Quality Control procedure when fabric shrinkage measurements are required. Nevertheless, it is useful to know how results obtained using the Reference Procedure compare with the relaxation procedures that are more normally used for shrinkage testing either by the in-house QC department or by customers.

Shrinkage values predicted by the STARFISH software are based on the Reference Dimensions and therefore they predict the (average) worst case that the product will ever encounter. Any less demanding conditions will result in better performance.

For example:

- There are many customers who assess performance according to line dry, or flat dry testing methods.
- There are many countries in the world where tumble dryers are hardly if ever used.

In the former case, it is very tempting to deliver to the customer the performance that he requests, even though the STARFISH predictions may reveal that the product would not perform adequately to a multiple cycle tumble-drying test. In the long run, this could be a mistake since the ultimate consumer will soon discover the true performance of the product and may not buy again from that customer.

In the latter case, if the ultimate consumer will never see the Reference State, then he or she will still be satisfied with the product at a relatively high level of distortion, which nevertheless gives adequate performance after line drying. Even so, it is good practice to try to avoid the application of double quality standards where they are not really necessary.

For some fabric types the difference between the shrinkage measured with a tumble-drying test can be so much larger than that measured by a line drying test that it becomes difficult to select an appropriate level of distortion that is acceptable to consumers in markets where both types of laundering procedures are common.

Sometimes the situation can arise where a product is designed to have a low shrinkage to tumble-drying but will actually extend considerably in the width if it is only ever line dried. This is usually seen as an undesirable characteristic.

Conversely, a product that is designed to have a moderate shrinkage in a line dry test may shrink to an unacceptably large degree if it is occasionally subjected to tumble-drying.

Some examples are given in the following table.

Development of Shrinkage in Washing, Line Drying and Tumble-drying

Fabric Type	Length Shrinkage %				Width Shrinkage %			
	AW	LD	TD	TD-LD	AW	LD	TD	TD-LD
Mercerised Crosstuck	3.0	6.9	15.1	8.2	-7.2	-7.4	0.4	7.8
Bleached Interlock	13.5	17.1	15.6	-1.5	1.2	-2.2	9.5	11.7
Striped 1x1 Rib	14.3	13.3	14.5	1.2	0.5	-4.9	5.1	10.0
Mercerised Single Jersey	2.9	3.6	11.1	7.5	-3.3	0	3.3	3.3

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

AW = After 1 cycle washing, before drying

LD = After 1 cycle washing and line drying

TD = After 1 cycle washing and tumble-drying

In the overwhelming majority of cases, some careful thought in the design stage will produce an acceptable compromise but in extreme cases, it may be necessary, or advisable to supply a "do not tumble-dry" label in the garment as a last resort. In any event, if the manufacturer has determined the Reference State of his product, and if he is aware of the different level of shrinkage (or extension) to be expected after line drying, then a rational discussion can be held with the customer so that unexpected situations do not arise and lead to a loss of confidence and reputation.

Some of the differences that can be found in shrinkage measurements returned by different types of relaxation procedure can be summarised as follows:

1. Line-drying usually develops less shrinkage than tumble-drying, although the size of the difference depends on the fabric type and the processing history.
2. Length shrinkage shows a tendency to increase with the number of laundering cycles. After the first cycle, width shrinkage shows a tendency to decrease - particularly in Interlock and Rib fabrics. These fabric types often grow in the width direction.
3. Tumble-drying of fabrics that previously have only been line dried will increase the level of shrinkage, but not necessarily to as high a level as if the fabrics had been tumble-dried from new.

4. Line-drying of fabrics that previously have only been tumble-dried can recover some of the shrinkage, but it will not usually fall as low as if the product had never been tumble-dried.

It is important that each individual manufacturer checks the comparison for his own relaxation test method on his own products.