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A PRELIMINARY REPORT: FUZZ AND PILLING SURFACE CHANGES ON COTTON FABRICS MEASURED BY LINETECH INDUSTRIES' IMAGE ANALYSIS SYSTEM

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Abstract

One of Cotton Incorporated's Fiber Quality Research areas is Product Test Improvement. Although some projects are focused on the improvement of existing cotton fiber measurements, other research projects focus on developing new measurements or finding measurement and evaluation technologies that can be explored as tools to assess critical cotton fabric properties. Cotton's customers are not only mills and manufacturers but also retailers and consumers. Retailers set specifications that fabrics and garments must meet in order to be accepted from their suppliers. Consumers are the real arbiters of what fabric attributes are important as they wear and care for their cotton products. On the list of important performance attributes are appearance, colorfastness, and dimensional stability. This paper will describe the preliminary results of a study to evaluate a new image analysis system known as PillGrade® Automated Pill Grading System, developed and marketed by LineTech Industries, Inc., for measuring the appearance changes known as pilling and fuzz. Data will be shown for investigations to determine a satisfactory testing protocol that will lead to further investigations to compare subjective pilling grades to objective image analysis grades generated by LineTech's automated grading system on cotton samples. Other data describing fuzz image analysis grading and the incorporation of color readings, as additional measurement capabilities.

Introduction

Pills are bunches or balls of tangled fibers created on fabrics. Fuzz is the occurrence of hairs and filaments that protrude from the fabric surface. Fuzz is also sometimes referred to as hairiness and nap. The American Society for Testing Materials (ASTM), defines these surface changes in their Annual Book of Standards (see References).

ASTM has standard abrasion test methods that use several different instruments such as a Universal Abrasion Tester, Random Tumble Pilling Instrument, Martindale, et.al. that are widely used to predict pill, abrasion, and surface changes. These tests are standards developed by industry experts and published by ASTM in Vol. 07.01 and 07.02. Generally, these standards utilize photographic scales to aid in making judgments about the level of pills or abrasion observed on fabric test specimens.

Some companies in the textile supply chain choose to inspect fabrics and/or garments for pilling and fuzziness after fabric samples have been put through a laboratory evaluation process of repeated launderings. After the process, an inspector will subjectively grade the degree of pilling and fuzziness according to ASTM and/or ISO standards photographic scales of 1.0 to 5.0 where 5.0 indicates a low or non-existent degree of pilling and/or fuzziness and 1.0 indicates a high or severe degree of pilling and/or fuzziness.

The major drawback of this judgment technique is its subjectivity. One observer can grade differently than other observers. Further, different grades can be made in different testing laboratories, creating costly supply chain inefficiencies and disagreements.

Why was PillGrade Developed?

In 2003, a major US polyester fiber producer realized a need for an objective pilling measurement device as part of their project to improve the pilling resistance of polyester staple fiber. LineTech Industries, Incorporated, a Brooklyn, New York imaging technology company, well respected in the fibers industry for its automated imaging systems, was approached to develop an objective grading system. The PillGrade Automated Pill Grading System was a result of LineTech's development work. Since then, PillGrade has been accepted at various textile testing labs for objectively and automatically grade pilling.

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Materials and Methods

PillGrade is an automated three-dimensional imaging device that detects, measures, and counts pills on fabric specimens. The system primarily includes a PC, a camera with lens, a backlight, a toplight, 2 mirrors, a feed table, and motorized rollers, as shown in Figure 1.

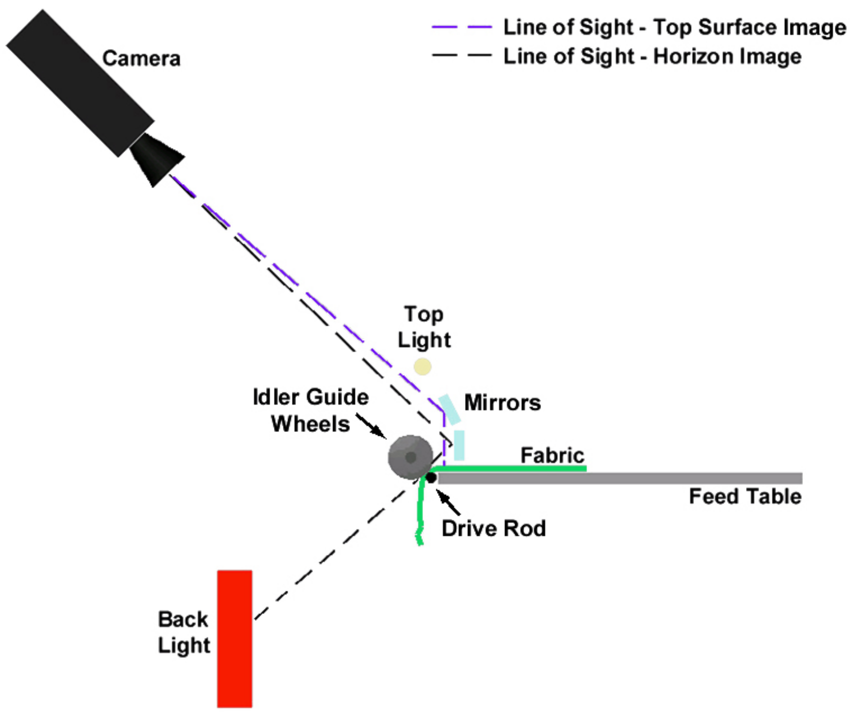

Figure 1. Schematic Illustration of a PillGrade Imaging System

During operation, a fabric specimen is placed onto the feed table and then fed in between the drive rod and the idler guide wheels, which grabs a fabric specimen, pulling it forward, and directing the specimen around the fulcrum of a drive rod. A camera, focused across the 3.0 inch fulcrum width of the drive rod, captures images of the horizon of the fabric specimen against a backlight, creating a silhouette-like horizon image as shown in Figure 2. The camera's horizon line of sight image follows an optical path: from the camera to the mirror, to the fabric's cross section horizon perspective, and then to the backlight. This configuration allows the fabric to bend around the fulcrum of the drive rod so that pills and surface disruptions are clearly contrasted against the evenly illuminated backlight. Thirty-three images are sequentially captured over every inch of fabric feed length so that every image represents 1/33-inch of a specimen's vertical feed length.

The specimen image shown in Figure 2 includes various colored lines, which indicate the rectangular backlight threshold region (blue), the overheight and underheight error limits (aqua and purple), the fabric surface indicator (red), and the left and right borders of the 2-inch inspection width (dotted green).

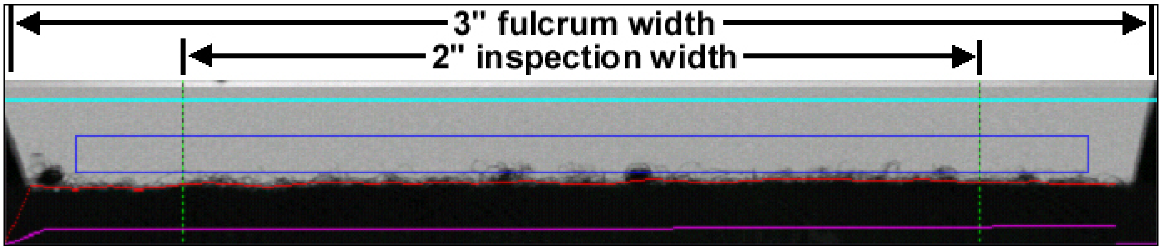

Figure 2. Backlit PillGrade Specimen Image

Image processing detection and measurement algorithms are performed on every individual image frame to detect and measure pills and surface disruptions. Once a specimen has been completely fed through the rollers, pill and other measurement results from each individual frame are compiled and pills that are detected in consecutive frames at the same width position are logically compressed to count as a single pill, using the center frame position as the pill's vertical locating coordinate.

Once a specimen completely moves through the rollers, the center sixty-six consecutive images (where each image represents 1/33-inch of vertical feed length X the 2 inch inspection width) are plotted onto an XY display as illustrated in Figure 3. The XY display is slanted to give a three-dimensional viewing appearance and the pill locations are marked by pill markers color coded by pill size. The camera, utilizing the top light and the slanted mirror, simultaneously scans the top down surface view of the fabric much like a line scanner office fax machine. It is important to note that the pills and other surface disruptions are detected and marked in the XY display, independent of the textile surface pattern and appearance, but the surface is nonetheless scanned and displayed with the pill markers in the correct relative spatial position.

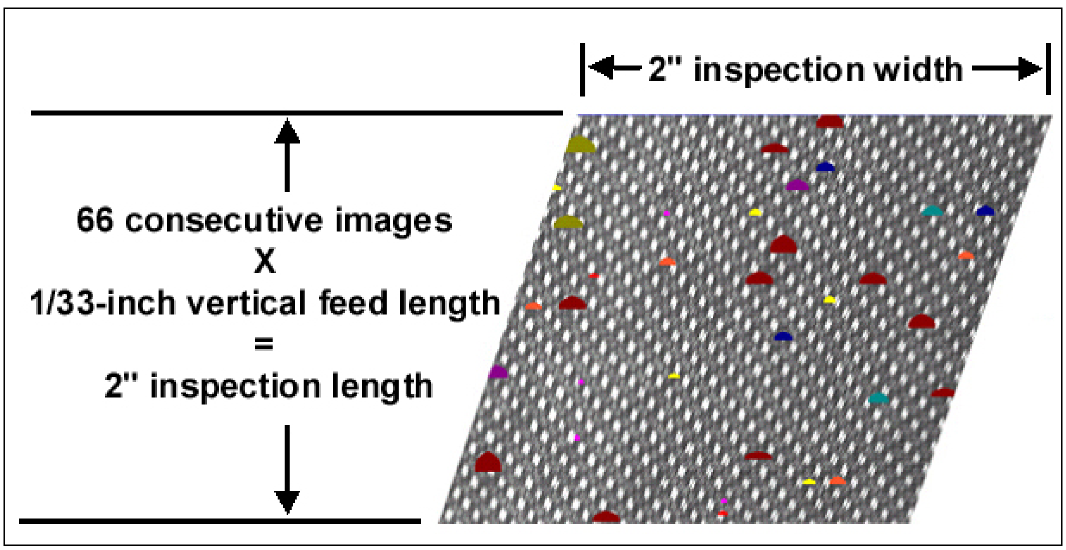

Figure 3. Scanned Area of a Specimen by PillGrade

Image processing detection and measurement algorithms

As detailed above, PillGrade performs pill and other surface disruptions detection and measurement algorithms on each individual horizon image and compiles the data results from all image frames. At the request of Cotton Incorporated, LineTech developed the detection and measurement algorithms for the separation of surface disruption, declared as fuzz, from the actual pills detected. On each image, PillGrade performs a sequence of algorithms of each individual image to detect and measure pills and fuzz. The digital camera captures and records to memory the XZ array of 8-bit (0-255) pixels, where the X axis is aligned with the three inch fulcrum width and the Z axis is aligned with the cross sectional fabric height (while the Y axis is aligned with the fabric feed length, or in other words, the video time function).

The backlight, the lens iris, and the camera's gain are set so that the backlight's threshold region's light level is always approximately at 67% (171/255) of the camera's full-intensity level. This light level allows for good contrast between the darkened fabric, pills, and fuzz and the backlight.

The first image processing step is to apply a binary threshold to the image for fabric baseline detection, then a separate binary threshold is applied to the image for pill detection, followed by a separate binary threshold applied to the image for fuzz detection. These binary thresholds are represented in Figure 4, where the red line in each of three images represents the fabric baseline threshold division. The upper and lower regions of the pill and fuzz threshold regions are shown in black and yellow.

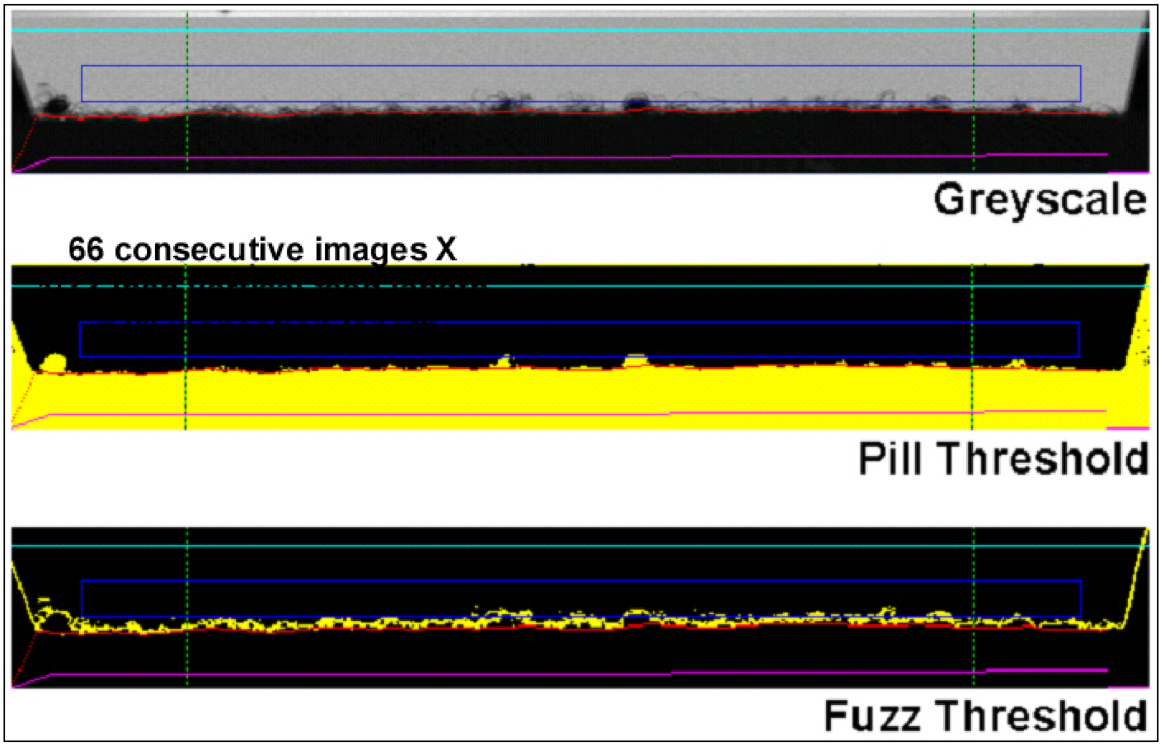

Figure 4. Binary Images of a Specimen's Baseline, Pill, and Fuzz Images

Detection of the baseline, pills, and fuzz are made on a sub-pixel measurement basis by detecting, along every pixel column from left to right within the two inch inspection region, the transition threshold pixel location in 1/100 of a pixel units. The resulting pill XY locations are recorded and plotted in the XY fabric display (see Figure 3), and color-coded according to pill XZ size.

Determination of the 1-5 Pill Grade

PillGrade objectively detects, measures, and counts pills on a fabric specimen. In order to correlate the extensive pill data to the 1.0-5.0 industry standard pilling grade, correlation work was done was done by LineTech. However, much of the correlation work was questionable since a wide range of visual grades was shown by expert observers in reputable testing laboratories. Three independent labs reported their visual grades on the same fourteen pilled samples. Three specimens from each sample were graded using ASTM D3512 photographic scale. Table 1 shows a wide range of pill grades with the exception of Samples 4, 10, and 13. Variability between result grades was too wide for correlation. So, the question of which lab results to use was raised. This data further supports the need for objective surface change measurements.

Table 1. Visual Pilling Grades from Three Independent Laboratories

Sample ID	Lab #1	Lab #2	Lab #3
1	4.5	3.0	3.8
2	4.0	4.0	3.3
3	3.0	1.0	1.5
4	4.5	4.5	4.0
5	3.5	4.5	2.8
6	4.0	4.5	1.8
7	4.5	4.5	3.8
8	4.5	5.0	3.8
9	3.5	4.5	2.8
10	2.0	2.0	1.0
11	2.5	4.5	1.3
12	4.0	4.5	3.3
13	2.0	2.0	1.0
14	3.0	2.0	1.5

However it is important to note that the sample-to-sample grade trend lines for each of the labs is consistent on an intra-laboratory basis suggesting that different observers can make repeatable, relative grade assessments but different observers are likely to be unable to produce repeatable, absolute grade assessments.

Temporarily abandoning the lab result data, the ASTM pilling grade scale photograph was examined to develop a "pill data: 1.0-5.0 grade" correlation equation. Pill quantity versus 1.0-5.0 grade, as depicted in the ASTM photographs, were plotted as shown in Figure 5. The chart shows that the relationship between pill density (pills per constant area) and the 1.0-5.0 grade is not linear, but logarithmic. Also plotted is another pill system developed by Dr. Bugao Xu, University of Texas–Austin (see References). Further support for this point can be found in the psychophysical Weber-Fechner Law, which states that "subjective value is a logarithmic function of physical value".

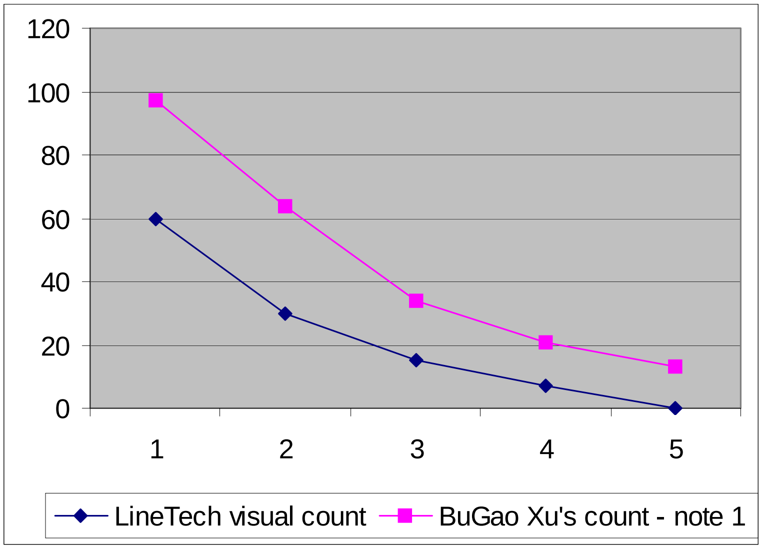

Figure 5. ASTM Photograph Scale Pill Grade Image Correlation

It was further determined that the ASTM photos are limited because the photograph scale only represent one distinct type of pilling (scale photos are of woven fabric). It is general knowledge that different fabrics have many different surface change features and characteristics, no always seen as the pill formation seen on the ASTM photo. For instance, most knitted fabrics have a propensity to fuzz and pill. Therefore, it was concluded that the ASTM photographic data could not provide the sole correlation data to establish a logarithmic correlation equation between pilling data and the 1.0-5.0 grade.

In order to obtain more regression data, LineTech scanned a wide variety of graded specimens supplied by various mills and laboratories to use to correlate the PillGrade-generated pill measurements to the 1.0-5.0 grade scale, focusing on the need to match the labs' relative grade assessments, rather than focusing on the impossible task of matching the labs' absolute grade assessments. These statistical and empirical studies resulted in the following correlation equation:

$$\textbf{Grade} = 6 - [1 + 0.75(\textbf{WeightedPills/inch}^2)]^{0.45}$$

Where:
Weighted pills = quantity of pills weighted by XZ area, where XZ areas range from 0.3mm^2 to $>3.9\text{mm}^2$ and are weighted according to the Pill Size Weighting Formula:

$$\textbf{Pill Size Weighting Factor} = 8.5587 \cdot (\textbf{XZ area})^{-1.0082}$$

and represented by the logarithmic grade curve shown in Figure 6:

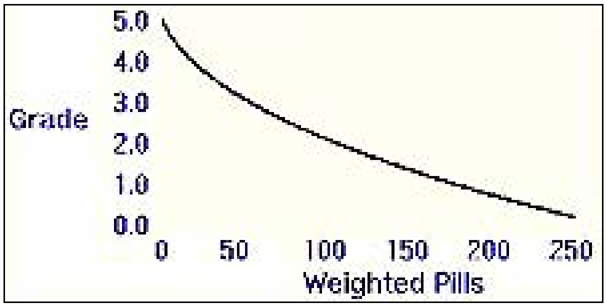

Figure 6. Logarithmic Grade Curve

PillGrade Image Analysis Software Expansion

In 2004, Cotton Incorporated and LineTech Industries entered a cooperative research project to investigate whether PillGrade's software analysis program could be used for additional measurements of physical properties that influence consumers' perception of surface change. Internal Textile Chemistry research investigations of enzyme processing, dyeing, chemical and mechanical finishing, impact on surface changes on cotton fabrics after repeated launderings had revealed that some cotton fabrics and combinations of processing steps did not produce pilling. However, fuzz formation and the perception of color change after laundering were deemed related to the issue of unacceptable surface changes by consumers. The perception of change of color on fabric with heavy fuzz or pilling was deemed to be that the disruption of a fabric surface character caused light to be reflected differently, thus, creating the perception of color fading or loss.

LineTech was challenged with the objectives to add the measurement of fuzz to PillGrade's scanned imaging and to initiate an attempt to measure or incorporate color reading into a total surface change analysis output. Such modifications were made to a PillGrade System that was installed at Cotton Incorporated.

A study was developed to determine of testing protocol for the PillGrade System to develop a satisfactory testing protocol, to compare visual pilling grades to those produced by PillGrade, and to explore the application of PillGrade's fuzz measurement capabilities, and to initiate a database for the incorporation of color into the surface change evaluation process. The study investigated the following questions:

1. What effect does specimen size have on PillGrade's output?
2. What effect does specimen fabric direction have on PillGrade's output?
3. What is the repeatability of PillGrade's output?
4. Can PillGrade produce comparable pill grades on various woven and knitted cotton fabric?
5. Is PillGrade's analysis of fuzz reasonably descriptive of fuzz judged by a Cotton Incorporated visual fuzz scale?
6. Can PillGrade software utilize external color measurements to help understand the relationship between consumer perception of surface change?

Results and Discussion

With any new measurement system , some trials are needed to become familiar with an instrument and its data output. It should be noted that the establishment of a testing protocol was necessary before further design of experiments could be developed for complete statistical confirmation of PillGrade's repeatability and precision. Therefore, the preliminary study did not have sufficient samples or sampling on which firm conclusions.

Questions 1-3 stated above present the first elements in the protocol study to be investigated. Two, knitted fabrics were chosen for this part of the study. Fabric 1 was a 35cotton/65 polyester ring spun interlock knitted fabric in its greige state; Fabric 2 was the same fabric in a dyed and finished condition. Fabric 2 had been laundered twenty-five times. A fiber content blend was chosen to insure pilling would likely occur. The PillGrade instrument fulcrum width provided some limitations but specimens sizes 4.0 x 4.0 inches and 5.0 x 5.0 inches were selected for the size categories in the study. The specimen size for ASTM D3512 Random Tumble Pilling standard test method is 4 3/16 x 4 3/16 inches cut in the bias alignment (see References). Five specimens from each fabric samples were run four separate times on the PillGrade System. Figure 7 shows that the 4.0 x 4.0 inch specimen size category produced lower variance compared to those in the 5.0 x 5.0 inch category. The 5 x 5 size category data set had an outlier data point on one greige specimen that may have been influenced by the greige sample not having been exposed to typical wet processing stages.

Does Specimen Size Influence PillGrade Repeatability?

	4 x 4 in specimen		**5 x 5 in specimen**	
	Grade Average	Variance	Grade Average	Variance
Fabric 1 & 2	4.3853	0.2401	3.8396	1.6514

P-Value = 0.0210

Statistically Significant Differences Exist at the 90% Confidence Interval

4 x 4 in specimen is preferable

Figure 7. Specimen Size PillGrade Analysis Results

Specimen orientation, i.e. specimens cut parallel to the fabric sample length edge or cut out at a 90° angle or bias, was the next question to help create a reasonable test protocol for the PillGrade system. Figure 8 shows that the parallel specimen cut produced lower variance compared to the bias cut specimens, with a P-value of 0.0120.

Does Specimen Orientation Influence PillGrade™ Rating?

	Parallel Cut		**Bias Cut**	
	Grade Average	Variance	Grade Average	Variance
Fabrics 1 & 2	4.3286	0.6308	3.6923	1.8167

P-Value = 0.0120

Statistically Significant Differences Exist at the 95 % Confidence Interval

Parallel cut is preferable

Figure 8. PillGrade Specimen Orientation Analysis Results

The impact of fabric construction machine direction on pill grades produced by the PillGrade system did not have a dramatic influence on the repeatability. For this part of the study, Fabric 3 was used. It was a 100% cotton interlock fabric that had been dyed black and finished with resins and enzyme combinations. All sixteen samples were laundered twenty times. Four specimens from each condition were taken. The specimens were introduced to the PillGrade scan zone in four orientations: head, foot, right side-to-side, and left side-to-side. The machine direction for a knitted fabric is relative to the loop configuration; i.e. whether the head of loops are introduced first or the loop foot, or across loop columns. Figure 9 shows that knitted fabric machine directions did not produce a significant difference in PillGrade pill grades. There was so little difference between the right and left side across presentation that those data were combined.

Does the Direction of the Feed Influence the Values?

	Head		**Foot**		**Side to Side**	
	Grade Average	Variance	Grade Average	Variance	Grade Average	Variance
Fabric 3	4.8397	0.0713	4.8244	0.0696	4.8536	0.0818
	P - Value = 0.5060					
	No Statistically Significant Difference					
	The direction of the feed does not influence repeatability of the rating					

Figure 9. Fabric Direction Introduction Influence on PillGrade Values

The final question to answer was whether the number of specimen used and/or the number of times each specimen was run would improve the repeatability. A few possible combinations were selected for the part of the study. The combinations are shown in Figure 10.

ANOVA

Groups	Count	Average	Variance
10 x 10	100	3.49	0.1024
3 x 3	9	3.03	0.2825
5 x 2	10	2.04	0.0826
10 x 1	10	3.02	0.0724

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.1326	3	1.7109	15.6008	1.00451 E-07	2.675
Within Groups	14.0371	128	0.1097			
Total	19.1697	131				

Figure 10. The Influence of the Number of Specimens and Test Runs on PillGrade Data

From the data a test protocol was drafted that incorporated parallel cut specimens, five specimens each run two times, with no precaution needed for which machine direction used.

Additional trials were run on a variety of fabrics, both woven and knitted. Additional data were collected on LineTech's fuzz measurement and the incorporation Cotton Incorporated color change measurements. The interpretation of fuzz data and the relationship to color change measurements has not been completed by the authors at the date of this report.

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