COMMERCIAL COTTON VARIETY SPINNING STUDY
HVI AND AFIS SPINNING RELATIONSHIP

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Abstract

In 2005, there were 22,638,247 upland cotton bales classed by the United States Department of Agriculture (USDA) American Marketing Service (AMS). USDA-AMS uses the High Volume Instrument (HVI™) to class all bales for fiber length, length uniformity, micronaire, strength, color (Rd and +b), trash, and leaf grade. Industry uses these results as well as fiber quality measurements obtained from a slower piece of testing equipment called the Advanced Fiber Information System (AFIS). The Cotton Quality Research Station (CQRS) of the USDA-ARS, located in Clemson, SC, has completed a comprehensive study of the relationship of cotton fiber properties to the quality of spun yarn. Cotton was grown and harvested from three of the largest producing growing regions (Georgia, Mississippi, and Texas) and subsequently ginned at their respective locations. This study evaluated HVI and AFIS fiber qualities and their impact on yarn using modern, high speed processing equipment. Cotton was spun into yarn at the CQRS laboratory by each of three spinning methods (ring, vortex and rotor spinning) with characteristics of the yarn and spinning measured. A previous manuscript detailed descriptive statistics and distributions for the fiber and yarn. This manuscript explores the common fiber quality measurements obtained from the HVI and AFIS and how well they help predict yarn quality and processing efficiencies.

Introduction

Cotton fibers, a viscoelastic material, are the fundamental building blocks used to form the more complex structure of yarn and ultimately fabric. Fiber characteristics (e.g. geometric, mechanical, and chemical properties) influence yarn characteristics (e.g. strength, extensibility, friction, stiffness and resilience). The resultant strength of yarn is an important aspect of yarn quality so that spinners select cottons based upon their suitability for textile processing with acceptable quality and spinning efficiency (e.g. low number of ends down). Increasing micronaire tends to increase irregularity and frequencies of thin and thick places and decrease yarn strength (Hunter and Lee, 1980). Increases in micronaire are often associated with a slight increase in frequency of yarn neps (Hunter and Lee, 1980). A cotton bale is a bale of fibers with variability; however, a multiple bale laydown is utilized to minimize cotton bale and fiber variability for better yarn properties. It has been demonstrated with cotton yarns containing high yarn strength variability or low spinning strength would require low production rates or must be used in heavy yarns (Graham and Taylor, 1978). Graham and Taylor (1978) further state that cotton yarns containing high spinning strength as well as low spinning strength variability could be processed at high production rates or used to produce fine yarn for quality products.

Establishing a relationship between yarn and fiber properties is necessary to better understand the resultant yarn structure. Correlations of yarn strength to fiber strength, fiber cohesion, and fiber regularity were first presented by F. T. Peirce in 1946 (Bogdan, 1956; Bogdan 1967). Currently, fiber properties normally considered for fiber-to-yarn research have included the common HVI™ properties such as micronaire, length, length uniformity, strength, elongation, color, and trash. Nearly all cotton bales are classed via the HVI™ and in 2005 there were 22,638,247
upland cotton bales classed by the United States Department of Agriculture (USDA) American Marketing Service (AMS). The HVI™ “benchmark” properties have been considered the most important and most readily acceptable factors in predicting cotton quality by the U.S. Textile Manufacturers.

To achieve better processing efficiency and processing control, textile mills often perform secondary measurements (length, short fiber content, maturity, and fineness) acquired using a slower instrument, the AFIS™. These AFIS™ measurements can concurrently be utilized for fiber-to-yarn research. Yarn properties typically considered for fiber-to-yarn research include strength, uniformity (such as evenness and defects), appearance, and processing efficiency (such as ends-down). It is generally accepted that the following factors affect yarn quality: fiber properties, non-lint content, short fiber content, blend levels, yarn count (size), yarn twist, processing machines (type and settings), and spinning systems (type and settings). To avoid confusion produced by fiber blends, cotton is characteristically the lone fiber evaluated. To avoid machinery and setting differences, fiber is typically processed on the same textile processing and spinning systems with the same yarn properties. To predict yarn properties, researchers have studied fiber-to-yarn models with both theoretical (Bogdan, 1956; Bogdan 1967; Ghosh et al., 2005) and statistical regression analysis (Ethridge et al., 1982; Hunter and Gee, 1982; Mogahzy et al., 1990; Ramey et al., 1977; Ureyen and Kadoglu 2006).

There is no uniform agreement on the key fiber properties related to spinning performance because the problem is complex and multifaceted. The type of yarn, end-use of yarn, and required yarn properties will further affect the desired fiber properties. It has been stated that key properties for the three spinning systems are as follows: length, strength, fineness, and friction (ring-spinning); strength, fineness, length, cleanliness, friction (rotor-spinning); and length, fineness, strength, friction, cleanliness (vortex-spinning) (Deussen, 1993). The question of which fiber properties are important is further compounded by having multiple ways to measure a single property (e.g. fineness obtained using the HVI™ or AFIS™). Higher grades of cottons based on HVI™ measurements do not necessarily result in better yarn quality and spinning performance due to the formation of short fibers and neps from additional ginning to produce higher grades. Some individuals have concluded that it is more important to closely control fiber length distribution than strength or fineness measurements. To simplify research, cotton was spun into yarn at one laboratory by each of three spinning methods (ring, vortex and rotor spinning) with characteristics of the yarn and spinning measured.

It is acknowledged that as fiber length increases fiber strength tends to increase (Morton and Hearle, 1962). The question of how fiber properties relate to spinning performance is an old one. Despite much research, the issue is not resolved, and has grown more complex with advances in instrumentation and processing technologies. Fiber properties are not likely independent and contain interactions with unknown relationships. The Cotton Quality Research Station (CQRS) of the USDA-ARS has completed a comprehensive study of the relationship of cotton fiber properties to the quality of spun yarn. A preceding manuscript described the commercial variety spinning study design, the measurements and testing procedures, the three spinning processes, the fiber property distributions, yarn characteristics, and spinning performance described by summary statistics and histograms. This manuscript will discuss, evaluate, and predict the impact of common and traditional fiber measurements (HVI™ and AFIS™) on yarn quality and processing efficiencies using modern, high speed processing equipment.

**Model**

Measurement of the HVI and AFIS properties of the 154 lots of blended stock are described by Foulk et al. (2007). A total of 7 HVI fiber measurements (fiber length, length uniformity, strength, micronaire, trash, Rd, and +b) were measured for each of the 154 blended lots. HVI™ classification was performed on bale samples prior to bale blending. For the first three years of the study, 32 HVI™ measurements were taken for each cotton lot with years 4 and 5 utilizing 24 HVI™ measurements for each lot. To better utilize all collected data standard deviations were calculated for variables where replicate measurements were taken. For each spinning lot, the distribution of HVI™ classification values were summarized for each measurement and cotton variety by two variables, the sample mean and the sample standard deviation.

A total of 6 AFIS fiber measurements (fineness, upper quartile length (UQL), short fiber content (SFC), Maturity Ratio, Neps (count/gram), and visible foreign matter (VFM)) were measured for each of the 154 blended lots. The Advanced Fiber Information System (AFIS™) (Uster Technologies Inc., Knoxville, TN) is a destructive method that aeromechanically opens fibers and separates fiber, trash, and dust for electro-optical measurements thus producing various distributions. These blended stock AFIS™ measurements were obtained for all cotton spinning lots with
three tests of 3,000 fibers each performed by one technician on a sample and the results averaged to obtain an observation. For each spinning lot, the distribution of AFIS™ values were summarized for each measurement by two variables, the sample mean and the sample standard deviation.

The 154 lots of blended stock were spun into yarn by each of three spinning methods and twelve measures of spinning performance were measured in this study. Details of testing and processing conditions along with a summary of spinning results are discussed by Foulk et al. (2007). This report examines the relationship of HVI and AFIS fiber properties to the 14 spinning performance variables using a hierarchical modeling strategy. The models were used to predict 14 x 3= 42 yarn characteristics. A modeling strategy was developed using SAS regression models limited to no more than 10 different variables. For each spinning method and spinning performance outcome, multiple linear regression models are fit using as predictors: (1.) the (mean) HVI fiber properties alone; (2.) the means and standard deviations of the HVI properties; (3.) the (mean) AFIS fiber properties alone; (4.) the means and standard deviations of the AFIS properties; (5.) the (mean) HVI and AFIS properties together; and, (6) the means and standard deviations of the HVI and AFIS properties together. The models were fit to data from the 154 blended lots using SAS procedure STEPWISE with a significance level of 20% as the criterion for variables to enter and stay in the model. This technique is a method of analyzing the variability of a dependent variable by using information available on independent variables. A forward variable selection method enters variables into a model one at a time based on a pre-set significance level to search for an acceptable model. Significance level entry (SLE=0.20) for significance criterion for entry of a variable into the model and significance level stay (SLS=0.20) were the criterion for removal from the model.

**Discussion**

Before assessing fiber properties it is advantageous if one graphically evaluates the relationships and better comprehends the methodology prior to modeling. One Figure (contact author) demonstrates the HVI fiber bundle relationship between fiber length, strength, and fineness so that finer fibers are longer and stronger. Another Figure (contact author) demonstrates the relationship between AFIS maturity ratio, length, and fineness. Three other Figures (contact author) reveal the fiber length and strength relationship to rotor, vortex and ring yarn consequently demonstrating that stronger and longer fibers produce stronger yarn. Another three Figures (contact author) demonstrate the year to year variability and relationship between ring yarn strength and HVI length, micronaire, and strength with longer fibers, finer fibers, and stronger fibers producing stronger yarn. Three more Figures (contact author) demonstrate the year to year variability and relationship between rotor yarn strength and HVI length, micronaire, and strength with longer fibers, finer fibers, and stronger fibers again producing stronger yarn. Three other Figures demonstrate the year to year variability and relationship between ring yarn strength and HVI length, micronaire, and strength with longer fibers, finer fibers, and stronger fibers producing stronger yarn.

Models were first fit for rotor (contact author), ring (contact author), and vortex (contact author) spinning using typical HVI properties as predictors. These are the properties upon which cotton is sold and these models will provide a baseline for judging how much improvement in prediction (R²) is gained by using different HVI predictors (contact author). Secondly models were fit for rotor (contact author), ring (contact author), and vortex (contact author) spinning using typical HVI properties and the standard deviation of these properties such as may be seen in multi-bale laydown. These models demonstrate the improvement in prediction (R²) is provided by using the standard deviations of the typical HVI properties (contact author). Utilizing standard deviations with HVI properties permitted average R² values to increase by 0.08, 0.10 and 0.04 for ring, vortex and OES spinning respectively. Since a cotton bale is a bale of fibers with variability; HVI results demonstrate that it is becoming more important to minimize cotton bale and fiber variability along with fiber property standard deviations.

Models were then fit for rotor (contact author), ring (contact author), and vortex (contact author) using typical AFIS properties as predictors. These are the properties upon which textile mills may make use of and these models demonstrate the improvement in prediction (R²) is gained by using only AFIS predictors. Secondly models were fit for rotor (contact author), ring (contact author), and vortex (contact author) spinning using typical AFIS properties and the standard deviation of these properties such as may be seen in multi-bale laydown. These models further demonstrate how much of an improvement in prediction (R²) is provided by using the standard deviations of the typical AFIS properties (contact author). By including AFIS properties along with standard deviations, average R² values increase by about 0.03 for all three methods. Since a cotton bale is a bale of fibers with variability; AFIS results demonstrate that it is becoming more essential to reduce fiber property standard deviations.
After separately completing HVI and AFIS model fitting, these properties were combined to first using only the typical HVI and AFIS properties as predictors and fit for rotor (contact author), ring (contact author), and vortex (contact author) spinning. This was performed to determine how much of an improvement in prediction (R2) is gained by using predictors from two different types of measurements (contact author). Finally, HVI and AFIS measurements along with respective standard deviations were used to determine how much of an improvement could be utilized using standard measurements and their standard deviations and fit for rotor (contact author), ring (contact author), and vortex (contact author) spinning. These models further demonstrate how much of an improvement in prediction (R2) is provided by using the standard deviations of the typical fiber quality properties (contact author). Finally, when HVI and AFIS properties with their standard deviations are all considered, average R2 values increase by about 0.05 for all three spinning methods relative to when just HVI properties and standard deviations are used. Since a cotton bale is a bale of fibers with variability; outcome of the HVI and AFIS model fitting demonstrates that with increasing speeds it is becoming more important to minimize cotton fiber variability.

Numerous mills are interested and keenly aware of their mass flow of cotton and waste output and how it relates to processing efficiency. In predicting total card waste, HVI fiber properties alone (R2=0.834) are better able to predict than AFIS fiber properties alone (R2=0.179). In predicting total card waste using HVI fiber properties, trash is the single most important property with the final model containing strength, Rd, trash, and uniformity. However, combining measurements from HVI and AFIS or including standard deviations for fiber properties further improves the coefficient of determination. In predicting total card waste using HVI and AFIS properties along with standard deviations the coefficient of determination increases to 0.897 and includes Rd, +b, trash, SFC, neps along with the standard deviation of micronaire, strength, length, and uniformity. The opening and cleaning waste coefficient of determination is relatively similar for HVI (0.465) and AFIS (0.483) with slight improvements seen by including both HVI and AFIS or standard deviations.

Textile mills efficiency is related to how well it is able keep the yarn processing without an ends down. In predicting ends down it is extremely difficult to predict the ends down for ring spinning with R2=0.026 for HVI properties alone, R2 = 0.0533 for AFIS properties alone, and R2 = 0.0902 for HVI and AFIS properties and the single most important property trash. By including standard deviations the R2 only slightly improves for HVI and AFIS properties with standard deviations (R2 = 0.204). Compared to ring spinning, vortex and rotor spinning is easier to predict with R2 = 0.631 and R2 = 0.611, respectively using HVI and AFIS properties along with standard deviations. For vortex spinning ends down efficiency the single most important property is fiber length uniformity, while for rotor spinning it is trash.

Ring and vortex spinning, the average R2 values exceed 0.50 for seven of the yarn properties and are below 0.50 for five of them. The average R2 values of the 12 properties for ring, vortex and OES are 0.535, 0.542 and 0.425 respectively, indicating that the HVI fiber properties are not as strongly predictive of OES spinning performance as for ring and vortex spinning. Generally R2 values for the 12 yarn properties are similar for the ring and vortex spinning methods, with mostly lower R2 values for OES. A notable exception is ends down where the OES R2 = 0.502 compared with 0.431 for vortex ends down and 0.026 ring ends down.

Evaluating the coefficient of determination values in Tables (contact author) demonstrates generally how the Statimat yarn strength, Statimat yarn elongation, yarn thick places, yarn low places, yarn coefficient of variation, and yarn appearance can better predicted than yarn neps, yarn low places, yarn major places, yarn minor places, yarn long thick places, and yarn long thin places. For these three spinning systems, the AFIS fiber properties show a much weaker association with yarn properties than do the HVI fiber properties. Compared to the HVI properties, AFIS properties do an inferior job of predicting ring spun yarn properties. Adding the AFIS properties to the HVI ones improves predictions only slightly and boosts the average R2 values about 0.06. It further demonstrates how HVI properties alone are better predictor properties than AFIS properties. Using the HVI properties alone as predictors, some yarn characteristics such as Strength can be predicted quite well for all three spinning methods (ring R2 = 0.887, vortex R2 = 0.833, OES R2 = 0.865) while other properties such as Long Thick Places are poorly predicted (ring R2 = 0.053, vortex R2 = 0.084, OES R2 = 0.028). Combining the essential and important HVI and AFIS properties subsequently improves the coefficient of determination for the three spinning systems. Consequently, adding standard deviations to the set of potential predictors additionally increased the R2 values. Tables (contact author) include a summary of the 3 x 14 = 42 models in terms of R2 values that includes a “mean” which is the average R2 value for each spinning method. Generally, spinning performance is not as well predicted for rotor spinning as for ring and vortex spinning which have similar mean R2 values.
Yarn strength can be predicted relatively well predicted for all three spinning methods as indicated by the high $R^2$ values for that variable. The Statimat ring yarn strength has an $R^2$ value of 0.887 when using HVI properties, an $R^2$ value of 0.584 when using AFIS properties, and an $R^2$ value of 0.914 when using essential and important HVI and AFIS properties. The Statimat ring yarn strength has an $R^2$ value of 0.924 when using HVI properties with standard deviation predictors, an $R^2$ value of 0.620 when using AFIS properties with standard deviation predictors, and an $R^2$ value of 0.931 when using essential and important HVI and AFIS properties with standard deviation predictors. For ring spun yarn and HVI properties, strength is the single most important property, followed by trash, micronaire, and uniformity. For ring spun yarn and AFIS properties, fineness is the single most important property, followed by short fiber content, maturity, and neps. For ring spun yarn using HVI, AFIS, and standard deviations, strength is the most important property followed by the standard deviation of strength, micronaire, short fiber content, and length standard deviation. These results are generally in agreement with Deussen (1993) who stated that key properties for ring spinning are as follows: length, strength, fineness, and friction. Friction has been linked to cotton fiber crimps in cotton fibers with longer lengths and maturity (Clegg and Harland, 1924; Morton and Hearle, 1993; Patil, 1992; Foulk and McAlister., 2002). These results also agree with F.T. Pierce who in 1946 stated that correlations of yarn strength to fiber strength, fiber cohesion, and fiber regularity were important.

In summarizing $R^2$ values for all measured yarn properties, rotor spinning is the most difficult to predict of the three spinning systems. Yarn strength is a property that determines yarns final value, the Statimat rotor spun yarn strength has an $R^2$ value of 0.865 when using HVI properties, an $R^2$ value of 0.745 when using AFIS properties, and an $R^2$ value of 0.907 when using essential and important HVI and AFIS properties. The Statimat rotor yarn strength has an $R^2$ value of 0.888 when using HVI properties with standard deviation predictors, an $R^2$ value of 0.755 when using AFIS properties with standard deviation predictors, and an $R^2$ value of 0.909 when using essential and important HVI and AFIS properties with standard deviation predictors. For rotor spun yarn and HVI properties, strength is the single most important property, followed by micronaire, uniformity, and Rd. For rotor spun yarn and AFIS properties, fineness is the single most important property, followed by maturity, short fiber content, and visible foreign matter.

For rotor spun yarn using HVI, AFIS, and standard deviations, strength is the most important property followed by the micronaire, short fiber content, fineness, and visible foreign matter. These results are generally in agreement with Deussen (1993) who stated that key properties for rotor spinning systems are as follows: strength, fineness, length, cleanliness, friction. Friction is not an HVI or AFIS measurement but is associated with crimps found in more mature cotton with longer lengths (Clegg and Harland, 1924; Morton and Hearle, 1993; Patil, 1992; Foulk and McAlister., 2002). These results also agree with F.T. Pierce who in 1946 stated that correlations of yarn strength to fiber strength, fiber cohesion, and fiber regularity were important.

Cotton can be spun at very high speeds using a vortex spinning frame. The Statimat yarn strength has an $R^2$ value of 0.833 when using HVI properties, an $R^2$ value of 0.523 when using AFIS properties, and an $R^2$ value of 0.872 when using essential and important HVI and AFIS properties. The Statimat vortex yarn strength has an $R^2$ value of 0.878 when using HVI properties with standard deviation predictors, an $R^2$ value of 0.540 when using AFIS properties with standard deviation predictors, and an $R^2$ value of 0.892 when using essential and important HVI and AFIS properties with standard deviation predictors. For vortex spun yarn and HVI properties, strength is the single most important property, followed by Rd, uniformity, and micronaire. For vortex spun yarn and AFIS properties, fineness is the single most important property, followed by micronaire, and short fiber content. For vortex spun yarn using HVI, AFIS, and standard deviations, strength is the most important property followed by the Rd, uniformity, micronaire, and standard deviation of the uniformity. These results are generally in agreement with Deussen (1993) who stated that key properties for vortex spinning systems are as follows: length, fineness, strength, friction, cleanliness. As previously acknowledged friction is not an HVI or AFIS measurement but is associated with crimps found in more mature cotton with longer lengths (Clegg and Harland, 1924; Morton and Hearle, 1993; Patil, 1992; Foulk and McAlister., 2002). These results also agree with F.T. Pierce who in 1946 stated that correlations of yarn strength to fiber strength, fiber cohesion, and fiber regularity were important.
Summary

Results from this study agree with other studies in that stronger and longer fibers produce stronger ring, rotor, and vortex yarn. Cottons studied in this project indicate that the Statimat yarn strength, Statimat yarn elongation, yarn thick places, yarn low places, yarn coefficient of variation, and yarn appearance can better predicted than yarn nepes, yarn low places, yarn major places, yarn minor places, yarn long thick places, and yarn long thin places. For these three spinning systems, it further demonstrates how HVI properties alone are better predictor properties than AFIS properties alone. Combining HVI and AFIS properties subsequently improves the coefficient of determination for the three spinning systems. A significant aspect of this study suggests that since cotton can be highly variable it is important to minimize cotton bale and fiber variability by evaluating fiber property standard deviations. For ring spun yarn strength using all predictors, fiber bundle strength is the most important property followed by the standard deviation of strength, micronaire, short fiber content, and length standard deviation. For rotor spun yarn strength using all predictors, fiber bundle strength is the most important property followed by the micronaire, short fiber content, fineness, and visible foreign matter. For vortex spun yarn strength using all predictors, fiber bundle strength is the most important property followed by the Rd, uniformity, micronaire, and standard deviation of the uniformity. These results are generally in agreement with prior studies who stated that key properties for the three spinning systems are as follows: length, strength, fineness, and friction (ring-spinning); strength, fineness, length, cleanliness, friction (rotor-spinning); and length, fineness, strength, friction, cleanliness (vortex-spinning). Future studies will evaluate HVI and AFIS fiber measurements in depth as well as classic and supplementary fiber measurements.

Disclaimer

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture, information is for information purposes only, and does not imply approval of a product to the exclusion of others that may be suitable.

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References


