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TEXTILE TECHNOLOGY

White Speck Quantification: A Human Inspection Technique

James.L. Simonton*, Mario G. Beruvides, and M. Dean Ethridge

ABSTRACT

Before a quality-related issue can be addressed from a causal and predictive perspective, there has to be a reliable and repeatable system designed to detect and quantify the problem. Current fiber testing was not designed to measure or detect the presence of dead or immature fibers in the small quantities that have been determined to be detrimental to the quality of dyed finished products. In the absence of applicable fiber testing, the most logical step would be the development of a counting procedure that would allow the accurate and repeatable quantification of white specks in a test medium that has significance to the end product. It is a logical hypothesis that white specks appearing on the surface of dyed yarn will also appear to some degree on the surface of cloth made from that yarn. To test this hypothesis, human inspection techniques were developed to quantify and compare white specks present on yarn and cloth made from that yarn. Using this inspection technique, the quantification of white specks was less variable on the surface of yarn than on dyed knit fabric tubes prepared by the Fiber Analysis Knitter (FAK). Yarn was less variable reading-to-reading and operator-to-operator. The method described in this study using dyed yarn showed promise as a measurement system for the accurate and repeatable quantification of white specks.

Due to the lack of secondary cell wall development, immature fibers are weaker, less rigid, and have a lower density than mature fibers. These factors result in higher propensity for immature fibers than for mature fibers to form neps (Hebert et al., 1988). In an undyed state, entangled fiber clusters are generically classified as neps. In most cases, fiber neps are made of at least five fibers (Herbert et al., 1988). After the application of dye, when some neps remain undyed, the specific classification of "white speck" is used. The combination of low dye retention and high reflectivity, gives the white speck its characteristic light, shiny appearance on the surface of dyed cloth or yarn. The exploration into the relationship between neps and white specks in both fiber and yarn is hampered by the lack of quantification methodology.

High volume instrument (HVI) (Uster Technologies; Knoxville, TN) fiber testing, based on average fiber properties, was not designed to measure or detect the presence of immature fibers in the small quantities that have been determined to be detrimental to the quality of dyed finished goods (Zellweger Uster, 1999). It has been estimated that even in fabric with severe white speck contamination, the percentage of white speck fibers (by weight) is most likely less than 0.10% of the total fibers (Watson, 1989). These amounts would be too small to have significant effects on the average fiber properties, as measured by current commercial instruments, but are substantial enough to negatively impact the commercial value of the fiber to the end user (Goynes et al., 1996).

The main focus of this research was to perform research for the development of human inspection techniques that can be used for the quantification of white specks. It was hypothesized that operator variability would be less using dyed yarn compared with dyed knit cloth as the counting medium. To determine the least variable counting medium, comparisons of operator-to-operator and reading-to-reading variability were made for both counting media.

MATERIALS AND METHODS

For this study, white specks were defined for the operators as "clusters of fibers that are noticeably lighter in color compared to adjacent areas." To avoid conflicting personal definitions of the terminology used, each operator was trained in the identification of white specks using standard counting procedures.

J.L. Simonton and M. D. Ethridge, International Textile Center, Texas Tech University, P.O. Box 45019, Lubbock, Texas 79409-5019; M. G. Beruvides, Industrial Engineering Department, Texas Tech University, MS 3061, 201 Industrial Engineering, Lubbock, Texas 79409-3061.
* Corresponding author: james.simonton@ttu.edu

The 15 yarns that were selected for comparison were taken from an inventory of commercial, 50.8/1 number metric (30/1 Ne), 100% cotton, ring-spun yarn. The selection criterion was based on prior knowledge gained during a pilot study of this research that indicated the yarns contained varying degrees of white specks (Simonton et al., 2001).

Solamidine Blue 2RLL (100%), commonly known as Direct Blue 80 (Albanil Dye Stuff; Jersey City, NJ), was selected for this study. Smith (1991) categorized dyes by their ability to cover immature fibers, and determined that Direct Blue 80 dye was sensitive to immature fiber. Based on this information, Direct Blue 80 was used for both yarns and knits.

During the pilot study, sample illumination was a key factor in operator counting performance. The work revealed that the ability of an operator to detect white specks was improved when both cool white and yellow day light sources were used simultaneously (Simonton et al., 2001). The Leslie Hubble CAC 60-5 VeriVide light cabinet (Equitex; West Yorkshire, UK; Figure 1) was selected for use as a standard source of lighting for the study. The VeriVide light cabinet was equipped with both Artificial Daylight (D75) and Cool White (CW) light sources.

Figure 1. Leslie Hubble Ltd. VeriVide Model CAC 60-5 Light Cabinet used by the operators in counting white specks.

The lower work surface of the light cabinet was equipped with an adjustable viewing platform (Figure 1). Each operator used the viewing platform to adjust the angle between the light source and sample to achieve the best visual differentiation between the white specks and the adjacent yarn or knit (Kaiser, 2000; Wilson and Corlett, 1995). Prior to each reading a light meter was used to measure illumination at the bottom surface of the light cabinet. Illumination provided by the VeriVide light cabinet was consistent for both yarn and knit readings throughout the study.

Yarn. A Chavis Model 44 yarn winder (Chavis Textile Mfg. Inc.; Gastonia, NC) was used to place each of the fifteen yarn samples onto stainless steel dye tubes for dyeing. After winding, they were package-dyed with Direct Blue 80 in a single batch using a 15-package capacity Gaston County Package Dye Machine Model 702 RFC (Gaston County Dyeing Machine Co.; Gastonia, NC).

After dyeing, an Alfred Sutter yarn board winder was used to wind samples onto 178 mm wide by 279 mm long by 3.2 mm thick, black, rigid, paper yarn boards (Alfred Sutter; New York, NY). The Alfred Sutter yarn board winder was set to place 6.3 equally spaced wraps per centimeter on each board for a horizontal distance of 14.6 centimeters (Figure 2). With this setup, each board had 25.7 linear meters of yarn per board viewing side for a total of 51.4 linear viewing meters per yarn board.

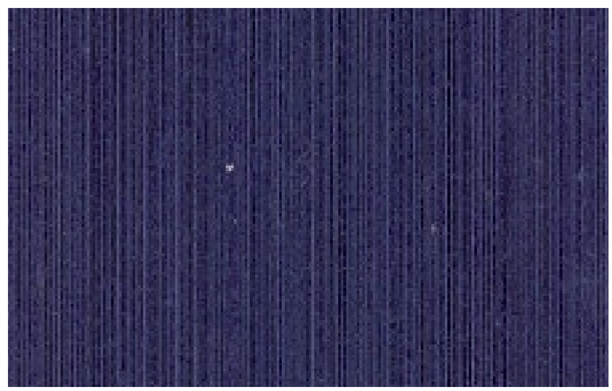

Figure 2. An example of white specks on a yarn board.

Five replications of each dyed yarn sample were made for a total of 75 yarn boards, each having “A” and “B” sides. The “A” and “B” designations were arbitrary designations for the purpose of preventing the operator from reading the same side twice. Five replications yielded a total of 256.9 linear meters of yarn on the face of the boards per sample yarn.

The board “reading” process involved placing each sample into the viewing box of the VeriVide light cabinet. The operators positioned each board in the viewing box with the aid of an adjustable viewing platform. After positioning the board, the operator used a counting technique that traversed from left to right, then right to left, while moving from top to bottom. A pointed probe was used to help the operator maintain focus while counting (Wilson and Corlett, 1995). Three separate operators, on side "A" first and then on side "B," counted white specks. Each operator made three readings on each board.

Knits. The 15 sample yarns were used to knit individual single-knit jersey fabric. A Fiber Analysis Knitter (FAK) (Lawson-Hemphill; Spartanburg, SC), equipped with 7.9 needles per centimeter (20 needles per inch) on an 8.9 centimeter diameter cylinder (3.5 inches), was used to produce the single-knit jersey tubes. Five replications of each of the 15 yarn samples were made giving a total of 75 knit tubes. Four sides, labeled A, B, C, and D, were identified on each knit tube. "A" side was designated as the outside front, and "B" side was the outside back of the knit tube. "C" and "D" sides were obtained by turning the tube inside out. "C" was the inside front opposite "A", and "D" was the inside back opposite "B." Each knit tube was also marked with a white orientation line located under the sample number on the "A" side to facilitate alignment. The knit tubes were simultaneously dyed using a Gaston County 90 liter capacity Laboratory Dye Beck (Gaston County Dyeing Machine Co., Gastonia, NC).

After dyeing, all knit tubes were transferred to the VeriVide light cabinet for "reading." A 102 mm by 229 mm template that was made from 4.7 mm thick, black, foam board was placed inside of each knit tube before viewing (Figure 3). This gave a total of 232 square centimeters per side. With four sides per sample reading, a total of 928 square centimeters were viewed. The operator counted white specks first on the "A" side and then on the "B" side. The knit sample was then turned inside out and placed back onto the template. Once the template had been placed inside of the knit tube, the orientation line on the "A" side, as seen from the "C" side, was used to achieve correct alignment.

Statisical analysis. A Wilcoxon matched-pairs test for dependent samples was used to examine differences between the three white speck readings for each yarn and knit by each operator, and coefficients of variation were also used to compare operator variation among readings for both counting media. The percentage of coefficient of variation (CV%) was calculated using the following equation:

(1) $CV\% = (s / \mu) * 100$

where s = the standard deviation for each sample between readings 1, 2, and 3 for each counting medium, and μ = average of readings 1, 2, and 3 for each counting medium.

Figure 3. FAK knit tube sample loaded on a template for viewing white specks.

The Mann-Whitney U test for independent samples was used to examine the operator-to-operator differences in white speck readings. Operator reading-to-reading performance was also examined using pair-wise comparison of the three readings for both yarns and knits. The comparison was calculated using the following equations:

(2) $((R1 - R2)/R1)*100 = \%$ difference Reading 1 to Reading 2

(3) $((R2 - R3)/R2)*100 = \%$ difference Reading 2 to Reading 3

(4) $((R3 - R1)/R3)*100 = \%$ difference Reading 3 to Reading 1

A Spearman R rank order correlation was used to examine the proportionality between operators.

Since the data was discrete in nature and was derived using a counting technique, it was assumed that the distribution would be non-normal and Poisson in nature (Hayter, 1996). With an assumption of non-normal distribution, it was necessary to select the proper transformation to conduct an analysis of variance. Since the counting variances are not homogenous, the data had to be stabilized using square root transformation in order to meet the conditions required for analysis of variance. The square root transformation is commonly used to stabilize variance and improve the normal approximation of the distribution (Box et al., 1978; Krifa and Frydrych, 2002). This transformation is adequate when the variance is proportional to the mean, which is the case for Poisson distributions (Box et al., 1978).

To examine the effects between factors, an ANOVA design was used that allowed each sample yarn to be separated into yarn and knit factors. Each factor was broken down further into three operators. Each operator was separated into three readings for each of the five replications of the yarn or knit.

A regression analysis was used to examine the relationship between white specks per unit length of yarn and per unit of area of knit. Selecting convenient units of measurement, i.e., length for yarns and area for fabrics for white speck counts facilitated yarn and knit comparisons. Therefore, the measurement of white specks was expressed as the number per meter of yarn and the number per square centimeter of fabric. For both counting media, each of the operator's three readings for each sample was averaged to obtain a total white speck count per sample by counting medium. These averages were divided by the total meters or square centimeters observed per five replications to obtain the lowest unit for comparison. These calculations were accomplished by using the following formulas:

(5) WSLM = ((TYWS1 + TYWS2+ TYWS3)/3) / 257 meters per 5 reps

(6) WSSCM = ((TKWS1 + TKWS2 + TKWS3)/3) / 4640 cm^2 per 5 reps

where WSLM = white specks per linear meter, TYWS1 = total yarn white specks observed per sample by operator 1, TYWS2 = total yarn white specks observed per sample by operator 2, TYWS3 = total yarn white specks observed per sample by operator 3, WSSCM = white specks per square centimeter, TKWS1 = total knit white specks observed per sample by operator 1, TKWS2 = total knit white specks observed per sample by operator 2, TKWS3 = total knit white specks observed per sample by operator 3. The results of these conversions are presented in Table 1.

Table 1. Conversions of white speck counts on yarn and knit samples

Sample	White speck counts [z]	
	Yarn / linear m	Knit / cm^2
1	1.196	0.348
2	1.114	0.513
3	2.285	1.043
4	1.939	0.830
5	1.458	0.501
6	0.976	0.504
7	1.005	0.401
8	0.953	0.430
9	2.692	0.953
10	3.207	0.781
11	2.289	0.781
12	2.180	0.571
13	1.745	0.607
14	2.736	1.007
15	1.543	0.530

[z] For both yarns and fabrics, each of the operator's three readings for each sample was averaged to obtain a total white speck count per sample by counting medium. These averages were divided by the total meters (257 m) for the yarn samples or square centimeters (4640 cm^2) for the fabric samples observed per five replications to obtain the lowest unit for comparison.

RESULTS AND DISCUSSION

Comparisons of operator readings. When comparing the readings of each operator, only one of the nine yarn readings was significantly different, and seven of the nine knit readings were significantly different ($P \leq 0.05$) (Table 2). This indicates that successive readings for yarns were more consistent than for the knits.

Based on the percentage coefficient of variation between readings, yarn was a less variable counting medium than knit fabric for two of the three operators (Table 3). For the third operator, there was no difference between yarns and knits. A comparison of all three operators for both yarn and knit CV% can be seen in Figure 4.

Table 2. Significance of white speck counts between readings for each operator for the yarns and knit fabrics

Reading	Significance [z]					
	Operator 1		Operator 2		Operator 3	
	Fabrics	Yarns	Fabrics	Yarns	Fabrics	Yarns
1 to 2	Yes	No	Yes	No	Yes	No
2 to 3	Yes	No	Yes	No	No	No
3 to 1	No	No	Yes	Yes	Yes	No

[z] Significance determined by the Wilcoxon matched pairs test for dependent variables at $P \leq 0.05$.

Table 3. Percentage coefficient of variation between readings for each operator for yarn and knit fabric samples

Sample	Coefficient of variation (%) [z]					
	Operator 1		Operator 2		Operator 3	
	Fabric	Yarn	Fabric	Yarn	Fabric	Yarn
1	3.91	0.52	1.69	3.06	5.90	1.57
2	8.63	1.74	2.11	2.23	6.18	1.12
3	4.72	0.50	2.60	0.32	2.41	0.59
4	0.41	0.81	5.22	0.76	3.31	4.89
5	2.20	2.05	6.63	0.92	2.77	2.78
6	5.22	1.38	6.37	0.94	4.28	4.56
7	0.62	2.35	2.47	1.29	1.58	1.99
8	3.11	1.67	2.86	2.54	3.73	6.86
9	2.90	0.61	3.54	0.72	1.49	2.19
10	4.00	0.41	4.76	1.85	6.02	4.05
11	6.78	0.40	4.56	2.21	2.95	5.49
12	1.46	3.07	6.37	2.96	4.60	2.58
13	4.44	0.70	4.07	0.52	3.02	7.34
14	1.50	0.84	2.97	1.54	3.59	4.59
15	2.20	0.83	2.46	0.82	3.00	6.65
Average	3.47	1.19	3.91	1.51	3.65	3.82

[z] Percentage of coefficient of variation determined by the formula, $(s / \mu) * 100$, where s = the standard deviation for each sample between readings 1, 2, and 3 for each counting medium, and μ = average of readings 1, 2, and 3 for each counting medium.

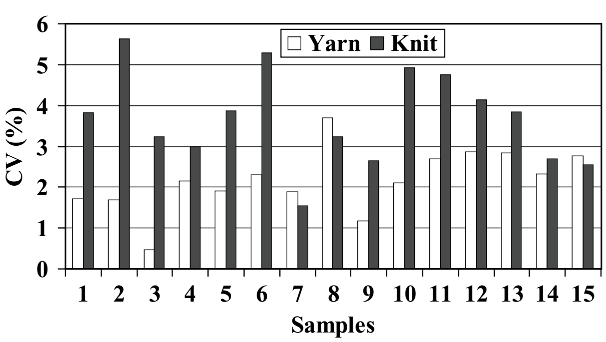

Figure 4. Comparisons of the percentage of coefficient of variation (CV) for white speck counts on the 15 yarn and knit samples for the three operators.

Comparisons of operator performance. When comparing readings among operators, two of the three comparisons were significantly different for knits and none were significantly different for yarns ($P \leq 0.05$) (Table 4). This indicates that readings by different operators were more consistent for yarn than for knits.

The percentage differences for operators between readings, expressed as absolute values, are presented in Figures 5 and 6. For the yarn, operator three was the most variable. Upon reviewing the data, this operator's first reading was identified as the source of the difference. Comparisons between the second and third reading were similar to the differences of the other two operators.

Table 4. Significance of white speck counts between operators for the yarns and knit fabrics

Operators	Significance [z]	
	Knits	Yarns
1 to 2	No	No
2 to 3	Yes	No
3 to 1	Yes	No

[z] Significance determined by the Mann-Whitney U test for independent variables at $P \leq 0.05$.

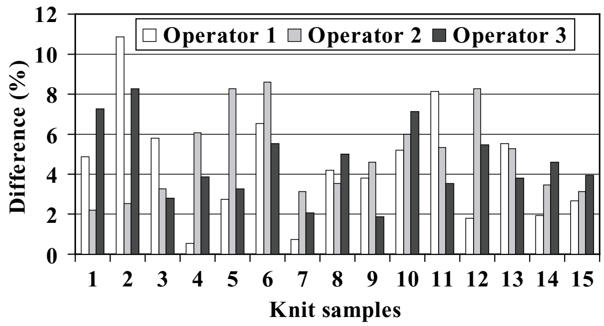

Figure 5. Average percentage differences among the three counts for white speck counts on the 15 knit fabric samples by the three operators.

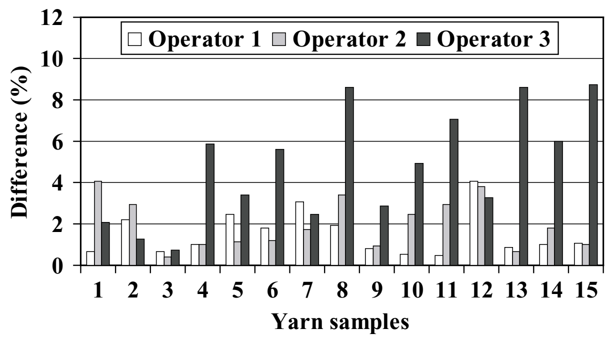

Figure 6. Average percentage differences among the three counts for white speck counts on the 15 yarn samples by the three operators.

The average correlation between operators was 0.87 and 0.98 for knits and yarns, respectively. These results further support the hypothesis that yarn is the less variable counting medium when using human inspection for the detection of white specks. The correlation between yarn and knits was 0.84.

Dyed yarn had a lower coefficient of variation between operator readings than dyed knit cloth (Table 3). This point was also supported by the lower percentage difference between readings and higher correlation for yarn between operators. In general, this indicated that the range of white speck counts by an operator making multiple counts would be more uniform for yarn than for knits.

The results of the analysis of variance are provided in Table 5. None of the four-way or three-way interactions were significant ($P > 0.05$). Samples, counting medium (yarn or fabric), operator, and the two-way interaction between sample and type were significant. Samples were expected to be significant since samples were selected that had different levels of white specks. The difference between yarns and knits confirms the hypothesis that they would be different. Operator significance indicates that operators see white specks differently and would have to be trained to reduce or eliminate their effect.

Table 5. Summary of ANOVA on white speck counts on the 15 yarn and fabric samples by the three operators

Effect [y]	*F*-value	*P*-value [z]
Sample	154.11	<0.001*
Counting medium	183.52	<0.001*
Operator	21.37	<0.001*
Reading	0.48	0.635
Sample x counting medium	18.39	<0.001*
Sample x operator	0.11	1.000
Counting medium x operator	2.74	0.065
Sample x reading	0.10	1.000
Counting medium x reading	0.30	0.738
Operator x reading	0.27	0.899
Sample x counting medium x operator	0.26	1.000
Sample x counting medium x reading	0.12	1.000
Counting medium x operator x reading	0.76	0.554
Sample x counting medium x operator x reading	0.11	1.000

[y] There were 15 samples each of yarn and knit fabric (counting medium) evaluated for white specks by three operators. Each operator counted each sample three times (reading) for white specks.

[z] Values designated with * indicate a significant *P*-value.

The combination of averaging operator readings and converting to units of length and area worked to smooth data to provide a meaningful regression analysis. A relationship exists between white specks per linear meter and white specks per square centimeter (Figure 7). The relationship had a highly significant ($P \leq 0.01$) coefficient of determination (R^2) of 0.7204.

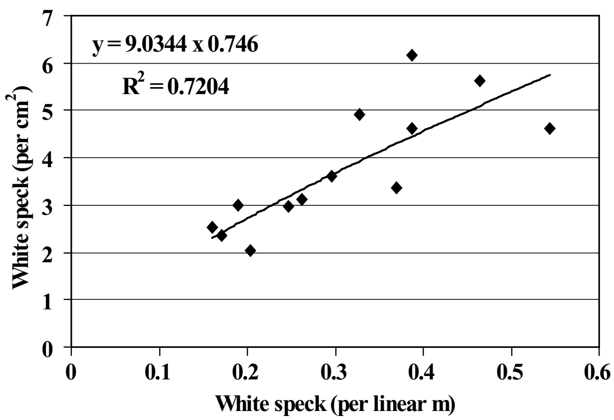

Figure 7. Results of regression analysis on the relationship between the number of white specks (WS) per linear meter of yarn and white specks per square centimeter of fabric.

Test hypotheses. There were three testable hypotheses for this research. First, within operator counting variability (reading-to-reading) when counting white specks will be less on dyed yarns than on dyed knit cloth as the counting medium. Second, operator-to-operator variability will be less for yarn than for knits. Third, a predictable relationship between white specks per unit length and white specks per unit of area for knits made from the test yarn will exist. In summary, for all three hypotheses the null hypotheses was rejected (Table 6).

Table 6. Summary of the testable hypotheses evaluated in this study

Hypothesis	Null (H_0)	Alternate (H_1)
Within sample operator counting variability (V)	$V_{Knit} = V_{Yarn}$ **(Rejected)**	$V_{Knit} > V_{Yarn}$ **(Accepted)**
Operator-to-operator counting variability	$V_{Knit} = V_{Yarn}$ **(Rejected)**	$V_{Knit} > V_{Yarn}$ **(Accepted)**
White speck counts (WS) per unit length of yarn relationship to white specks per unit of area in knit cloth	$WS_{Knit} \neq WS_{Yarn}$ **(Rejected)**	$WS_{Knit} = WS_{Yarn}$ **(Accepted)**

DISCUSSION

Results demonstrated that using dyed yarn as the counting medium for white specks was feasible. Regression results supported the hypothesis that white specks appearing on the surface of dyed yarn would also appear on cloth made from that yarn. It is thought that this relationship will be product-specific; i.e., the relationship will likely vary for different yarn counts and fabric constructions.

Using a human inspection methodology, yarn was a less variable test medium for the quantification of surface white specks than dyed knit FAK tubes. In comparison to FAK knit cloth, yarn was less variable reading-to-reading and operator-to-operator.

The development of a human inspection methodology for the detection of white specks in dyed cotton yarn and knit cloth was the first step in establishing a procedure that can be used to gather baseline work. This research will be used in the development and validation of future procedures.

Future plans should include establishing robust and statistically valid methods for accurately and efficiently measuring white speck counts on the surface of dyed yarn. Once developed, these test methods should be used to focus research efforts on the systematic exploration of causal factors and interdependent relationships influencing the white speck content in cotton.

ACKNOWLEDGEMENTS

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