TECHNICAL BULLETIN

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ISP 1009

A GUIDE TO IMPROVED SHRINKAGE PERFORMANCE OF COTTON FABRICS

This report is sponsored by the Importer Support Program and written to address the technical needs of product sourcers.

INTRODUCTION

Product specifications of textile and apparel products have always had a profound effect on the thinking and planning of managers in all areas of textile and apparel production. In today's competitive markets where quality is expected at a low price, apparel companies are demanding low shrinkage from their suppliers to meet the needs of the consumer. In addition to low values, the shrinkage from garment to garment for the same style must be consistent. Traditionally, apparel manufacturers have set rigid specifications for their suppliers that in many cases allow little room for error in processing. In fact, some shrinkage specifications for apparel products may not be attainable at all by the suppliers of that product.

In addition, many testing methods have been devised to measure shrinkage. Acceptance, rejection, and discount penalties are dependant on this gathered data. Further, in depth analysis of this data can allow for a better understanding of the causes of inconsistent or high shrinkage. A better understanding can then impact production techniques to make the shrinkage phenomena manageable. Indeed, more realistic specifications for a finished product can then be set for a fabric or garment based on the knowledge learned. This knowledge can also impact other product specifications such as weight and width as well as the determination of garment pattern layouts. Even with this knowledge, it is often overlooked as to how these specifications can limit a mill's ability to manufacture goods that yield good shrinkage characteristics on a consistent basis. Therefore, in order to be successful in controlling shrinkage, there must be an understanding by all parties involved in bringing a product to market as to what makes a fabric or garment shrink. The discussion that follows will be focused on fabrics.

SHRINKAGE DEFINED

The term ***shrinkage*** can simply be defined as *a change in the dimensions of a fabric or garment*. This dimensional change may be in a positive (growth) or negative (shrinkage) direction for fabric length, width, and thickness. Although the thickness of a fabric changes with processing and use, it is not a consideration in this discussion. For a cotton fabric, shrinkage relates to the loss of the length and/or width dimensions. In garment form, the shrinkage characteristics relate not only to a change in fabric dimensions, but also can relate to other parameters such as seam puckering, torquing, and overall garment fit.

For this discussion, shrinkage can be further defined as *a dimensional change in a fabric or garment caused by an application of a force, energy, or a change in environment that either allows the goods to relax or forces the fabric to move in a given direction.*[1] Cotton fabrics are often predisposed to dimensional instability, especially knits which are very sensitive to applied forces or energies. Therefore, whenever a cotton knit fabric is manipulated in processing, its dimensions will change. If the fabrics are tested for their dimensions after a given process, the results may be different than from the previous process. Obviously then, shrinkage at any step in processing is "***residual***" in nature. By definition, residual is defined as "*something that remains after a part is taken, a remnant, a remainder*." Another viewpoint is defined as "*an internal aftereffect of an experience or activity that influences later behavior.*"[2] From these definitions, it is easy to see that forces in processing that stretch fabric result in more shrinkage, and forces that contract or compress the fabric, result in less shrinkage. Therefore, residual shrinkage will be the amount of shrinkage a fabric contains plus or minus what subsequent processing stresses apply to or remove from the fabric. Poor control of these forces in processing can lead to high garment shrinkage as the aftereffect.

Woven fabrics are much more stable than knitted fabrics and do not react as severely to stresses. However, much lower shrinkage specifications are demanded of wovens thereby making the impact of processing stresses just as important for cotton wovens as they are for knitted goods.

Shrinkage and the cause of shrinkage can be further defined or broken down into two different types: ***construction*** shrinkage and ***processing*** shrinkage. This means that shrinkage is affected by the construction parameters of the fabric, and it is also affected by the forces applied in processing in the dyeing and finishing departments as well as the apparel manufacturing facility.

Construction Shrinkage

After a cotton fabric is constructed on a knitting machine or weaving loom, it has inherent characteristics based solely on the yarn construction variables used. These characteristics or conditions are referred to as the greige delivered state and can be tested for various specifications including shrinkage. The type of shrinkage measured at this point is defined as construction shrinkage. ***Construction shrinkage*** is defined as *the amount of dimensional change in a fabric based solely on the construction variables used to create the fabric.* It is measured after fabrication but before subsequent processes.

Processing Shrinkage

All processing steps in a dyeing and finishing plant and in an apparel manufacturing operation affect the dimensions of a product. Some techniques have more impact than others. These steps create ***processing shrinkage***, which can be defined as *the dimensional change that a process adds to or removes from the construction shrinkage of a fabric*, and thereby changes the residual shrinkage accordingly. Length and width dimensions are both affected, and the fabrics may either be stretched or consolidated. Most often, the length is stretched and the width is reduced during wet processing. Some of this shrinkage is composed of elastic shrinkage and can be easily recovered while some of the change in dimensions may not be recovered, because the elastic limits of the fabric as constructed have been exceeded.

Elastic Shrinkage

Elastic shrinkage is defined as *a change in dimensions of a fabric as a result of the ability of the fabric to freely relax from tensions experienced during construction and other processing.* In the case of cotton greige knit goods, tensions in forming the knitted loop, from the takedown and from spreader mechanisms on a knitting machine, are examples of stresses that may induce elastic shrinkage, which becomes a part of the construction shrinkage. The stress in transporting of fabric in bleaching and dyeing machines as well as finishing operations will also induce elastic shrinkage. Normally, the recovery from elastic stresses (realization of elastic shrinkage) is fairly spontaneous when these stresses are relieved, especially in a dry medium.

It should be realized that because of these stresses during processing, the delivered dimensions that were measured for the greige fabrics are no longer applicable. The residual shrinkage has changed. In fact, the stresses involved may exceed the elastic limit and will prevent the finished fabrics from relaxing or bulking as much as the greige fabrics. Therefore, not only will the residual shrinkage be different, but also the relaxed dimensions of the processed fabrics will be different from the greige fabrics. ***Relaxed dimensions*** are defined as *the state at which a fabric is fully relaxed and will not shrink further as a result of washing and tumble drying.* Relaxed dimensions are also referred to as the ***reference state***.

In today's modern finishing plants, methods are used to attempt to overcome processing shrinkage and reduce construction shrinkage. These methods include relaxation drying, compaction, and/or chemical processes. Relaxation drying and compaction are examples of ***consolidation*** shrinkage. The former occurs naturally by deswelling of the cotton fiber/yarn assembly while applying unrestricted agitation with no tensions in the length or width. The latter is a dry mechanical effect gained by forcing the fabric structure to compact upon itself. The more processes of this type the mill can effectively apply along with linear forces removed from the processing, then the lower and more consistent the amount of shrinkage.

Just as greige and finished dimensions can be measured, the dyer/finisher can also measure the effect of each processing step on fabric shrinkage. Benchmarks for measuring dimensional change can be applied on the greige goods and measured at each point along the processing route. By using this technique of process monitoring, the finisher may realize and correct for any avoidable distortion problems that may occur along the processing route. For example, if the extraction step is shown to stretch the fabric in the length by significant amounts, then the finisher can adjust the machinery to lower the forces applied in this process to thereby reduce the distortion and lower shrinkage. The initial reaction of most management teams is that they cannot afford to do this type of monitoring in their plant; however, in-plant process evaluation costs are offset by the money they save by reducing reworks for shrinkage and also by eliminating from consideration those constructions for processing that cannot meet customer specifications due to their unsuitability to the processing equipment in place. An example of the effect of processing tensions is discussed later in this bulletin.

Drying Shrinkage

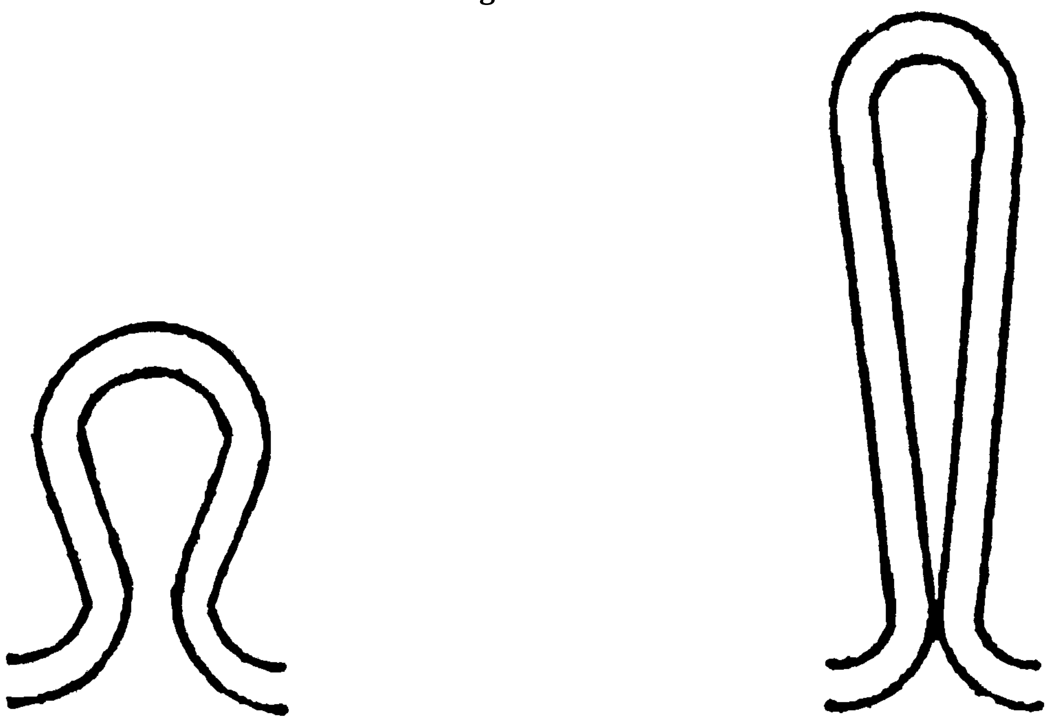
Drying shrinkage is defined as *dimensional change in a fabric when "deswelling" of fiber, yarn, and construction occurs in the drying step*. The structure shrinks upon itself as a result of the physics of drying.

This swelling and deswelling phenomena along with mechanical action is used in the AATCC Test Method 135-03. The test uses a washing machine to wet out (swell) the fiber/fabric under tensionless conditions and a tumble dryer to apply energy in the form of mechanical tumbling with heat to deswell and fully relax the fabric/garment. Tumble drying without restrictions (tension) is a form of mechanical compression and allows for maximum "drying shrinkage" to take place.

The importance of the swelling mechanism is significant. As the fabric wets out without tension, swelling of the fibers and subsequently the yarns and the fabric results. Upon swelling, the crimp in the yarn loops increases. In effect, the loops in the knitted structure try to assume their lowest energy state that is a more round configuration, which is the lowest energy state for the yarn and therefore for the fabric. The rounding of the loop results in a shortening of the loop and therefore relaxation and dimensional change.

In Figure 1, the loop shown on the right is elongated in the length direction and would exhibit high length shrinkage. After the fabric is allowed to shrink due to the swelling and deswelling under tensionless conditions and mechanical action, the loop assumes a rounded shape as shown on the left.

Figure 1



Relaxed Loop | Elongated Loop

Also during swelling and deswelling steps, absorbed or bound water acts as a lubricant, and the application of energy in the form of mechanical action (a dynamic force) upon the fabric will result in even higher levels of shrinkage.[3,4,5,6]

Therefore in drying (deswelling), the loops in a knitted structure are trying to assume a round configuration. Drying shrinkage is normally removed only by large amounts of energy as opposed to low amounts of energy needed to remove elastic shrinkage. It is important to realize that elastic shrinkage occurs in the early stage of drying.

In the initial stages of tumble drying, the removal of surface or non-bound water is achieved. Other than the simultaneous removal of elastic shrinkage, very little relaxation takes place, because the weight of water trapped in the cotton fabric and its lubricating effect acts as a force working against shrinking. After the surface water on the fibers in the structure has evaporated, deswelling occurs. It has been shown that at moisture levels below 20%, the greatest levels of relaxation occur.[4,5,6,7] The level of moisture at which the fibers/yarns deswell can be referred to as "critical moisture."

It may take several cycles of wetting and drying to achieve fully relaxed dimensions, although one cycle may remove around 90% of the total shrinkage available.

The graph in Figure 2 shows typical curves for shrinkage of cotton weft knits. Shown here are shrinkage curves for a cotton interlock, a single jersey, and a single pique. These shrinkage curves were made by tumble drying bleached white 100% cotton fabrics. Each sample was uniformly pad extracted to about 60% moisture content and then tumble dried. No heat was applied during drying in order to maximize the amount of mechanical action that results from tumbling. [3]

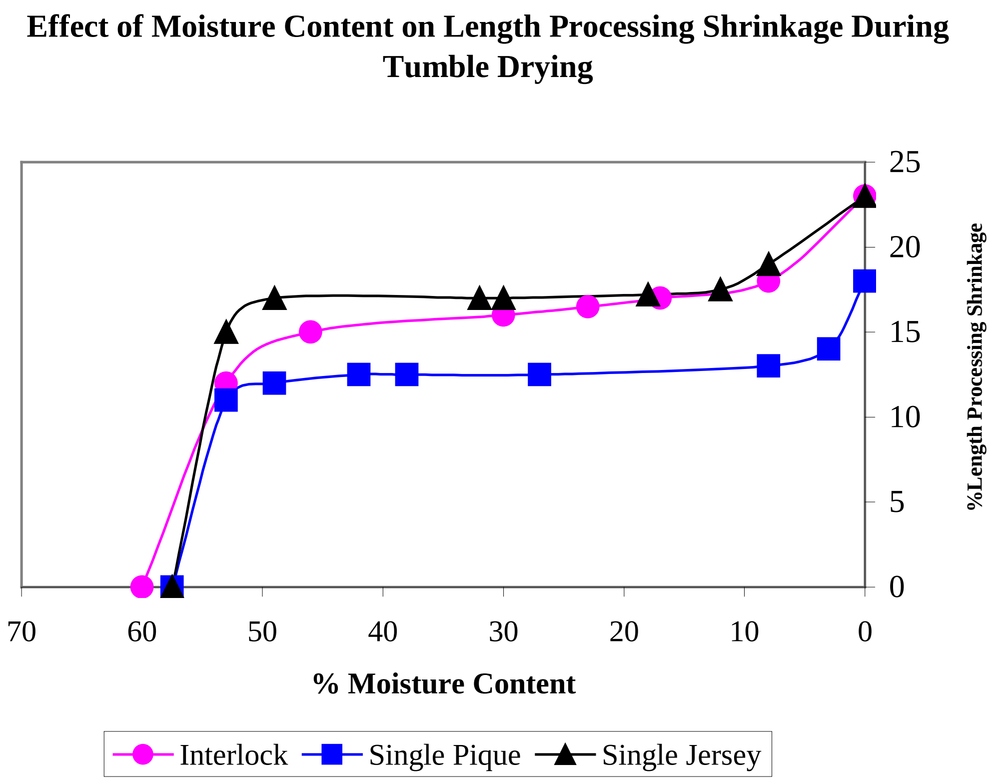
The initial moisture content was recorded and the specimens were measured after every five minutes of tumbling until they were dry. The moisture content was recorded at each time interval. In addition, the dimensional change in the length was recorded for each fabric at each interval. Length dimensional changes were always exhibited as shrinkage and each data point was plotted as "Length Process Shrinkage."

The process shrinkage for the length was then plotted on the vertical axis against the corresponding drop in moisture content as shown on the horizontal axis. The data reveals the shrinkage curve for each fabric.

The curves for each fabric type shown in Figure 2 can be broken down into three distinct parts. Elastic shrinkage is the initial part of the curve that shows an immediate, significant amount of shrinkage, which represents relaxation from applied stress. The flat part of the curve represents the segment of continuing evaporation of surface water and non-bound water. The shrinkage did not increase significantly until the moisture content of the fibers fell below critical moisture or the 20% level as represented in the third section of the curve. This portion is where deswelling or drying shrinkage occurs. In this phase of shrinkage, the shrinking process occurs very rapidly.

All the constructions behave very similarly. In fact, all 100% cotton knitted fabrics have as a "fingerprint" an initial area of elastic shrinkage followed by a flat area of little or no change and then an area of final shrinking. All fabrics tend to exhibit rapid elastic shrinkage.

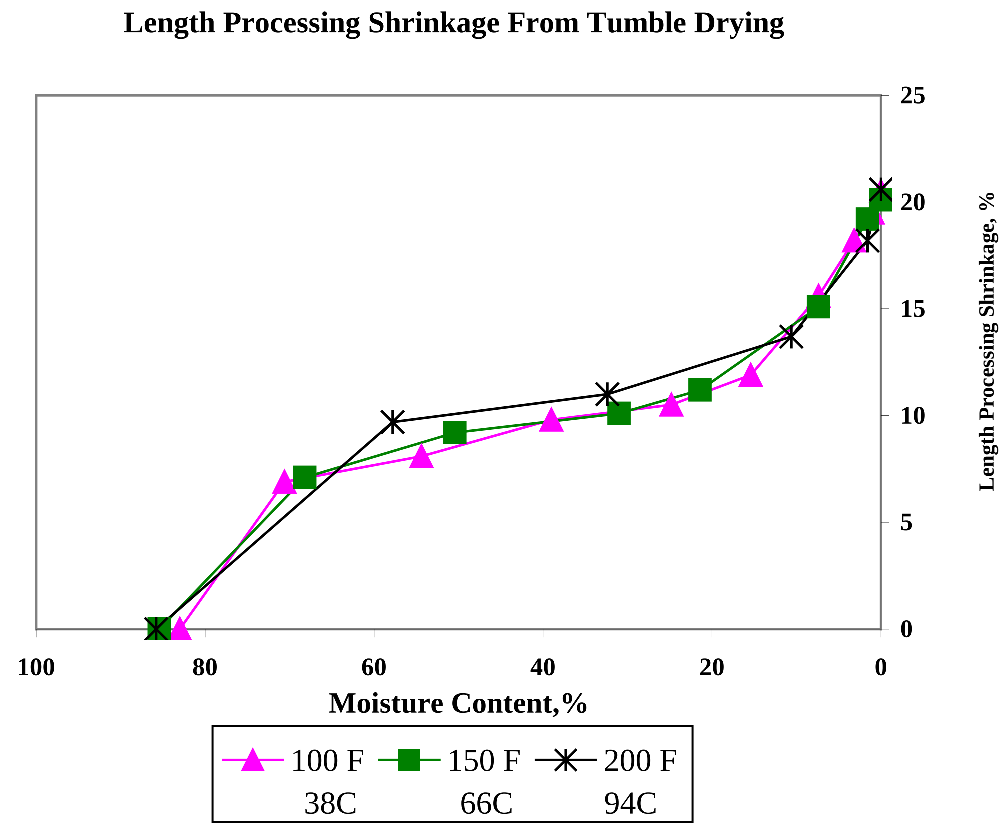
Figure 2: Effect of Moisture on Length Processing Shrinkage



With respect to the width dimension, the width of the fabric had shrunk during bleaching and did shrink further during the study. In order to control the width to desired specifications, other measures such as overspreading should be applied before drying.

As mentioned, heat was not used during the tumbling to maximize the effect of mechanical action. Many people think that heat during drying also causes cotton fabrics to shrink more. Figure 3 shows the results of applying different levels of heat during drying and its impact on length shrinkage. During this test, a 100% cotton interlock was bleached on a continuous range and tumble dried at different temperatures. The shrinkage curves were for 100^{o}F (38^{o}C), 150^{o}F (66^{o}C), and 200^{o}F (94^{o}C) with an initial moisture content before drying of around 82-85%. The data clearly shows that the shrinkage curves and total shrinkage values were identical for all three temperatures commonly encountered in home laundering. Also, the curves show the initial portion of elastic shrinkage, the portion of very little shrinkage while moisture content decreases, and the final portion of drying shrinkage where the moisture content fell below 20%.

Figure 3: Effect of Heat on Shrinkage during Tumble Drying



METHODS FOR REDUCING SHRINKAGE

Now that shrinkage has been defined, the factors that have an impact on performance will be looked at in detail. There are many factors that relate to shrinkage. These include the fiber, the yarn size and type, construction variables, wet processes, finishing procedures, apparel manufacturing techniques, and garment care methods.

Cellulosic fibers are not as easily stabilized as are thermoplastic synthetics, because they cannot be heatset to attain stability. Also, synthetic fibers do not exhibit the swelling/deswelling scenario that cotton exhibits. However, the comfort and overall appeal of cotton has resulted in greater demand by the consumer and by usage in the textile industry. Therefore, the relaxation of fabrics made with cotton fibers requires either mechanical and/or chemical means for stabilization.

Yarns, of course, are made with fibers and exhibit the same characteristics as the fiber. Yet the manner these fibers are oriented in a yarn will affect certain properties of the fabric including shrinkage. Cotton singles yarns of high twist will usually yield higher shrinkage values than yarns of lower twist levels and will certainly yield greater skewing or torqueing. Rotor spun yarns do not typically yield significant different length shrinkage values than ring spun yarns, but are usually wider and certainly exhibit less fabric and garment torque. Plied yarns of either type usually yield very little skewing tendencies, but do not impact shrinkage.

Different constructions can have significantly different shrinkage characteristics. For example, the performance of a single pique is certainly different from that of a jersey or interlock made from the same yarns and should be processed in a different manner. For example, the “tuck” stitches in a pique tend to make the fabric wider and less extensible than single jersey. Typically, pique fabrics have much higher length shrinkage than width shrinkage.

Wet processing procedures generally exhibit stress on a fabric. Continuous processes during dyeing and preparation for drying usually stretch the length and pull down or reduce the width, sometimes beyond their elastic limit thereby changing the relaxed dimensions.

Finishing procedures may reduce or increase the dimensional stability of the fabric. If relaxation dryers, compactors, and/or crosslinking agents are used, then the residual shrinkage after wet processing can be reduced.

Apparel manufacturing processes often increase the level of shrinkage in a fabric. The laying down of the layers for cutting and the physical manipulation of the panels in sewing are examples of where shrinkage values can be increased. In fact, garments comprised of different fabric constructions may have some panels relax with handling in cut-and-sew while other panels may grow.

Garment care labeling and laundering practices will have a direct influence on shrinkage performance. If the label calls for line or flat drying, then mostly elastic shrinkage will affect performance. However, if tumble drying is suggested, then all available residual shrinkage will be realized.

The best chance to achieve low shrinkage in cotton knitted fabrics is to totally engineer the product from fiber selection through all processing steps. The parameters for success can be outlined as follows:

1. Proper product specifications and fabrication.
2. Low tensions during wet processing (dyeing and extraction).
3. Relaxation drying.
4. Finishing with compaction and/or crosslinking agents.
5. Low tension packaging for apparel manufacturing.

Proper Product Specifications

Of all the factors affecting shrinkage control, the most critical considerations are construction variables and processing tensions, especially those in the length. When a customer offers a mill a contract to supply a product, specifications will be agreed upon. These specifications will be subjective and objective. Subjective specifications usually include hand, shade, and appearance among others. Objective specifications can include fabric type, weight or yield, width, strength, and shrinkage. The objective list may be even more specific and include machine cut, cylinder diameter, number of needles, stitch density, yarn type, yarn size, and other parameters.

Communication between the apparel manufacturer and the mill is very important. The product specifications should be carefully discussed and planned between the parties involved. All parties must realize that any given greige construction setup cannot yield different specifications of weight and width after dyeing and finishing without resulting in different shrinkage values.

The mill must decide if it can produce the desired product based on the construction variables available in the plant for that product. The variables the knitter has to work with are the yarn, machine cut, machine cylinder diameter, and the stitch or course length at which the yarn is knitted. The machine cut and cylinder diameter will determine the total number of needles in the cylinder. The number of needles is the more important factor as the number of needles is directly related to fabric width. To determine the ratio of these variables that will be used, a knitter may use his experience, a computer prediction program, and/or whatever sources are available.

In many cases, the customer dictates the fabric construction parameters and machine cut for the desired product. At the same time, the mill will only have a finite number of machines and gauges and may have limited cylinder sizes unless they knit to body sizes. These limitations in machine gauge and diameters, in essence the choices of the number of needles, allow the knitter to choose primarily from only the yarn size and the course or stitch length as construction variables.

Course length is *the amount of yarn used for one revolution of the machine and is measured in inches or centimeters.* If the course length for one revolution is divided by the total number of needles in the cylinder, then the stitch length can be calculated. The **stitch length** is *the course length divided by the number of needles in the cylinder.* Like the number of needles, the stitch length is of utmost importance. For different diameter machines of the same gauge (i.e., different numbers of needles) knitting the same stitch length, the course length will change. Therefore, the stitch length is the more usable and accurate parameter for specifying the product. The stitch length has a significant impact on shrinkage. The smaller the stitch length, the less yarn length per stitch, the tighter the stitch, and the shorter the loop. Tighter knitting as compared to looser knitting yields less shrinkage in the length and more in the width and a heavier fabric.

The cut or gauge of the machine determines the range of usable yarn sizes. For a given cut of machine, finer yarns can be knitted more tightly to give the same yield as a heavier, coarse yarn. Finer yarns cost more, but knitting them tightly gives better control of length shrinkage and still meets the desired fabric yield. However, the width will be affected because a tighter stitch will result in a narrower fabric. Once the fabric setup is decided upon and the goods are knitted, they must be tested for delivered and relaxed dimensions.

A closer look at delivered and relaxed dimensions is important. Greige delivered dimensions are those yielded off the machine and should meet greige goods specifications. These dimensions usually include weight, width, and shrinkage. Stitch density or stitch counts (i.e., courses and wales per inch) may also be used to further define dimensions. At this point, residual shrinkage will be equal to construction shrinkage, and these numbers will reflect on the total relaxed state of these greige goods. Therefore, it is advantageous to measure the same parameters (i.e., yield, width, stitch counts) for the fully relaxed goods as were measured for the delivered goods in order to understand "relaxed" dimensions. The fabric wants to shrink to the relaxed state where it is dimensionally stable. Evaluation of these relaxed numbers will reveal the most stable configuration the goods will ever achieve. Also, this data can be very valuable, because it may point out potential problems with the construction in relationship to where the fabric wants to relax and where the customer wants the fabric to be finished.

An example of the impact of relaxed dimensions can be seen in Table I. This data was measured for a 100% cotton, 28 cut single jersey made with combed 30/1 ring spun yarns. The stitch length used was a tight stitch. It is obvious that the delivered and relaxed dimensions for the greige goods are somewhat different. For weight, the delivered goods weighed 4.0 ounces per square yard and the relaxed fabric weighed 5.2 ounces per square yard. The relaxed fabric was six inches narrower. Courses increased from 46 to 56 per inch and wales from 32 to 39. In addition, the finished goods also exhibited similar changes from the delivered to the finished.

A significant comparison is that between the greige and finished relaxed states. They are somewhat different. The relaxed finished goods have fewer courses per inch than the relaxed greige goods - 51 versus 56. This loss of courses or change in fully relaxed dimensions for the length is a result of processing stresses exceeding the elastic limit of the fabric. In surpassing the elastic limit, the fabric has become permanently stretched. Also, the relaxed width for the finished goods is less than for the relaxed greige width. This is another indication that length processing tensions were great enough to permanently change the width. This loss of width is also indicated by an increase in the number of wales per inch for the finished relaxed.

Table I: Delivered Versus Relaxed Dimensions

	Oz/Yd^2 (g/m^2)	**Width Inches (centimeters)**	**CPI x WPI (per 3 cm)**	**Shrinkage % (LxW), 5 HLTD**
Greige*				
Delivered	4.0 (135)	36 Tubular (91)	46 x 32 (54 x 37)	12.1 x 15.9
Relaxed	5.2 (176)	30 Tubular (76)	56 x 39 (66 x 46)	--------
Finished*				
Delivered	4.4 (149)	30 Tubular (76)	48 x 38 (56 x 44)	7.3 x 3.5
Relaxed	4.9 (166)	29 Tubular (73)	51 x 40 (60 x 47)	--------

*Single Jersey: 28 Cut, 30/1 CP RS, 2256 Needles, 26 Inch (66 cm) Diameter 243 Inches (617 cm) per Revolution, 0.1077 Inches (.2735 cm) per Stitch

Low Tension Wet Processing

Each step in wet processing applies some stress to a knitted fabric. Some processes require that the fabric be pulled continuously through a range or cycled through a vessel in order to get a desired effect. Jet dyeing machines, becks, bleaching ranges, and pad and beam processing units all pull on the fabric in the length direction during the process. Equipment manufactured today applies less stress on the fabric than did those of only ten years ago; however, it is common for these machines to stretch fabrics in the length. At the same time, some soft flow and overflow jet dyeing machines actually either do not stretch the fabric or may even relax the goods in the length. Unless it is restrained, the width of a knit fabric will relax upon wetting out in all these vessels as a result of the tensions on the fabric in the length. In this respect, a knit fabric acts like an accordion.

The extraction process is the single greatest area of concern for length distortion in wet processing for knit fabrics. Strides have been made in recent years to reduce the amount of fabric stretch in extraction; however, length stretch of 10% and higher is commonplace.

Table II shows how a knitted fabric will readily change dimensions as a result of a force or forces applied to it. The effect on residual shrinkage is also shown. The table shows shrinkage and width data for a 100% cotton interlock fabric after each mill processing step. This 24-cut interlock was marked with process shrinkage squares and was processed through a typical dyehouse sequence. At each step, the samples were tested for processing dimensional change and residual shrinkage. These numbers clearly show the mobility of the fabric and how the tensions in each processing step change the residual shrinkage and the width. In the greige state, the fabric was 33 inches (83 cm) wide tubularly and 28 inches (71 cm) fully relaxed. After overflow jet processing, the interlock fabric had actually shrunk in the dye machine by 4.0% in the length. The width had come down to almost its relaxed dimension of 28 inches (71 cm). The residual shrinkage numbers indicated that the dyeing process had removed the 4.0% shrinkage from the fabric.

However, the linear forces in pad extraction lost all that was gained in the jet and caused a 4.0% dimensional change (growth) in the fabric over the greige dimension. Also, this linear force was high enough to force the width of the fabric (27 inches) to be narrower than that of the greige fully relaxed state (28 inches). Therefore, the residual shrinkage in the length was greater than that of the greige and the width grew by 3.5%, because it was narrower than the reference state.

Table II: Comparison of Different Processes as Related to Residual Shrinkage for a 100% Cotton Interlock

Process	**Dimensional Change % (+/-)***	**Width Inches (Tubular) *(centimeters)***	**Residual Shrinkage % (LxW), 5 HLTD**
Greige Goods (relaxed dimension)	0 x 0	33 *(83)* [28/(*71*)]	19.0 x 15.0
Overflow Jet (scour, bleach, dye)	4.0 x 12.0	29 *(73)*	15.0 x 3.5
Pad Extracted (plaited)	+4.0 x 18.0	27 *(68)*	20.0 x +3.5
Relaxed Dried (overfed and spread)	12.0 x 9.0	30 *(76)*	9.0 x 7.0
Compacted	16.0 x 7.5	30.5 *(77)*	5.0 x 8.0

Fabric: 24-cut Interlock with 40/1 CP RS Yarn – Width Specification of 30 Inches (76 cm)
* Dimensional change over the greige dimensions.

The fabric was then spread to 34 inches (86 cm) with overfeed and dried on a relaxation conveyor belt dryer with maximum mechanical action to a desired width specification of 30 inches (76 centimeters). The length lost in extraction over jet processing were regained as well as an additional 8.0% gained. The data shows that since the greige goods were made, the length was now 12% shorter resulting in residual shrinkage of 9.0%. By spreading and overfeeding, the desired finished width of 30 inches (76 cm) was met, and the width shrinkage was at 7.0%. These low residual shrinkage numbers insured that compaction would be successful. Compaction was applied and accounted for a change of another 4.0% relaxation. The residual shrinkage numbers were at 5.0 by 8.0%. The width of 30.5 inches (77.5 cm) was delivered slightly above the cut-and-sew width to allow for loss in laying out of the goods on the cutting table. This data further points out that if the stress in the extraction step had not been so severe, then the shrinkage numbers would have been even lower.

Relaxation Drying

Relaxation dryers are available in conveyor belt systems, suction drum units, combinations of both, and continuous tumblers. All systems make use of mechanical action during drying to provide the energy to yield lower shrinkage. In order for a knit fabric to shrink during drying, certain criteria must take place. The methods used to shrink the fabric must be able to overcome the static friction that exists within the loops of the knitted structure. Key factors for relaxation drying should include:

1. Releasing of all tensions from the fabric, especially its own weight and that of any water it might contain at the entry of and in the dryer.

2. The use of softeners to aid fabric structure mobility by reducing the static friction at yarn intersections.

3. Mechanical action either by air flow and belt vibration.

4. Sufficient and uniform mechanical action to overpower all static friction within the structure but at levels low enough to prevent stretching.

5. A uniform air flow in intensity, varied in direction, but not offsetting in application.

6. Necessity to either spread the fabrics with overfeed at the entry of the dryer or to spread at a station just before the dryer.

7. Maintaining sufficient overfeed in all drying zones to allow for complete mobility in the fabric length during deswelling.

8. Tension free precision plaiting of the fabric for apparel manufacturing or for the next processing step.

Compaction

During compaction, static friction is overcome by physical force. Compaction is the use of compressive forces to shorten the fabric to reduce the length shrinkage. This is achieved by heated roll and shoe compactors or compressive belt systems to force the length of the loop in a knit to become not only shorter, but also more round in configuration thereby resulting in lower length shrinkage values. This process is a consolidation process resulting in "**consolidation shrinkage**."

Softener selection has a big impact on the efficiency of the compactor. The use of improper softeners can prevent the compaction force from being effective by causing slippage between fabric surfaces and machine components in the shrinking zone. Softeners may also reduce the static friction so much that the yarn loops may easily compact, but then lose the compaction during subsequent processing. Corrugation or wrinkling of the surface because of improper loop movement during compaction can be a big problem to finishers. This is a defect usually associated with over-compaction, but it can also be caused by improper or non-uniform softener application as well as improper moisture content at the compactor.

Chemical Finishing

Chemical crosslinking has been the most used method for stabilizing cotton knit apparel fabrics especially those finished in open-width form. Compaction methods have also been effective but have been mainly used on underwear fabrics and most tubular goods. The advent of wet processes that impose lower tensions on fabric, such as the evolution of relaxation dryers and the improvement of compaction machinery including open-width, have combined to reduce the need for or level of chemical finishing. However, the desire for very low shrinkage without the corresponding increase in bulk experienced with compaction of a knit structure has led to the continued use of crosslinking agents for cotton products.

Chemical crosslinking affects the swelling of cotton and reduces shrinkage by altering the normal shrinking (swelling/deswelling) phenomena. In fact, a well-designed crosslinking system will permanently alter the shrinkage thereby altering the relaxed dimensions. Other benefits of a chemical finish would be a better appearance as related to wrinkling after washing and tumble drying, less tendency to pill or form surface fuzz from repeated laundering, and improved color retention for some dyestuffs. The disadvantages are losses of strength and shorter wear life.

To realize how crosslinking affects a cotton knitted fabric in terms of shrinkage and relaxed dimensions, Table III offers a group of data for the delivered and relaxed dimensions of a 28-cut single jersey made with 30/1 combed ring spun yarn. Conditions shown in the data include dyed, relaxed dried, crosslinked, and compacted. When finished with a softener only on a relaxation dryer, the goods have good shrinkage values at 7.3 by 3.5%. After a crosslinking finish, the shrinkage values were lower and more balanced at 5.0 by 5.0%. When compacted only (no crosslinking), the shrinkage values were also good at 4.5 by 6.0%. The difference in the fabrics can be seen when comparing the relaxed weights, widths, and stitch counts.

The relaxed dimensions of the relaxed dried and compacted finish are very similar. Both had relaxed weights of 4.9 ounces per square yard while the crosslinked relaxed yield was much lower at 4.0 ounces per square yard. Course and wale counts per inch for these conditions are greige (60 x 47), compacted (61 x 47), and crosslinked (56 x 47). This further indicates a significant change in the fabric structure (relaxed state) due to the influence of the crosslinker on the swelling of the cotton.

Therefore, the use of crosslinking agents will allow for improved shrinkage control without increasing the yield as much as compaction or relaxed drying. However, it must be remembered that there will be a loss in strength and wear life when compared to systems without crosslinking agents. Combinations of relax drying, compaction, and/or chemical crosslinking can offer the very best performance in terms of residual shrinkage and consistency in performance from lot-to-lot, roll-to-roll, and yard-to-yard.

Table III: Comparison of Compaction to Crosslinking for Shrinkage Control

Fabric/Condition	**Oz/Yd^2 (g/m^2)**	**Width Inches (centimeters)**	**CPI x WPI (per 3 cm)**	**Shrinkage % (LxW), 5 HLTD**
Greige Goods Delivered	4.0 (135)	36 Tubular (91)	46 x 32 (54 x 37)	12.1 x 15.9
Relaxed	**5.2 (176)**	**30 Tubular (76)**	**56 x 39 (66 x 46)**	**----- x -----**
Dyed, Relaxed Dried (softener only) Delivered	4.4 (149)	30 Tubular (76)	48 x 38 (56 x 44)	7.3 x 3.5
Relaxed	**4.9 (166)**	**29 Tubular (73)**	**51 x 40 (60 x 47)**	**----- x -----**
Crosslinked Delivered	4.0 (135)	30 Tubular (76)	43 x 38 (50 x 44)	5.0 x 5.0
Relaxed	**4.6 (155)**	**29 Tubular (73)**	**48 x 40 (56 x 47)**	**----- x -----**
Compacted Delivered	4.3 (145)	31 Tubular (78)	49 x 37 (57 x 43)	4.5 x 6.0
Relaxed	**4.9 (166)**	**29 Tubular (73)**	**52 x 40 (61 x 47)**	**----- x -----**
Fabric: 28-Cut Single Jersey, 30/1 CP RS Yarn				

Testing

Methods for measuring the shrinkage of cotton fabrics or garments are many. The most reliable methods use a system that will agitate the goods without tensions or restrictions during a wet agitation step and during a drying step. A method detailed in the 2004 AATCC Technical Manual designated as AATCC Test Method 135-2003 is a reliable method for relaxing cotton fabrics.[7]

In this method, a home-laundering machine is used to wet out the fabric, which swells the cotton fibers and applies agitation without tension. Wetting out of the fabric without tension is generally enough to allow for “elastic shrinkage.” For complete and reliable shrinkage results, it is recommended to wash and tumble dry at least five cycles.

CONCLUSIONS

The importance of understanding shrinkage and it causes is key to its control. In summary, a partnership between a mill and an apparel firm is a necessity for success in the marketplace. This is true whether the product is a national or store brand at retail. Mutual planning and engineering of a product is the only recipe for success. In order to meet product specifications, the correct yarn, machine set-up, and dyeing and finishing processes must be chosen. Arbitrary specifications and improper choices of processing routes are a guarantee for failure in the battle to control shrinkage for cotton fabrics.

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