

ENGINEERED KNITTING PROGRAM FOR 100% COTTON KNIT FABRICS.

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INTRODUCTION

After centuries of knitting cotton yarns into various constructions, high levels of shrinkage in fabrics and garments remain an enigma to many people. However, the performance characteristics of a cotton knit fabric as related to its relaxation and therefore shrinkage are as basic and predictable as any other mathematical or physical model. In fact, a knitted structure when processed through textile dyehouse processes and consumer laundering is no different than any other engineering structure or material that can be measured for dimensions and performance during its production and use. Cotton Incorporated has now developed a system (a program) that will allow a manufacturer or yarn and knitting machine through dyeing, finishing, and apparel

processing. This systematic approach to engineering cotton knit fabrics is based on the fundamental relationships between the fully relaxed fabric that has been wet processed and the construction parameters in knitting.

The objective of the Engineered Knitting Program is to better understand and thereby control the shrinkage characteristics of cotton knit fabrics. Why do cotton knit fabrics shrink to different levels when produced at different weights and widths (in essence, different course and wale count per square area)? Do these differences result because of knitting variables only or does dyeing, finishing and garment manufacturing have an impact on the level of relaxation? Finally, is a manufacturer or user of cotton knit fabrics accumulating large amount of data as related to dimensions of the fabrics (such as weight, width and shrinkage), does this data have any value other than serving as a physical descriptor? This presentation will show that knit fabric performance can be predicted and understood from empirical data gathered from those fabrics. Further, a computer program can be developed at each manufacturing facility that will allow each product line to be engineered to achieve their customers' desired cut-and-sew weights and widths with low shrinkage. This program will not only be based on the yarn and knitting setups, but also on the wet processing techniques used in that facility.

DISCUSSIONS

Obviously, the most critical considerations for developing a product are the construction variables on the knitting machine and the length processing tensions applied in the dyehouse. In this study, a total of over 400 different combinations of constructions, yarns, machines, and finishes were evaluated. The basic constructions studied were single jersey, interlock, single pique and 1×1 rib. Further, over 5000 fabric

tests were performed, and over 20,000 data points were measured on the fabrics. Evaluations were performed in the greige and after each separate processing step throughout dyeing and finishing. Analysis of all this data yielded "K-Factors" which relates the structure to its processing. These factors became the basis for the predictions of fabric performance.

"K-Factors" are constants derived from empirical data measured in the reference state. The data most important are those of stitch length, yarn count and the courses and vales per inch. The "Reference State" of a fabric is the dimensions of the substrate when it will not shrink any further. "Reference state" is also known as the "relaxed state." The consumer is normally the only person who experiences the fabric in this state of normalcy. Reference conditions are reached when the fabrics have been washed and tumble dried until no further shrinking occurs. On nearly all fabrics, this state will be achieved after five cycles of washing and tumble drying.

"K-Factors" have been known for over thirty years and have been used by some scientists in the industry. Only in the most recent of times has it been realized by these researchers that the technology used to process the fabrics in dyeing and finishing have an impact on the reference state of the fabric. There are programs for the prediction of knit fabric performance in use in the industry today. Some programs incorporate "K-Factors" for the prediction of fabric performance while others use different criteria for the prediction. None of these systems are accurate for a particular grouping of processing equipment in the dyehouse without a calibration feature. Others do not incorporate dyehouse techniques at all.

Cotton Incorporated believes that to be most effective, each plant must calculate the "K-Factors" for each of their processing lines. For example, a continuous bleaching

range may result in a different reference state for the same greige style than will an overflow jet when both fabrics are extracted, dried and finished in the same manner. In fact, the greige fabric "K-Factors" will not match the "K-Factors" of either of these processing routes. Therefore, the same greige style processed on these two systems will yield different shrinkage values when finished to the same weight and width specifications, Conversely, all 100% cotton fabrics knit of the same construction (i.e. jersey) from the same spinning system (i.e. ring spun) and processed through the same dyeing and finishing systems would have the same "K-Factors."

Currently, Cotton Incorporated is using the well published "K-Factors" cited in the literature plus a new one based on the fabric yield. These factors are defined as: " K_w " for width and wales per inch (WPI), " K_c " for length and courses per inch (CPI), " K_r " for the ratio of CPI to WPI, and finally, " K_y " for the yield (ounces per square yard). For this discussion only the K_w , K_c and K_y will be used.

The factor, K_w , for the wales per inch and width is derived from the relationship that says tat the wales per inch in the reference state are inversely proportional to the stitch length. The mathematical value of the proportion is the constant ("K-Factor"). The equation is expressed as folows:

$$\text{Wales per inch} = \frac{K_w}{\text{Stitch length, } L} \quad \text{or} \quad \text{WPI} = \frac{K_w}{L}$$

$$\text{therefore, } K_w = \text{WPI} \times L$$

The factor for the courses per inch and length is derived from the relationship that says that the courses per inch in the reference state are inversely proportional to the stitch length. The value of the proportion is the constant. This equation is expressed as follows:

$$\text{Courses per inch} = \frac{K_c}{\text{Stitch length, } L} \quad \text{or} \quad \text{CPI} = \frac{K_c}{L}$$

therefore, $K_c = \text{CPI} \times L$

The factor for the yield is derived from the relationship that says the ounces per square yard in the reference state are inversely proportional to the product of the yarn count and the stitch length. This equation is expressed as follows:

$$\text{Ounces per sq. yard} = \frac{K_y}{\text{Yarn count} \times L} \quad \text{or} \quad \text{Oz / yd}^2 = \frac{K_y}{\text{Ne} \times L}$$

therefore, $K_y = \text{Oz / yd}^2 \times \text{Ne} \times L$

These equations have been used by Cotton Incorporated to calculate factors for 100% cotton single jerseys, interlocks, single piques and 1½ ribs on the different dyeing and finishing processes in its pilot dyeing and finishing laboratory as well as for production facilities. For this discussion, only the constants for a series of single jersey fabrics which were processed in a mill will be discussed. The processing sequence consisted of preparation and dyeing in an overflow machine, machine, balloon pad extraction, relax drying on a conveyor dryer, and compaction.

These "K-Factors" for dyed single jersey were based on four gauges of jersey knitting with eight different counts of yarn at three different levels of stitch tightness. Each fabric had its "K" values calculated after compaction, and these were all averaged together for each gauge to create the "K-Factors" used in the program. It was found that all gauges had the same "K-Factors." These values are shown below:

"K-Factors" for 100% Cotton Single Jersey

$$K_w = 4.170$$

$$K_c = 5.785$$

$$K_y = 15.670$$

*Overflow Jet dyed, pad extracted, relaxed dried and compacted tubularly.

The best way to show these relationships is by the use of "X-Y" graphs. Figures 1,2 and 3 show the plots for K_w , K_c and K_y respectively. Figure 1. gives the plot for K_w . Each data point represents a different machine gauge and yarn count knit at different stitch lengths. The wales per inch in the reference state (Y-axis) are plotted against the reciprocal of the stitch length (X-axis). The best fit for the slope of the line is the constant value $K_w = 4.170$. These data points have an R-square of 0.996 which is excellent.

Figure 1.

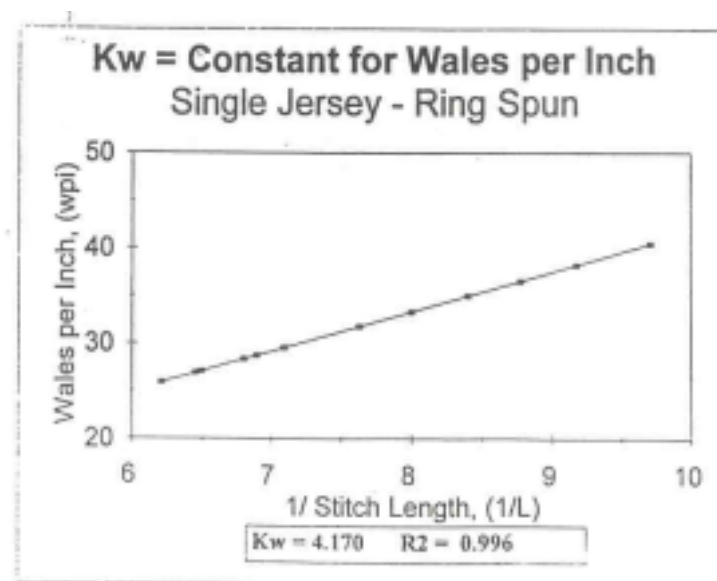


Figure 2. gives the plot for K_c . The courses per inch in the reference state (Y-axis) are plotted against the reciprocal of the stitch length (x-axis). The slope of the line is the constant value $K_c = 5.785$. These data points have an R-square of 0.993 which is also excellent.

Figure 2.

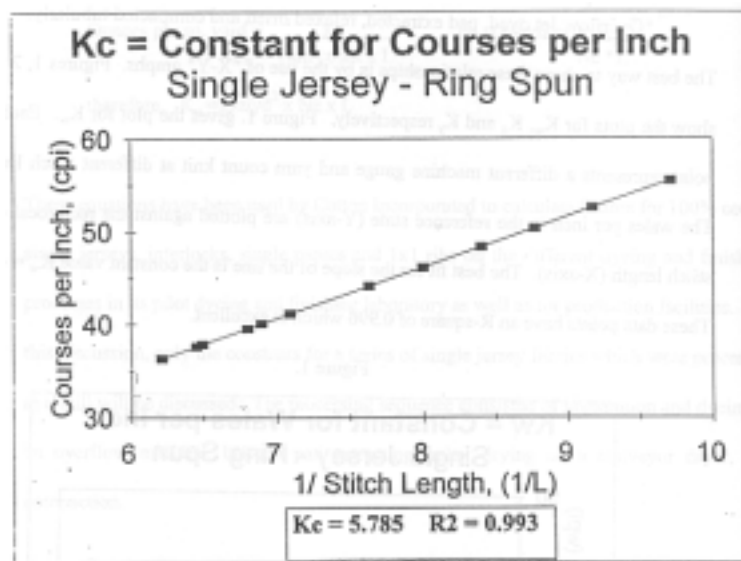
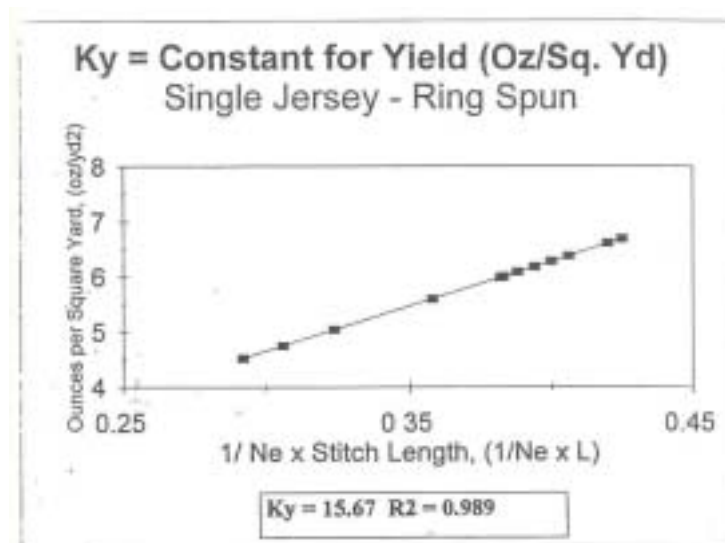


Figure 3. gives the plot for K_y . The ounces per square yarn in the reference state (Y-axis) are plotted against the reciprocal of the stitch length multiplied by the yarn count (X-axis). the best fit for the slope of the line is the constant value $K_y = 15.670$. These data points have an R-square of 0.989 which is excellent.

Figure 3.



Once the "K-Factor" values have been developed for a plant process (a grouping of machines such as jet, extractor, dryer, etc.), a simple computer spread sheet program can be written to predict the weight, width, courses per inch, wales per inch and shrinkage for any fabric that would be processed through that particular sequence of operations. Other data could also be generated if needed on same spreadsheet, such as, costs, production time at different efficiencies, etc. In fact, the written program can be as comprehensive as desired by the manufacturer.

DEMONSTRATION

A simple demonstration is shown in the following text. For this example, it is desired to produce a 100% cotton single jersey fabric on a 20 gauge knitting machine of 18 inch diameter with 1104 needles using an 18.1 carded ring spun yarn at a stitch length of 0.166 inches. The targeted weight and width for the fabric after jet dyeing and finishing would be 5.0 ounces per square yard at 22 inches tubular with maximum shrinkage of five by five percent length by width. Our plant would use an overflow jet for preparation and dyeing followed by balloon pad extraction, relaxation drying on a conveyor belt dryer, and compaction as the final finishing step. As shown in the "DISCUSSION" segment of this paper, "K-Factor" values have been established for this processing sequence. Therefore, a simple spreadsheet program using these "K-Factors" in the calculations was used to predict whether this knitting setup processed on these dyehouse machines would meet the requested yield, width, and shrinkage values.

Figure 4. is a printout of the spread sheet without the data being entered, The program allows for the construction parameters of cut, diameter, needles in the cylinder, yarn count, and stitch length to be entered as standard or given values (shown in the upper

portion of the printout). The course length needed to produce the wanted stitch length for one revolution of the knitting machine is calculated and displayed beneath the stitch length. The computer then calculates the reference state and lists these values in the lower left hand box of Figure 4. Once the desired shrinkage values are entered in the lower right hand box, the computer then calculates the "delivered" dimensions of weight, width, courses, and wales per inch to give the desired shrinkage values.

Figure 4.

ENGINEERED KNITTING PROGRAM		SINGLE JERSEY - RING SPUN - DYED	
Construction Parameters		Given	
Cut		Yarn Count	
Diameter		Stitch Length	
Needles		Course Length	0.00
REFERENCE STATE		Product Specifications	
Method A		% Length % Width	
Width	0.00	Shrinkage, given	
CPI	ERR	DELIVERED Method A	
WPI	ERR	Width 0.00	
Oz/yd2	ERR	CPI ERR	
		WPI ERR	
		Oz/yd2 ERR	
Method A is based on the stitch length being given.			

Figure 5. shows that when the cut, diameter, the number of needles, yarn count, stitch length, and shrinkage requirements are entered, the program will calculate the delivered and reference weights, widths, and stitch counts for the fabric. This data shows that with the specified stitch length and yarn count, a fabric of 4.73 ounces per square yard at 23.13 inches tubular would be delivered to give (55)% shrinkage. As is realized, this would not be acceptable because a 5.0 ounces per square yard fabric at 22 inches tubular

was specified.

Figure 5.

ENGINEERED KNITTING PROGRAM			SINGLE JERSEY - RING SPUN - DYED		
Construction Parameters			Given	Calc.	
Cut	20		Yarn Count	18.00	18.00
Diameter	18		Stitch Length	0.165	0.1579 *
Needles	1104		Course Length	183.26	174.31
REFERENCE STATE			Product Specifications		
	Method A	Method B	% Length	% Width	
			Shrinkage, given	5	5
			DELIVERED	Method A	Method B
Width	21.97	20.90	Width	23.13	22.00
CPI	34.85	38.64	CPI	33.11	34.81
WPI	25.12	26.41	WPI	23.85	25.09
Oz/yd2	5.24	5.51	Oz/yd2	4.73	4.98

Method A is based on the stitch length being given.
Method B is based on the delivered width and shrinkage being given.

Figure 6. shows that when Method B is added to the program, the desired width can be entered into the set of "givens" and the computer will calculate the stitch length needed for the yarn and machine specified to give the desired shrinkage and width. The new stitch length is shown under "Calc." in the upper half of the spreadsheet. The data in Figure 6. gives a delivered yield of 4.98 ounces per square yard at 22 inches with five percent shrinkage in both the length and width directions. This new stitch length would be 0.158 inches and the new calculated course length from which to set up the knitting machine would be 174.31 inches. This revised stitch length gives a yield of 4.98 ounces per square yard which would be acceptable.

Figure 6.

ENGINEERED KNITTING PROGRAM			SINGLE JERSEY - RING SPUN - DYED		
Construction Parameters				Given	Calc.
Cut	20		Yarn Count	18.00	18.00
Diameter	18		Stitch Length	0.166	0.1579 *
Needles	1104		Course Length	183.26	174.31
REFERENCE STATE			Product Specifications		
	Method A	Method B	Shrinkage, given	% Length	% Width
Width	21.97	20.90		5	5
CPI	34.85	38.64	DELIVERED	Method A	Method B
WPI	25.12	26.41	Width	23.13	22.00
Oz/yd2	5.24	5.51	CPI	33.11	34.81
			WPI	23.86	25.09
			Oz/yd2	4.73	4.98

Method A is based on the stitch length being given.
Method B is based on the delivered width and shrinkage being given.

Figure 7.

ENGINEERED KNITTING PROGRAM			SINGLE JERSEY - RING SPUN - DYED		
Construction Parameters				Given	
Cut	20		Yarn Count	18.000	
Diameter	18		Stitch Length	0.166	
Needles	1104		Course Length	183.264	
REFERENCE STATE			Product Specifications		
	Meth. A & C		Shrinkage, given	% Length	% Width
Width	21.97			5	5
CPI	34.85		Calc. Method C	4.55	0.12 *
WPI	25.12		DELIVERED	Method A	Method C
Oz/yd2	5.24		Width	23.13	22.00
			CPI	33.11	33.27
			WPI	23.86	25.09
			Oz/yd2	4.73	5.00

Method A is based on the stitch length being given.
Method C is based on the stitch length, weight and width being given.

Figure 7. gives yet another analysis that is beneficial to the manufacturer. It may be desired to use the greige goods with the stitch length of 0.166 inches and also finish the goods to 5.0 ounces per square yard at 22 inches. Obviously, if this is accomplished, the

shrinkage cannot be five by five percent. Method C is used to allow for the original stitch length to be used with the weight and width targets kept as specified. The program then calculates the shrinkage values that would result and shows these in the lower right hand portion of the spreadsheet next to "Calc. Method C." The resulting analysis gives shrinkage values of 4.55% in the length by 0.12% in the width.

This has been a very simple demonstration as to how the Engineered Knitting Program can be used. Other calculation methods can and have been written to predict which yarn counts, machine diameters, etc. should be used under different delivered specifications.

CONCLUSIONS AND RECOMMENDATIONS

Manufacturers of 100% cotton knitted products should be using some method to determine if they will have success meeting their customer specifications without having to knit, dye, finish and test every candidate. Computer prediction systems are already on the market that will give the manufacturer a good idea of what they can or cannot do. This presentation has attempted to show the industry that they already have the information available to them within their operations to also develop a program that will be specific to their actual production facilities. Evaluation of their fabrics and facilities by these methods will pay dividends of only as a result of their better understanding what goes on in their operations.

Because "K-Factors" are based on goods actually processed through a particular grouping of wet processing equipment, they indicate levels of performance actually achieved. This system of "engineering cotton knits for performance" will give the manufacturer a good indication of whether he will be successful in his efforts. Other

considerations include the of "K-Factors." In addition, there are indications that it may be possible to predict the performance of resin finished cotton knits by the use of "K-Factors." At the worst, this systematical approach will allow the knitter/finisher to:

- develop specific products for specific customers
- fine tune specific wet processing equipment,
- incorporated cut-and-sew processes into the fabric processing flow, and]
- will drastically reduce the required testing of the fabric for shrinkage will be predictable.

ADDENDUM

The singe jersey fabrics processed in this discussion were also evaluated after processing through a continuous bleach range for cotton knit fabrics. This range consisted of a dry scray, a saturator, steaming in a wet "J-bow," rope washing, and balloon extraction. After bleaching, the goods were pad extracted in a "Tri-pad" with spreading and some overfeeding. The goods were plaited in a box and then dried in a suction drum drier. After drying, the goods were compacted tubularly with a heated roll/shoe compactor. These fabrics were then analyzed for "K-Factors" as in the previous study. These values are shown in Table 2. along with the "K-Factor" values for the overflow jet dyeing system shown in the paper.

Table 1. Comparison of "K-Factors" of Different Processing Routes on the Same Greige Goods		
	Process	
	Jet	Continuous
K _w WPI or Width	4.170	4.276
K _c CPI or Length	5.785	5.567
K _y Yield of Oz/Yd ²	15.670	15.445

It is obvious that the different processing routes gave different "K-Factors." What can these values tell us?

A higher "K- Factor" value after processing on a particular grouping of equipment for the same greige goods means that the reference state value for that parameter is a larger number. For example, the K_w value for the continuous process is larger than the value for the jet process. This indicates that there are more wales per inch in the reference state for the continuously bleached fabric. In other words, the fabric is narrower which is a result of high length tensions in this type of processing. Conversely, the K_c value for the continuously bleached goods is smaller than for the jet process. This means there are less courses per inch for the bleached fabrics as compared to the jet processed. This is another indication that the goods have been permanently elongated in the length. Also, the K_y value for the continuous process is smaller than the jet process value. This is a result of the elongation of the goods in processing as well as the loss of weight from the bleach bath used to produce an optical white. Also, there is no add-on of weight from dyestuff being applied to the fabric as was the case in the jet process.

Finally, it is obvious that to finish any goods after processing in these two systems, it would be impossible to achieve the same level of shrinkage when finishing to the same weight and widths. If it is desired to have the same weight, width, and shrinkage requirements after finishing off these two processes, the greige goods for each would have to be knit differently. In this scenario, the use of a program of prediction based on "K-Factors" for this bleaching range would be of great help.