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TEXTILE TECHNOLOGY

Measuring White Specks in Dyed Cotton Fabrics Using the Optimas Imaging System

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ABSTRACT

White specks are fiber clusters that appear as small white flecks on dyed fabrics. Their minute size and depth of shade increases the subjectivity and complexity of detecting and/or measuring them. No standard methods exist to quantify the level of white specks. Image analysis was evaluated as a means to measure white specks in order to remove subjectivity from the classification of manual dye defects. This paper provides systematic procedures for the evaluation of white specks on dyed fabrics. Software, hardware, and methods to obtain the white speck count, average size, and percentage white area are discussed in detail. The Optimas 5.2 software program uses a computer, two monitors, a video camera, and a photographic camera stand. The study involved eight plain weave fabrics each with visually distinct levels of white speck content. These fabrics were initially used to identify the system and software best suited for white speck quantification. The manual thresholding method was precise for one operator, but showed significant differences between operators. The fabrics were evaluated for their white speck content using the manual thresholding method (very operator dependent), and again using the new auto-thresholding method to minimize operator input. The auto-thresholding method uses light meters to maintain constant lighting levels and then automatically sets the threshold levels. The system detected different levels of white specks for these fabrics as expected. The auto-thresholding method was more accurate in actual count of white specks than the manual method. This measurement system gives the textile industry a standard tool and procedure to measure fabric appearance. White speck measurements are necessary not to correct the problem on the finished fabric, but as a way to measure changes in levels of white specks as a result of breeding, fields, ginning, and mill processing studies.

White specks are small fiber clusters that are made-up of immature fibers (often "fused" together) that appear as small white flecks on dyed fabrics. This condition can exist on both woven and knitted fabrics. The appearance of white specks on dyed and finished fabrics continues to be a sporadic and periodic problem for dyers and spinners (CI, 2007). White specks on finished dyed fabrics are immature fiber clusters that appear white on the surface of a darkly dyed fabric, or as non-uniform streaks in the fabric (Fig. 1). Unfortunately, these defects are not detected until after the dyeing stage of processing, which results in a fabric that cannot be marketed as first quality. It is estimated that the U.S. textile industry has lost approximately $200 million annually in recent years because of dye defects (Bel-Berger et al., 1996). International marketing of U.S. cotton is much more important now than it was 10 years ago. The United States is exporting about three-fourths of its cotton production. As U.S. mill production has dropped, mill production and consumption of cotton in China has increased significantly. Actual U.S. shipments to China are presently over 4.8 million bales or about 27% of the U.S. crop of 18 million bales. Neps have become an international problem for U.S. cottons, particularly in China. More than 90% of neps in finished fabric incorporate immature fiber

Figure 1: Dyed fabric displaying white specks.

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(Hebert, 1988) and appear as white speck neps, the most critical neps for fabric quality. It is important for the United States to understand other countries' perception of U.S. cotton quality. Relaying nep/white speck research to China has helped ensure continued access to China, a market worth $733 million in 2003 to U.S. cotton producers.

Scanning electron microscopy (Goynes, 1996) demonstrates that white specks are a mass of immature fibers that are exceedingly flat and ribbon-like (Fig. 2). Compared with a fully mature fiber, immature fibers have little secondary wall development that results in a fiber with low stiffness (Furter, 1992). Those fibers with a bit of secondary wall development often appear separated, but are still flat and ribbon-like, and are typically tangled into knots known as neps. The shortness of the path of light through the extremely thin walls of the immature and dead fibers accentuates the light-colored or white appearance of dye resistant neps. In addition, the immature fibers have an accelerated rate of sorption and desorption compared with mature fibers and expel dye more easily, so they retain very little color (Cheek and Wilcock, 1988). These dead or undeveloped fibers completely collapse into a flat ribbon that reflects light and consequently appear as white specks on dark shades of dyed fabric (Peter and Bowes, 1989). Because of this, image analysis seemed a natural choice to measure the defect, but because of the reflective nature of the defect, lighting would be critical.

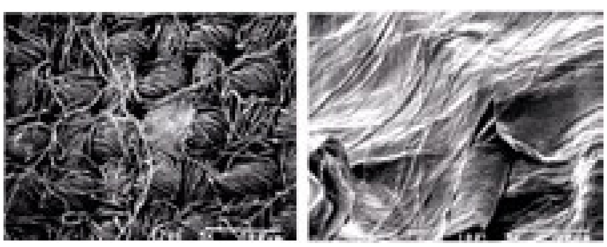

Figure 2: Photomicrographs of white specks on a dyed fabric.

Image analysis is used to detect the pore size in nonwovens (Xu, 1996), as well as to measure structural parameters of individual fibers and fiber bundles (Xu, 1997). Quality control utilizes the techniques of image analysis in order to measure fabric and yarn density, yarn configuration, and the geometry of knit fabrics to ensure that the specifications for a certain fabric are met (Zhang et al., 1996). Using the Cambridge Quantimet 570, researchers derived a means to compare the wrinkling of fabrics using a video camera to capture the images (Dobb and Russell, 1995). Identifying the correct lighting for capturing the images was a challenge, since these measurements were dependent on the lighting conditions. It was imperative to provide consistent lighting at optimal positions to eliminate any false readings (Dobb and Russell, 1995). Comparing the shade variations between wool and wool/cotton blends provided an interesting challenge for image analysis. Based on the versatility of image analysis, it seemed appropriate to evaluate fabric white speck content because of the high contrast between the white speck and the fabric.

Typically, fabrics are evaluated for their white speck content in a subjective manner. Image analysis is a tool that permits a consistent, objective means of quantifying the white speck content of a finished fabric. Several imaging systems are commercially available that service a wide variety of applications from the medical field to manufacturing tolerance testing; however, not all imaging software and systems are suitable for the macroscopic white speck detection. Many systems are capable of defining trends, providing consistent relative rankings, but not all are capable of yielding the same white speck content every time the fabric is tested. In order to define the appropriate image analysis system and technique for white speck analysis, eight fabrics each with a visually distinct level of white speck content were analyzed. Initial research identified a system that was appropriate for white speck detection and a technique for generating consistent data. In initial studies in white speck analysis using the Optimas system, the operators adjusted the brightness and contrast and then manually set the threshold until they felt that the white speck was accurately highlighted (Von Hoven, 1997). Consistency was maintained by using the same technician to perform subsequent studies. When other technicians tested the fabrics, the data paralleled the initial technician's data, but because of operator subjectivity, the white speck data were at a different level. To minimize the subjectivity of white speck analysis, the lighting factors, reflectance reading from the fabric, contrast, and brightness were always set to the same level, producing a consistent image for analysis. Auto-thresholding was also used to eliminate subjectivity of an operator. Using these techniques, the subjectivity of determining dye defects has been replaced by objective quantitative data that can be used for comparative purposes. This tool provides a means to study cultivar, harvesting, and processing effects on dye resistant neps.

Von Hoven (2000) reported that Optimas was a good tool for measuring white specks; however, Optimas 5.2 is not a user-friendly program. This paper reports on the development of an automated method to measure white specks and was written as a guide for white speck measurements. The new automated measurements are compared with the manual measurements from Optimas 5.2 reported by Von Hoven (2000).

MATERIALS AND METHODS

Hardware setup. Image analysis for this study was done using Excel (Microsoft; Redmond, WA) and the Optimas 5.2 software (Media Cybernetics; Bethesda, MD) on a Gateway 2000 P5-120 computer complete with a dual monitor set-up consisting of the Gateway computer monitor (Irvine, CA) and a Sony Trinitron RGB Monitor (Tokyo, Japan), an Imaging Technologies frame grabber (Bedford, MA), and a Microimage Video Systems RGB/YC/NTSC color camera (Boyertown, PA) mounted on a camera stand (Kaiser Fototechnik; Buchen, Germany) with four photographic lights. The F-stop was set at 4, and the lens of the camera was placed 47 cm (18.5 in) above the fabric surface to extract the image. A level was used to ensure that the camera was parallel to the fabric sample. A photograph of the analysis system is provided for guidance (Fig. 3).

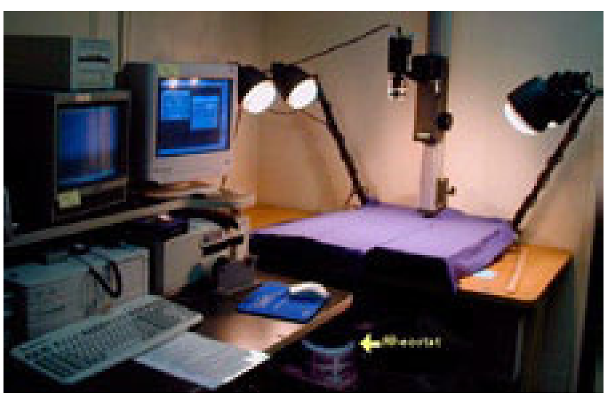

Figure 3: The Optimas image analysis system.

Lighting. A Polaroid MP-3l land camera stand (Waltham, MA) was used with four tungsten (120 V, 300 W) flood photography lights for uniform lighting of the fabric. There are arms on either side of the camera stand, each with two floodlights. The floodlights on each arm are 47 cm (18.5 in) apart with the face of the lamps 47 cm (18.5 in) from the camera. If the base of the camera stand has a strong contrast with the fabric, such as white, black, or highly reflective, it will affect the data taken on the edges of the fabric, so the base of the fabric stand was covered with fabric from the study to eliminate any problems. It is important to maintain a constant background that will not affect the threshold.

For the manual thresholding method, the lights on the camera stand were set on low without a rheostat, and the base of the camera stand was covered with black felt fabric. A contrast of 120 and a brightness of 217 were set in the Optimas camera menu and produced an analyzable image. The contrast and brightness may be adjusted if factors, such as a change in lighting because of bulb replacement, or lighter or darker fabrics are being analyzed.

For the auto-thresholding method, the lights on the camera stand were set on high and connected to a rheostat. This allowed the lighting system to be adjusted to a predetermined meter reading. A contrast of 243 and a brightness of 184 were set in the Optimas camera menu and produced a consistent image for analysis of each sample as viewed and measured on the Sony monitor. Many factors affect the level of reflected light as measured by the camera, such as the position of the operator, room lighting, and base of the camera stand. It is important that these factors remain the same when thresholding is set and as each 7.62 cm by 10.16 cm (3 in by 4 in) sample is tested. To maintain a constant background that will not affect thresholding, the sample should be large enough to cover the base of the camera stand as it is moved during testing. The fabric should be smoothed out before testing as the high and low areas in the fabrics create shadows that also affect the data. An easier option is to cover the base of the camera stand with a piece of fabric, similar in shade to the sample that is to be tested. The sample is then laid flat on cardboard that is slightly smaller than the sample. The cardboard carrier can easily be shifted to test all areas of the fabric sample.

Light meters. An Extech Instruments digital light meter (Model 401025; Waltham, MA) (Fig. 4) was used to measure illuminance (visible flux density). The light sensor was mounted in a Kodak Polycontrast Filter holder (Rochester, NY) that was pointed toward the fabric and mounted over the lens of the video camera (Fig. 5). The operator could then take the measurement while sitting in the same position as for testing without affecting the lighting. The rheostat was adjusted until the light meter luminance reading was 234 ± 1 lux (23.4 ± 1 lm/m^2).

Figure 4: Consistent images are produced for analysis by using reflective measurements as a tool to adjust lighting. Aiming the Vivitar 45 Exposure meter towards the fabric with ASA set at 800, the rheostat was used to adjust the lights until the meter read 11 EV to set the level of lighting. The lighting was fine tuned using the An Extech Instruments digital light meter (Model 401025).

Figure 5: The lighting was fine tuned using a digital light meter (Model 401025). The rheostat was adjusted until the light meter luminance reading was 198”2 lm/m^2 (198”2 Lux).

Measuring white speck. Place the fabric sample on the base of the camera stand. Fabric should be smooth and free of debris (try double-stick tape to remove debris). Using the Calculate Areas in the Percent Area menu of the software, the Percentage White, the area of the white specks detected divided by the Region of Interest (ROI) was calculated. The number and area of the white specks in addition to the Percentage White are measured.

Eight fabric study. Eight fabrics were produced from four cotton cultivars. Deltapine 90 (DP 90; Delta and Pine Land Co.; Scott, MS) was a commercial Delta Upland cultivar, and Stoneville 825 (STV 825; Monsanto Co.; St. Louis, MO) was a Mississippi cultivar. The other two cultivars were Acala cottons (J.G. Boswell Corp.; Corcoran, CA); EA-C30, an experimental cotton bred for early maturity, and EA-C32, a Prema cotton. Two of the four lots for each cultivar were single carded using the Mark IV card (Crosol; Greensville, SC). The other two lots were tandem carded using the Mark IV tandem card. The tandem card was improperly set, resulting in an increase in dye defects. Because of cultivar and carding differences, the eight fabrics had visually different levels of white speck. This study is not a about cultivar or processing effects on white specks, but these differences are incorporated into the samples to include a wide range of white speck levels.

Both 30/1 and 40/1 yarns with a 3.8 twist multiplier (T.M.) were ring spun. Plain weave fabrics were woven from 30/1 warp yarns and 40/1 filling yarns for all cultivars to produce eight fabrics of 100% experimental yarns (Bel et al., 1993; Bel-Berger et al., 1996). The fabrics were dyed and then ranked in order of appearance of white specks. The fabric that appeared to have the lowest level of white specks was ranked one, the fabric with the next lowest white speck content was ranked two, and so on until the fabric with the highest white speck content was ranked eight.

Dyeing procedure. The fabrics of both studies were finished with a 0.1% Prechem 70 (Ivax Industries; Horsham, PA) and 0.3% tetrasodium pyrophosphate 30 min. boil-off, a caustic scour for 1 h at 94 °C with 1.1% Prechem SN (Ivax Industries), 1.1% Mayquest 80 (Ivax Industries), 0.1% Prechem 70, and 0.7% sodium hydroxide followed by the same boil-off procedure. The fabric was then bleached with 0.1% Prechem 70, 0.5% Mayquest BLE, 3.0%

peroxide, and Albone 35 (DuPont Chemical Corp.; Wilmington, DE), followed by an acid scour at 40 °C for 45 min with 0.1% acid, and dyed in a Zimmer Dye jig (Zimmer American Inc.; Spartanburg, SC) with 2% Cibacron Navy F-G Blue (Ciba Specialty Chemicals; Greensboro, NC), 0.5% Calgon (Calgon Carbon Co.; Pittsburgh, PA), 8% sodium chloride, 0.8% Na_2CO_3, and 0.5% Triton X-100 (Sigma Aldrich; St. Louis, MO). All chemicals were determined from the weight of the bath, except for the dye, which was based on the weight of the fabric. This is a fiber reactive dye that binds to cellulose, and since the "specks" have very little cellulose not much, if any, dye binds to the specks (Fig. 1).

Statistical analysis. Eight replications of 30 positions for each of the eight fabrics were evaluated. There were no significant differences between the eight reps. The 30 positions for each of the eight fabrics for four different dates were included in the statistical analysis. Analysis of variance was performed on the complete data set (SAS Institute; Cary, NC). The area of white is calculated as the percentage of the fabric that appears white (percentage white). The means of two, three, and up to thirty positions (sub-samples) were plotted against the number of replications to indicate the minimum number of images needed to produce the percentage white mean. To verify the minimum number of images required per fabric, an analysis was performed on a data set containing 30 images and a data set containing 25 images to see if the means were significantly different.

The validity of the technique was checked by comparing the image analysis data to the white speck content determined by the manual method of image analysis on this same system (Von Hoven, 2000). A regression analysis was performed on the percentage white area determined by both the manual and automatic measurements. The percentage white area used in the regression was the mean of all of the replications for each fabric; 8 reps for 30 locations for each of the fabrics dates yielding 120 observations that were used to calculate the mean for each of the eight fabrics.

RESULTS AND DISCUSSION

The percentage white area values rather than white speck count were used in comparisons, because the percentage white area value takes both size and number into account, i.e. 20 large white specks would have a larger white area than 20 small white specks resulting in a more representative measure of the fabric white speck content. A fabric with a high white speck impact may have fewer larger white specks just as a fabric with low white speck content may have a large amount of small white specks. The Optimas system provided data that related well to the visual ranking of the fabrics, and further testing led to a way to minimize operator input. When the auto thresholding method was used to measure white specks, the only factor that the operator had to determine was the level to set for the maximum foreground limits (10% for low white speck fabrics and 20% for normal and high white speck fabrics) (Fig. 6). Auto thresholding was run with the foreground maximum set to 20% for normal and high white speck fabrics and to 10% for the three low white speck fabrics. The 20% threshold added false positives to the fabrics with low levels of white specks. A series of tests were run with a clear template on which each white speck was marked for the real white specks for each fabric. The template was laid over screen. Some of the results are shown in Figure 6. A threshold of 20% worked for all of the fabrics except for those with very low levels of white specks. The threshold was incrementally dropped by 1% until all three fabrics with low levels of white specks tested accurately. This threshold was 10%.

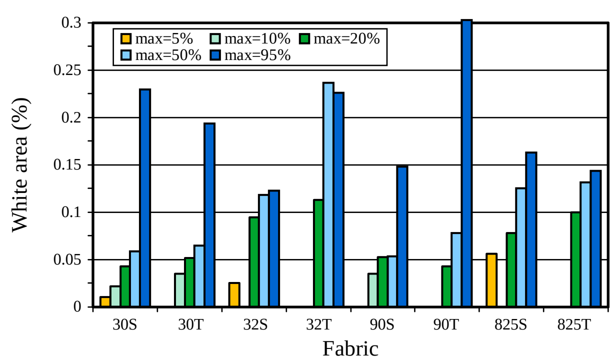

Figure 6. Effect of maximum foreground limits on the percentage white area.

The mean percentage white area for each of the eight fabrics was not statistically different for each of their dates of testing. The EA-C30 was always the fabric with the lowest white speck content, followed by DP 90, STV 825, and EA-C32, which had the highest percentage white area (Fig. 7). In this study, the second cylinder of the tandem card was accidentally misset (installer forgot to set this cylinder so it was left wide open for shipping mode) and caused an increase in white specks for each cultivar for both the manual and automatic threshold analysis (Fig. 7). The data also matched the subjective visual rankings as shown by Von Hoven (2000). The single and tandem carded fabrics for EA-C 332 and STV 825 had visually high (unacceptable quality) levels of white specks. Both EA-C 30 fabrics and the single carded DP 90 fabric had visually low levels of white specks (high quality).

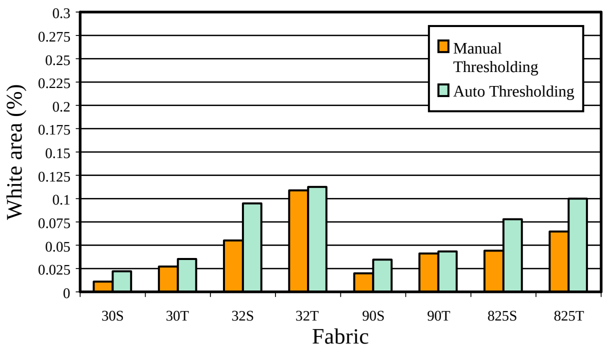

Figure 7: Comparison of manual and auto thresholding. Maximum foreground set to 20% for normal and high white speck fabrics (32S, 32T, 90T, 825S, and 825T) and to 10% for low white speck fabrics (30S, 30T, and 90S).

The daily percentage white area values for each of the fabrics had very little variation, indicating that the image analysis system and technique were measuring the white speck content consistently. A regression analysis of the relationship between the two thresholding methods provided a coefficient of determination (R^2) of 0.81 (Fig. 8). Using the graphic technique, the percentage white area means stabilized with 25 replications for the most variable fabric. For the eight fabrics, an ANOVA demonstrated that 25 images per fabric were not statistically different from 30 images per fabric. The ANOVA

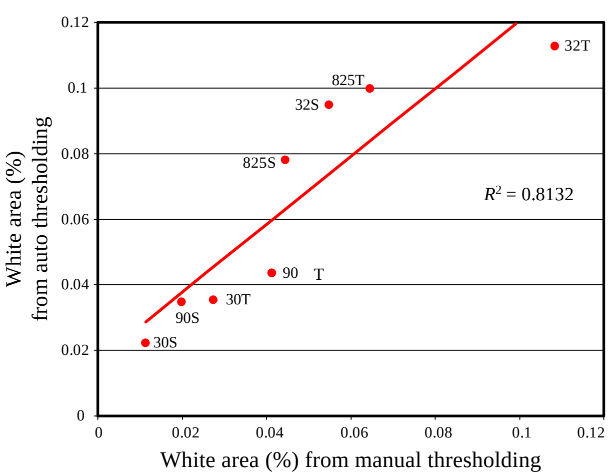

Figure 8: Comparison of percentage white area for manual thresholding and automatic thresholding.

and the graphical technique agreed that 25 images on a particular fabric were sufficient for white speck detection. Von Hoven's (2000) study using manual thresholding only needed 24 images.

CONCLUSIONS

The number of white specks is important but does not fully account for the appearance of the dyed fabric. Percentage white area is a value that can then be used to judge the overall quality of the fabric's appearance. Twenty-five replications for each fabric provided repeatable, statistically sound means for white speck content. The manual thresholding data correlated well with the automatic thresholding data. The subjectivity of determining these dye defects was replaced by objective quantitative data that can be used for comparative purposes. Lighting levels are critical for the auto-thresholding method. A light meter should be used to assure constant brightness and contrast values for analysis of fabric. Image analysis with auto-thresholding and multiple replications is less dependent on the operator and white speck count is more consistent with visual count. The manual thresholding proved consistent, but the actual counts were low. A new system specifically for white speck analysis is being developed, and plans are for the system to eliminate operator decisions. In making the image analysis system operator independent, industry will be able to have a standardized system of measuring white specks with the ability to compare other studies.

This tool also provides a means to study cultivar, harvesting, and processing effects on dye resistant neps. Future research will concentrate on minimizing operator dependence and increasing speed of testing by concentrating on automatic thresholding techniques and automatic fabric manipulation.

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