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# TEXTILE TECHNOLOGY

## The Effect of Bale Ageing on Cotton Fiber Chemistry, Processing Performance, and Yarn Quality

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### ABSTRACT

**The effects of ageing as a result of extended warehouse storage of baled cotton on fiber processing characteristics have not been extensively investigated. This study attempts to address this issue by characterizing some of the chemical and physical factors of the cotton fiber both before and after storage for 2 years, and by comparing any changes that occur with changes observed in yarn processing and resultant yarn quality. Results indicate that subsequent to storage, sugar content and moisture content both experience significant changes. Conductivity, pH, and wax content did not exhibit any statistically significant changes. Of the physical factors measured by HVI (micronaire, length, strength, uniformity, Rd, and +b), only +b exhibited a significant change. The changes in chemical components did not appear to have an impact on processing performance as inferred from the fact that fiber friction and yarn uniformity were not affected. Quality measurements on the resultant yarn, however, indicate a significant reduction in yarn strength. The primary conclusions from these results are that cotton aged for 2 years causes a detrimental effect on cotton quality because of the change in color grade, while a negative impact on yarn quality is seen as a result of decreased yarn strength. Possible causes for this observed decrease in yarn strength are discussed in terms of the measured chemical variables.**

The effects of ageing as a result of field weathering and warehouse storage on cotton fiber properties have been addressed in a number of studies (Aspland and Williams, 1991; ITC, 1989; McAlister, 1994; Marsh et al., 1954; Nickerson, 1951). Of the fiber properties measured (i.e. micronaire, length, strength, uniformity, reflectance, and yellowness), most of these studies found that the most significant changes involved color. This color change, as measured by +b or yellowness, appeared to be due in large part to the presence of fungi. These fungi use the chemical components of the fiber, including soluble surface materials such as sugars and organic acids, as a growth substrate. The color changes were further determined to have a substantial impact on the ability to dye the resultant fabrics made from the aged cotton fiber. Standard bleaching methods did not fully compensate for the +b changes, leading to potential influence on the hue and depth of dye shade. While previous studies have revealed that warehouse ageing may have a small effect on fiber tenacity and yarn strength, no attempt was made to assess the effect ageing on the processing of fiber into yarn (ITC, 1989).

Results from the five-year Leading Varieties Study performed at USDA-ARS Cotton Quality Research Station have indicated that field weathering in the form of heavy amounts of rainfall leads to a substantial increase in cotton fiber friction (Gamble, 2005), as measured by the Rotorring (Ghosh et al., 1992). Further studies have concluded that this increase in friction may in large part be caused by the loss of surface electrolytes (Gamble, 2006). The affect of these electrolytes on cotton fiber processing performance appeared to be due primarily to their anti-electrostatic properties. As fibers are opened during carding and subsequent processes, electrostatic charges may accumulate on the surface of the fibers. Further processing of these fibers is affected by this charge accumulation, because of the tendency of the fibers to simultaneously repel each other and adhere to metal and other surfaces of the processing equipment. The presence of moisture in conjunction with associated electrolytes serves to conduct this electrostatic charge away from the fiber. A recent surge of interest in friction has produced results demonstrating that in the case of cotton fabrics, frictional characteristics are associated with hand properties (Ajayi, 1992; Ramkumar et al., 2005). Changes in the friction characteristics of the constituent fibers may have some effect on the hand of fabrics produced from them.

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Warehouse storage of cotton for extended periods of time is another aspect of ageing. Previous studies found that at least two chemical factors, the pH and the glucose content of the water extract of cotton fiber, may be affected by long term storage (Gamble, 2003). In that study, a number of the cotton samples under evaluation were aged for at least 10 years, and displayed pH values that were substantially lower than more recently harvested cotton. In addition, glucose levels for the aged cottons were also significantly lower for the aged cottons. In order to further elucidate the role of surface chemical constituents on cotton fiber processing performance and yarn quality, this study was designed to address the effect of warehouse ageing on the chemical, physical, and frictional properties of cotton fiber stored in bales in order to determine whether storage of cotton for extended periods leads to changes in these variables, and whether these potential changes affect subsequent yarn production and quality characteristics.

## MATERIALS AND METHODS

**Cotton samples.** For this study, five Upland cotton (*Gossypium hirsutum* L.) samples (Table 1) from the 2001 crop year exhibiting a range of genetic diversity, micronaire, and growing regions were chosen. These samples are FiberMax 832 (FM 832; Bayer CropScience, Research Triangle Park, NC) and Paymaster 2200 (PM 2200; Delta and Pine Land Co.; Scott, MS) from Texas, Phytogen 355 (PHY 355; Dow AgroSciences; Indianapolis, IN) and Paymaster 1218 (PM 1218; Delta and Pine Land Co.) from Mississippi, and Deltapine 491 (DP491; Delta and Pine Land Co.) from Georgia. Initial measurements and processing were conducted on bale samples in 2002. Duplicate bales were stored in a warehouse with no climate control for temperature or humidity, which is typical of industry practice. Identical measurements and processing were performed on these samples approximately 2 yr after storage. Subsequent to bale opening, samples were conditioned at 65% relative humidity and 21 °C (70 °F) prior to HVI and chemical analyses. Values for all of the measured chemical components are reported relative to the weight of the conditioned fiber.

**Fiber measurements.** Micronaire was measured by high volume instrumentation (HVI) according to standard test methods (ASTM, 1997). Measurements of length, strength, uniformity, Rd, and +b were made by high volume instrumentation (HVI) according to standard test methods (ASTM, 1999).

**Textile processing.** Fiber blends before and after ageing were processed through the same modern Truetzschler Opening and Cleaning line (American Truetzschler Inc.; Charlotte, NC) and card to produce a 4960 tex sliver (70 grain sliver) at 68.2 kg/h (150 lbs/h). All fiber was processed through the sequence as follows: blending hoppers in a Fiber Controls Synchromatic Blending System (M & M Electric Service Inc.; Gastonia, NC), Axi-Flo cleaner (American Truetzschler Inc.), GBRA blending hopper (American Truetzschler Inc.), a RN cleaner (American Truetzschler Inc.), RST cleaner (American Truetzschler Inc.), DUSTEX fine dust remover (American Truetzschler Inc.), chute fed Saco Lowell card (Saco Lowell Inc.; Easley, SC), Rieter RSB draw frame (Rieter Corp.; Spartanburg, SC), Zinser 660 roving frame (Saurer, Inc.; Charlotte, NC), and Zinser 321 ring spinning frame (Saurer, Inc.). Sliver was run on a ring spinning frame into 29.5 tex yarns (20/1 yarns) at spindle speed of 16,500 RPM, a front roll speed of 260 RPM, and 7.22 twists/cm (4.1 TM).

**Yarn testing.** The Statimat-M (Zellweger Uster; Knoxville, TN) was used for yarn measurements, including strength, strength CV, and elongation. Uster II Evenness Tester (Zellweger Uster) was used to measure thick places and low places. Tensile properties of yarn were determined using standard test methods (ASTM, 1994). Classifying and counting faults in yarn were determined using standard test methods (ASTM, 2001b).

**Moisture determination.** Duplicate moisture determinations on the cotton samples before and after ageing were performed according to standard test methods (ASTM, 2001a).

**Conductivity, pH, and glucose measurements.** Cotton samples were extracted using 20 ml deionized water per gram of cotton. Three replicates were performed for each of the cotton samples. Each sample was agitated with a glass rod in order to promote wetting of the cotton surface. The resultant wetted sample was allowed to sit for 15 min before being wrung out. The resulting extract was then subjected to conductivity, pH, and glucose measurements. Conductivity measurements, reported in microsiemens per centimeter ($\mu\Omega^{-1}$ $cm^{-1}$), were performed on a Myron L Company Model EP conductivity meter (Myron L Co.; Carlsbad, CA). Measurements for pH were performed on a Orion Model 310 pH meter (Orion Research Inc.; Boston, MA). Glucose measurements, reported as the fraction (w/w) present on the fiber, were performed using a Yellow Springs Instrument Co. Model 2700 Bioanalyzer (YSI, Inc.; Yellow Springs, OH) equipped with a glucose oxidase membrane.

**Wax content.** Wax contents, reported as the fraction (w/w) present on the conditioned fiber, were determined by Soxhlet extraction. Six replicates were performed for each of the cotton samples before and after ageing. Extractions were performed using trichloroethylene as solvent on 2.5-gram samples of cotton. The resultant solutions were evaporated to dryness at 105 °C, leaving a wax residue that was subsequently weighed.

**Friction measurements.** Before and after ageing, four replicates for each of the cotton samples were evaluated for fiber-fiber friction using the Rotorring 580 (Spinlab; Knoxville, TN). Slivers in this case were approximately 208 grain/yard. Results of this measurement were converted to energy required to open a single fiber from the assembly using a previously described calculation reported in Joules (J) (Gamble, 2004).

**Statistics.** All linear regressions were performed using SigmaPlot 8.0 (SPSS Science; Chicago IL). *T*-tests were performed using SigmaStat 3.0 (SPSS Science).

## RESULTS AND DISCUSSION

Cotton samples aged as a result of warehouse storage for 2 yr did not exhibit significant changes in single fiber friction compared with the un-aged fiber, as measured by the Rotorring (Table 1). A previous study performed on cottons that had experienced high amounts of rainfall subsequent to boll opening and prior to harvest indicated that fiber friction displayed significant increases over non-weathered cottons (Gamble, 2005). Subsequent work indicated that removal of surface electrolytes from the cotton fiber surface may have been the primary cause for the observed behavior (Gamble, 2006). The samples in this study, however, were not subjected to field weathering conditions while in storage. As seen in Table 1, average surface concentrations of electrolytes, as indicated by the conductivity of the water extract, did not change as a result of the ageing process. Wax content and pH did not exhibit any statistically significant changes. The two other chemical factors shown in Table 1, moisture content and glucose content, did undergo appreciable change as a result of ageing. The decrease in glucose content may be due to fermentation by fungi, which use sugars as a growth substrate. The decrease in glucose content on the surface of the fiber did not have a significant impact on processing as determined by the fiber friction measurement. The decrease in fiber moisture content as a result of ageing may be due to one of two mechanisms, a) the decrease in hygroscopic surface sugars, or b) moisture loss from the cellulose component of the fiber. The average change in moisture content between the un-aged and aged cotton samples is 0.276% w/w, or 0.00276 on a weight fraction basis. The average weight fraction loss of glucose content is 0.00130. Cotton fiber exhibits roughly equal proportions of glucose and fructose, which was not measured in this work. Assuming a fructose content change of 0.0013, the average total sugar loss from the cotton fiber

**Table 1. Chemical and frictional fiber properties of 5 cotton samples before and after bale ageing for 2 yr**

| Age (years) | Cultivar (location)[z] | Fiber friction (J) | $H_2O$ fraction (x100) | pH | Wax fraction (x1000) | Conductivity (μΩ-1 cm-1) | Glucose fraction (x1000) |
|---|---|---|---|---|---|---|---|
| 0 | FM832(T) | 0.1695 | 7.20 | 6.12 | 6.45 | 1025 | 2.82 |
| | PM2200(T) | 0.1679 | 6.93 | 6.37 | 5.73 | 967 | 1.65 |
| | DP491(G) | 0.1938 | 6.80 | 6.75 | 3.83 | 692 | 1.63 |
| | PHY355(M) | 0.1824 | 6.83 | 6.91 | 4.41 | 717 | 0.90 |
| | PM1218(M) | 0.1965 | 7.10 | 8.24 | 2.89 | 600 | 0.48 |
| | Mean | 0.182 a | 6.97 a | 6.88 a | 4.66 a | 800 a | 1.52 a |
| 2 | FM832(T) | 0.1918 | 6.50 | 5.71 | 6.65 | 900 | 0.72 |
| | PM2200(T) | 0.1638 | 6.62 | 6.10 | 4.59 | 920 | 0.47 |
| | DP491(G) | 0.1762 | 6.63 | 6.33 | 3.60 | 680 | 0.46 |
| | PHY355(M) | 0.1754 | 6.61 | 6.36 | 2.81 | 720 | 0.25 |
| | PM1218(M) | 0.2306 | 6.60 | 7.30 | 2.67 | 620 | 0.14 |
| | Mean | 0.186 a | 6.59 b | 6.36 a | 4.07 a | 768 a | 0.41 b |

[z]Location: T = Texas, G = Georgia, M = Mississippi

[y]Means within a column followed by the same letter are not significantly different according to *t*-test ($P \leq 0.05$).

is approximately 0.0026. Both fructose and glucose are mono-hydrates at 65% R.H. and 70 °C, so that the expected moisture loss due to fungal degradation of these sugars would be approximately 0.00026, an order of magnitude less than that observed as a result of ageing. It was concluded that the observed moisture loss is likely because of a change in moisture content in the fiber cellulose fraction. It might be expected that such a substantial loss of water from the cellulose structure would result in a change in the morphology of the fiber, i.e. the frequency of convolutions exhibited by the fiber. Though convolutions were not measured as part of this study, the fact that fiber cohesion is not affected by the observed loss in moisture indicates that this possibility may tentatively be ruled out, since the relationship between fiber cohesion and fiber convolution frequency is widely accepted (Morton et al., 1993).

HVI fiber measurements were performed on bale samples of all 5 cottons both prior to and after ageing (Table 2). No significant changes were observed for micronaire, strength, uniformity, or Rd. Yellowness (+b) underwent a substantial increase (average 9.07 to 11.61), as was observed in previous studies (Aspland and Williams, 1991; ITC, 1989; Marsh et al., 1954; Nickerson, 1951). Properties of yarns processed from the same five cottons are shown in Table 3 and include

**Table 2. HVI fiber properties of 5 cotton samples before and after bale ageing for 2 yr**

| Age (years) | Cultivar (location)[Z] | Mic | Length (cm) | Strength (cN/tex) | Uniformity (%) | Rd | +b |
|---|---|---|---|---|---|---|---|
| 0 | FM832(T) | 2.89 | 3.00 | 29.16 | 80.28 | 78.38 | 9.59 |
| | PM2200(T) | 3.38 | 2.79 | 27.21 | 81.19 | 80.41 | 9.25 |
| | DP491(G) | 4.05 | 2.87 | 30.00 | 80.25 | 77.34 | 8.20 |
| | PHY355(M) | 4.80 | 2.82 | 28.74 | 82.00 | 74.00 | 8.57 |
| | PM1218(M) | 5.56 | 2.67 | 25.75 | 81.88 | 74.19 | 9.72 |
| | Mean | 4.14 a | 2.82 a | 28.17 a | 81.12 a | 76.86 a | 9.07 a |
| 2 | FM832(T) | 2.89 | 3.07 | 28.83 | 81.50 | 74.60 | 13.60 |
| | PM2200(T) | 3.38 | 2.82 | 27.14 | 83.04 | 77.99 | 12.03 |
| | DP491(G) | 4.05 | 2.90 | 30.20 | 81.70 | 76.75 | 11.10 |
| | PHY355(M) | 4.80 | 2.87 | 28.34 | 82.10 | 74.20 | 10.00 |
| | PM1218(M) | 5.56 | 2.64 | 25.50 | 82.00 | 74.97 | 11.34 |
| | Mean | 4.14 a | 2.87 a | 28.00 a | 82.07 a | 75.70 a | 11.61 b |

[z]Location: T = Texas, G = Georgia, M = Mississippi

[y]Means within a column followed by the same letter are not significantly different according to *t*-test results ($P \leq 0.05$).

**Table 3. Yarn properties of 5 cotton samples before and after bale ageing for 2 yr**

| Age (years) | Cultivar (location)[Z] | Opening waste (%) | Total card waste (%) | Strength (cN/tex) | Strength CV (%) | Elongation (%) | Thick places | Thin places |
|---|---|---|---|---|---|---|---|---|
| 0 | FM832(T) | 1.14 | 3.20 | 18.42 | 9.04 | 7.23 | 712 | 21 |
| | PM2200(T) | 0.96 | 2.12 | 16.83 | 9.35 | 7.74 | 611 | 66 |
| | DP491(G) | 2.78 | 2.31 | 17.90 | 9.14 | 6.87 | 684 | 129 |
| | PHY355(M) | 1.73 | 2.27 | 16.67 | 8.92 | 7.41 | 587 | 192 |
| | PM1218(M) | 1.24 | 1.99 | 16.18 | 9.62 | 6.33 | 487 | 189 |
| | Mean | 1.57 a | 2.38 b | 17.20 a | 9.22 a | 7.12 a | 616 a | 119 a |
| 2 | FM832(T) | 1.39 | 7.05 | 17.23 | 7.51 | 6.78 | 535 | 57 |
| | PM2200(T) | 1.21 | 5.06 | 15.25 | 8.06 | 7.35 | 670 | 123 |
| | DP491(G) | 3.41 | 5.40 | 16.70 | 7.97 | 6.52 | 657 | 102 |
| | PHY355(M) | 1.94 | 4.82 | 15.24 | 8.48 | 7.07 | 555 | 132 |
| | PM1218(M) | 1.60 | 4.87 | 14.69 | 9.83 | 6.17 | 482 | 138 |
| | Mean | 1.91 a | 5.45 a | 15.82 b | 8.37 b | 6.78 a | 579 a | 110 a |

[z]Location: T = Texas, G = Georgia, M = Mississippi

[y]Means within a column followed by the same letter are not significantly different according to *t*-test results ($P \leq 0.05$).

opening and cleaning waste, strength, strength CV, elongation thick places, and thin places. No substantial change was observed in waste produced during opening and cleaning processes. The observed increase in total card waste is due primarily to the fact that in the interim period between processing the new crop and aged cottons, the flats on the card were converted to a coarser and presumably more aggressive wire. Thin and thick places do not appear to be affected by bale ageing, which is consistent with the fact that the measured friction properties do not change (Table 1), indicating that processing performance is unaffected by the ageing process. As indicated in previous studies (ITC, 1989), yarn strength underwent a statistically significant 8% reduction (average 17.20 to 15.82 cN/tex) as a result of ageing. Although a statistically significant change in yarn elongation was not observed, a trend was observed. For each of the five cottons, elongation was decreased as a result of ageing. The reason for these behaviors is not readily apparent; however, since concomitant decreases in fiber strength and inter-fiber friction were not observed. Presumably, if fiber cellulose degradation because of oxidation and microbial processes had occurred, a resultant decrease in fiber strength would be reflected in the HVI strength measurement. Because this decrease was not observed (Table 2), however, it is likely that the decreased yarn strength was due to changes in the surface of the fibers, possibly related to the fact that sugar content decreased as a result of ageing. It is widely accepted that native surface sugars, primarily glucose and fructose, may under certain circumstances lead to cotton sticking to processing equipment (Hector and Hodkinson, 1989). Though most of the residual sugar content of the dried fiber is likely deposited in the lumen, some may also be present on the outer surface of the fiber. The presumed effect is that these sugars provide a degree of fiber cohesion because of a hydrogen bonding mechanism, though this effect may be apparent only when the fibers are in close proximity to one another, as in a yarn structure. In previous work, yarns were washed with water and yarn strength measurements performed subsequent to drying and reconditioning (Price et al., 2002). In that case sugars, along with any other water soluble components, were removed. Results indicated a nearly 2% decrease in yarn strength, consistent with the argument that surface sugars are correlated with yarn strength. The ageing of cotton, due in part to fungal growth on the fiber, results in decreased surface sugars. Under the assumption that these surface sugars display hydrogen bonding when fibers are in close contact, as in yarn structures, the corollary to fungal degradation of the sugars is decreased yarn strength.

## CONCLUSIONS

Results of this research indicate that long term storage of cotton leads to substantial changes in at least two non-cellulosic chemical components, including sugar and moisture content. These changes do not appear to have any direct effect on the processing characteristics of the resultant aged cotton, as indicated by the fact that fiber friction behavior was unaltered by the ageing process and that yarn uniformity was unaffected. One of the measured chemical components not experiencing a significant change was surface salt content, as measured by conductivity. This result provides validation for previous work that suggested that surface salt content is the primary fiber surface chemical constituent implicated in fiber friction behavior (Gamble, 2005). The only HVI measured quality characteristic of cotton fiber affected by ageing was deterioration in color grade, a result that has been previously demonstrated (ITC, 1989). This change in color grade, however, was accompanied by an apparent increase in fungal populations, as evidenced by the degradation of surface sugars. Of the yarn properties investigated, only yarn strength and possibly elongation were affected by extended warehouse storage. Results suggest that the decrease in surface sugars may be implicated in the concomitant decrease in yarn strength as a result of the disappearance of hydrogen bonding forces. This implication will be the subject of continuing investigation in this laboratory.

## REFERENCES

Ajayi, J.O. 1992. Fabric smoothness, friction, and handle. Textile Res. J. 62(1): 52-59.

American Society for Testing and Materials (ASTM). 1994. Standard test method for tensile properties of yarn by single strand method (D-2256). *In* Annual Book of Standards, Section 7.01, Textiles. ASTM International, West Conshohocken, PA.

American Society for Testing and Materials (ASTM). 1997. Standard test method for micronaire reading of cotton fibers (D1448-97). *In* Annual Book of ASTM Standards. Vol. 07.01. ASTM, West Conshohocken, PA.

American Society for Testing and Materials (ASTM). 1999. Standard test methods for measurement of physical properties of cotton fibers by high volume instruments (D5867-95). *In* Annual Book of ASTM Standards. ASTM, West Conshohocken, PA.

American Society for Testing and Materials (ASTM). 2001a. Standard test method for moisture in cotton by oven drying (D2495-01). *In* Annual Book of ASTM Standards. Vol. 07.01. ASTM, West Conshohocken, PA.

American Society for Testing and Materials (ASTM). 2001b. Standard test method for unevenness of textile strands using capacitance testing equipment (D-6197). *In* Annual Book of Standards, Section 7.01, Textiles. ASTM International, West Conshohocken, PA.

Aspland, R.J., and S.A. Williams. 1991. The effect of cotton color grade on the color yield of dyed goods. Textile Chemist and Colorist 23(2): 23-25.

Gamble, G.R. 2003. Variation in surface chemical constituents of cotton (*Gossypium hirsutum*) fiber as a function of maturity. J. Agric. Food Chem. 51:7995-7998.

Gamble, G.R. 2004. Implications of surface chemistry on cotton fiber processing. J. Cotton Sci. 8:198-204 [Online]. Available at http://www.cotton.org/journal/2004-08/3/198.cfm

Gamble, G.R. 2005. Cotton fiber chemical differences and their effect on friction behavior: A comparison of two crop years in the ATMI/ARS leading cultivars study. J. Cotton Sci. 9:56-64 [Online]. Available at http://www.cotton.org/journal/2005-09/1/56.cfm

Gamble, G.R. 2006.The influence of surface electrolyte and moisture content on the frictional behavior of cotton fiber. J. Cotton Sci. 10:61-67 [Online]. Available at http://www.cotton.org/journal/2006-10/1/61.cfm

Ghosh, S., J.E. Rodgers and A.E. Ortega. 1992. Rotor ring measurement of fiber cohesion and bulk properties of staple fibers. Textile Res. J. 62(10):608-613.

Hector, D.J. and I.D. Hodkinson. 1989. Stickiness in cotton. ICAC Review Articles on Cotton Production Research, No. 2, International Cotton Advisory Committee, Washington, D.C.

International Textile Center (ITC). 1989. Effects of ageing on cotton quality. Textile Topics 6:1-3.

McAlister, D.D. III. 1994. The effect of cotton ageing on the color variation of dyed fabric. M.S. thesis. Institute of Textile Technology, Charlottesville, VA.

Marsh, P.B., K. Bollenbacher, M.L. Butler, and G.V. Merola. 1954. The relative responsiveness of certain properties of cotton fiber to microbial action. Textile Res. J. 1:31-38.

Morton, W., Hearle, J., and Text, C. 1993. Physical properties of textile fibers. The Textile Institute, Manchester, U.K.

Nickerson, D. 1951. Effect of exposure and storage on color and other factors of quality in raw cotton. United States Dept. of Agriculture. Washington D.C.

Price, J.B., Cui, X., Calamari, T.A., and W.R Meredith, Jr. 2002. Cotton wax and its relationship with fiber and yarn properties. Part II: Wax content and yarn properties. Textile Res. J. 72(7): 631-637.

Ramkumar, S.S., Rajanala, R., and S. Parameswaran. 2005. Frictional characterization of polymeric materials-a review. AATCC Review 5(2):17-20.