PREDICTING YARN QUALITY USING MEASUREMENTS AT ALTERNATIVE STAGES OF THE SPINNING PROCESS

M. Dean Ethridge and Reiyao Zhu
Director and Head of Fibers Research, respectively
International Textile Center, Texas Tech University
Lubbock, TX

Abstract

A full complement of commercially available fiber property measurements are made on extra long staple (ELS) cottons, starting with the ginned fibers and repeating the measurements at progressive stages in processing leading up to yarn spinning. The behavior of the fiber measurements at different processing stages is observed and the relative performance of these alternative sets of measurements in predicting yarn strength and yarn non-uniformity is examined. This is done for Ne 50 combed ring yarns, Ne 36 carded ring yarns, and Ne 36 rotor yarns. The significant differences in predictive power that are observed cannot be explained by random measurement variations from stage-to-stage. Substantial differences are also seen in cause-and-effect relationships for ring versus rotor spun yarns.

Introduction

The use of fiber property measurements in statistically based quality control programs for yarn manufacturing has become common during the past fifteen years. Movement of this approach into the management mainstream has been based largely on the availability of high volume instrument (HVI) data, which was designed and primarily used for raw cotton; i.e., ginned and baled cotton lint. Since HVI measurements are based on bundles of fibers, they are sensitive to sample preparation and technique. Therefore, using HVI measurements at any stage beyond the raw fiber state raises questions of measurement errors and the relative utility of the measurements [Duckett, et. al. 1993; Fryer and Rust 1996; Fryer, et. al. 1994; Lord and Rust 1994; Suh, et. al. 1993].

The advent of the Advanced Fiber Information System (AFIS) provided the first commercial capability to focus automated measurements on individual fibers. This focus brought with it a greatly enhanced capability to get comparable measurements on raw versus partially processed fibers. Indeed, current uses of AFIS generally involve monitoring the effectiveness of the processing machinery and impacts on the fibers up through the finisher drawing [Oxenham, et. al. 1995].

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:696-705 (1997)
National Cotton Council, Memphis TN

Under controlled conditions within the spinning laboratories of the International Textile Center (ITC), the usefulness of alternative fiber property measurements at different stages may be authoritatively examined. The information obtained will enable progress toward (1) understanding the sampling and measurement effects on fiber property data and (2) improving the application of fiber property data to quality control management. This report focuses on the predictive power of measurements taken at alternative stages of fiber processing.

A companion report to this one is also being presented at the 1997 Cotton Textile Processing Conference [Zhu and Ethridge 1997]. Both of these utilize test results from 50 samples of extra long staple (ELS) cottons obtained from all over the world. The research necessary for both reports comes out of an Advanced Technology Program project funded by the Texas Higher Education Coordinating Board. A subset of the global cotton samples collected for the project are ELS cottons; an early emphasis on obtaining complete test results of this subset makes it possible to provide these reports.

Experimental Procedures

The cotton samples contained approximately 20 kg of ginned lint, in order to perform both fiber and spinning tests. The fiber tests used for this report are summarized in Table 1, where symbols used for each fiber property are also given. The fiber tests are consistent with the commercially available HVI and AFIS instruments; however, the HVI leaf measurement is omitted in favor of the AFIS trash measurement.

The yarn quality tests used for this report are the following:

- count-strength product (CSP = lb x Ne), measured by the Scot Pendulum Tester
- Non-uniformity (CV%), measured by the Uster Tester 3

The fiber tests were done at the following stages:

- Prior to opening and cleaning (on the ginned lint)
- After opening and cleaning but prior to carding (at the chute feeder)
- After carding (on the card sliver)
- After combing, if applicable (on the finishing drawing sliver)

Since the cotton was ELS, both combed and carded slivers were used for ring spinning, with the combed cotton being spun into Ne 50 yarn and the carded cotton being spun into Ne 36 yarn. Only carded slivers were used for rotor spinning and only Ne 36 yarn was spun on the rotor system.

The processing steps and machinery used are shown in Figure 1, including the branching to combing and to the rotor and ring spinning frames. Some critical machine parameters are given in Table 2; these were used throughout, in order that processing conditions be held constant in every test.

Data and Analysis

A statistical summary of all fiber property measurements taken on the 50 samples prior to processing is given in Table 3. Both the central tendencies and the dispersions of the data are characteristic of ELS cotton in the form of ginned lint. Since the samples came from all over the world, the properties should be spread over the full population distribution. However, the cottons used were generally good specimens of their varieties, so occurrences of deteriorated properties (from insects, weather stress, ginning, etc.) would not be expected. Four of the skewness values indicate a significant departure from a normal, bell-shaped distribution; these are length uniformity (U), reflectance (R), short fiber content (SF), and neps (N). The negative sign for U indicates that its distribution is skewed to the left side; the positive signs for the other three indicate that they are skewed to the right side.

Of course both the central tendencies and the dispersions of the fiber properties are altered by further processing. The impacts on average values of each of the eleven fiber properties is illustrated in Figures 2 through 12, comparing the values of raw cotton with those at the chute, the card, and the combing machine. The most graphic change in average values occurs, as would be expected, at combing, with (1) substantial increases occurring for strength, elongation, length, uniformity, and micronaire and (2) substantial decreases occurring for short fiber, diameter, trash, and neps. Not surprisingly, the least change in average values tends to occur between the raw state and the chute feeder to the card.

Pairwise correlation coefficients given in Table 4 reveal that 22 of the 55 possible coefficients are significantly different from zero; i.e., the properties they involve are significantly correlated at the 95% confidence level. The significant coefficients are in bold print in Table 4. The fiber properties that are most frequently correlated with other ones are elongation (E), length uniformity (U), and short fiber content (SF); each of these correlates significantly with 6 other properties. Micronaire (M) correlates significantly with 5 other properties. Eight of the correlation coefficients approximate 0.7, making them quite problematic for statistical separation of their effects on yarn quality. Four of these high coefficients apply to elongation, which raises the likelihood that it will complicate statistical estimation.

Looking at subsequent stages of measuring fiber properties, it is seen that at the chute feeder to the card the number of significant correlation coefficients drops from 22 to 19 (Table 5). Furthermore, the magnitudes of the significant coefficients decrease somewhat. Moving on to the card sliver, the number of significant correlation coefficients drops to 18; however, the magnitudes of some of them increase noticeably (Table 6).

In the cases where combing was done, the large changes made in several fiber properties lead to anticipation of large impacts on the pairwise correlation coefficients. In fact, the number of significant correlation coefficients dropped further to 14 (Table 7). Beyond the decreased number, however, the configuration of the significant coefficients was not greatly changed. Elongation is still involved in 5 of the significant correlation coefficients and micronaire is involved in 4 of them.

Preliminary multiple linear regression results were obtained by regressing yarn count-strength product (CSP) and yarn non-uniformity (CV%) on all the fiber property variables. This was done separately for the Ne 50 combed and ring spun yarn (Table 8), the Ne 36 ring spun yarn (Table 9), and the Ne 36 rotor spun yarn (Table 10). Results may be summarized as follows:

For CSP

- Prediction was best for the combed Ne 50 yarn on the ring system, since the regression results for it consistently had the highest coefficients of determination (R^2). The weakest fit among the three was for the Ne 36 yarn on the rotor system.
- Except for the combed yarn, the fiber property measurements taken on cotton at the chute feeder did the best job of predicting yarn CSP. The substantial alterations from combing in both the central tendencies and the distributions of fiber properties inevitably make that stage the best predictor for combed yarn.
- Only a small subset of the fiber property variables exhibit regression coefficients that are significantly different from zero (shown by the bold numbers in Tables 8, 9 and 10). The number of significant coefficients ranges from 2 to 6. Fiber strength is the only variable that maintains significance in every regression.

For CV%

- Prediction was best for the Ne 36 yarn on the rotor system; it was the only one which had significant regression equations for all three stages (as indicated by the F values in Tables 8, 9 and 10).
- Measurements at the raw and the chute stages appear to be useless in explaining the CV% for both the Ne 50 and the Ne 36 yarns on the ring system. Only at the card stage do the fiber measurements become useful in ring spinning.
- The six significant coefficients at the comb stage (for E, U, R, Y, SF and N) provide an almost perfect fit for the CV%--as shown by the R^2 value of almost 1.0 (Table 8).

To further examine the usefulness of fiber properties in predicting yarn quality, stepwise regression was used to screen fiber variables for both correlation with yarn variables and autocorrelation with other fiber variables. A straight-forward application of the stepwise regression procedure resulted in the "best-fitting" equations reported in Tables 11, 12 and 13. In these tables, only the coefficients which were significantly different from zero at the 95% confidence level are kept in the regression equations. Elimination of the insignificant coefficients greatly increases the F values of each regression, while the coefficients of determination (R^2) are reduced somewhat. Both of these results are to be expected.

Two strategic exclusions were made from the eleven fiber properties in order to obtain final regression results. These are explained below:

- Inspection of Tables 11, 12 and 13 reveals that the impact of fiber elongation (E) on yarn strength (CSP) is consistently negative. This is a fairly common result; however, it is contrary to the logical expectation. Likewise, the signs on significant E coefficients for non-uniformity (CV%) generally tend to be negative; this is also contrary to logical expectations. A preponderance of illogical signs on a significant variable is a classic symptom of a high autocorrelation. This fact, combined with the aforementioned tendency of E to be highly correlated with several other fiber variables, led to the suspicion that the E variable was thwarting the stepwise regression algorithm in sorting out the truly significant variables. This, in turn, led to the decision to exclude it from the group of variables used for the stepwise regression algorithm.

- Examination of the results also reveals that the trash content (T) of the raw cotton failed to show significance in any of the regressions. Since trash is simply a contaminant, its impact at any subsequent stage is going to depend on the efficiency of the machinery in removing it. Furthermore, since machinery performance was held constant for these experiments, the T variable is not a useful indicator of yarn quality. Therefore, it was decided to also exclude it from the group of variables used for the stepwise regression algorithm.

Results from excluding the E and T variables are summarized in Tables 14, 15 and 16. The explanatory power of the regression equations is only marginally impacted by the exclusions; furthermore, the results are now generally consistent with known directional influences of included fiber variables. Therefore, these are the preferred results to use in yarn quality control decisions.

Conclusions

Comparisons must focus on the raw, chute and card measurements. The combing operation drastically alters both the levels and the distributions of enough key fiber properties to guarantee that post-combing measurements on ELS fibers will be the best predictors of ring spun yarn quality. However, their usefulness at this stage of processing is limited largely to examining the effects of combing on the central tendencies and distributions of the various fiber properties; this is done in a separate paper [Zhu and Ethridge 1997].

Given the exclusion of measurements at the comb from a comparative evaluation of the fiber properties' explanatory power, the results summarized in Tables 14, 15 and 16 lead to the following conclusions:

<u>For CSP</u>

- Measurements on samples taken at the chute feeder going into the card machine consistently provided the best prediction for ring spun yarn. This could not be anticipated a priori; therefore, it is a major empirical result.
- Measurements at all three stages have approximately equal predictive power for rotor spun yarn
- The superiority of chute measurements to raw measurements for ring spinning may be due to the superior blending of the samples at the chute.
- The superiority of chute measurements to card measurements for ring spinning cannot be readily explained; it may be related to sampling anomalies caused by having to pull HVI samples from a bundle of fibers that have been put into the sliver form.
- Alterations occurred in the groupings of significant explanatory variables when moving from raw to chute to card measurements. Only fiber strength was a significant variable in all three of these (and in the comb measurements as well). It is noteworthy that both micronaire (M) and short fiber content (SF) consistently failed to show significance at the raw and card stages, but at least one (and usually both) of these did show significance at the chute stage. The largest number of significant variables tended to occur from measurements at the card, yet the cumulative explanatory power of the significant variables was generally no better than from chute measurements.

<u>For CV%</u>

- Measurements taken on the card sliver consistently provided the best prediction for both ring and rotor spun yarns.
- For the ring spun yarns, it was difficult to find even one significant explanatory variable at the raw fiber stage, and explanatory power hardly improved at the chute stage.
- For the rotor spun yarn, prediction was relatively much better at the raw and chute stages; furthermore, the same variables (M, D and N) held significance throughout all three stages.

- It appears that, for ELS fibers, differences in the raw fiber properties have little impact on non-uniformity of ring spun yarns; measurable impacts are more apparent after the fiber properties are "refined" by carding. (Obviously, the refinements from combing make prediction of CV% quite powerful.) In contrast, the physical structure of rotor spun yarns appears to make the CV% sensitive to key physical fiber properties.
- An overview of the results in all three tables suggests that the two key variables for predicting yarn non-uniformity are neps (N) and diameter (D).

These results must be treated as both incomplete and preliminary; incomplete because the data come from the relatively narrow range that characterizes the ELS cotton fibers and preliminary because even the ELS data will be augmented in the months ahead. Ultimately, similar results will be generated using a full range of both Upland and ELS cottons. When this is done, the linear structure imposed on the data in this report will likely be inadequate to capture the complexity of relationships among fiber and yarn properties [Ethridge, et. al. 1982].

References

Duckett, K. E., Z. Shou, R. S. Krowicki and P. E. Sasser. 1993. Cotton Fiber Fineness Distributions and Their Effects on the Tenacities of Randomly Sampled HVI Tapered Beards: Linear Density Effects. *Textile Research Journal*. Vol. 63, pp. 737-744.

Duckett, K. E., Z. Zhou, R. S. Krowicki, and P. E. Sasser. 1993. Cotton Fiber Fineness Distribution in HVI Test Specimens. Proceedings of the Fourth Cotton Quality Measurement Conference. pp. 1074-1075.

Ethridge, M. D., J. D. Towery, and J. F. Hembree. 1982. Estimating Functional Relationships between Fiber Properties and the Strength of Open-End Spun Yarns. *Textile Research Journal*. Vol. 52, pp. 35-45.

Fryer, L. F. and J. P. Rust. 1996. Effects of Cotton Fiber Blending and Processing on HVI Measurements—Parts I and II. *Textile Research Journal*. Vol. 66, pp. 349-365.

Fryer, L. F., P. R. Lord and J. P. Rust. 1994. Influence of Cotton Variables on Subsequent Process Performance. Proceedings Beltwide Cotton Conferences. pp. 1639-1640.

Lord, P. R. and J. P. Rust. 1994. Blending as a Systemic Problem. Proceedings Beltwide Cotton Conferences. pp. 1631-1635.

Oxenham, W., H. Aarnink and V. Vasisth. 1995. Using Advanced Fiber Information System to Monitor Fiber-Process Interaction. Proceedings Beltwide Cotton Conferences. pp. 1409-1413.

Suh, M. W., X. Cui and P. E. Sasser. 1993. Interpretations of HVI Bundle Tensile Properties through Single fiber Test Results—Effects of Fiber Slack. Proceedings Beltwide Cotton Conferences. pp. 1101-1104.

Zhu, R. and M. D. Ethridge. 1997. Examination of Changes in ELS Cotton Fiber Properties at Major Steps of the Spinning Process. Proceedings Beltwide Cotton Conferences. In this section of proceedings.

Table 1. Fiber Property Measurements

Instrument	Measurement	Symbol
Spinlab HVI	⅛ in Gauge Strength (g/tex)	S
	Elongation (%)	E
	Length (in)	L
	Uniformity Ratio (%)	U
	Micronaire Value (µg/in)	M
	Reflectance (Rd)	R
	Yellowness (+b)	Y
Uster AFIS	Short Fiber Content (% by weight)	SF
	Diameter (µm)	D
	Trash (no/g)	T
	Neps (no/g)	N

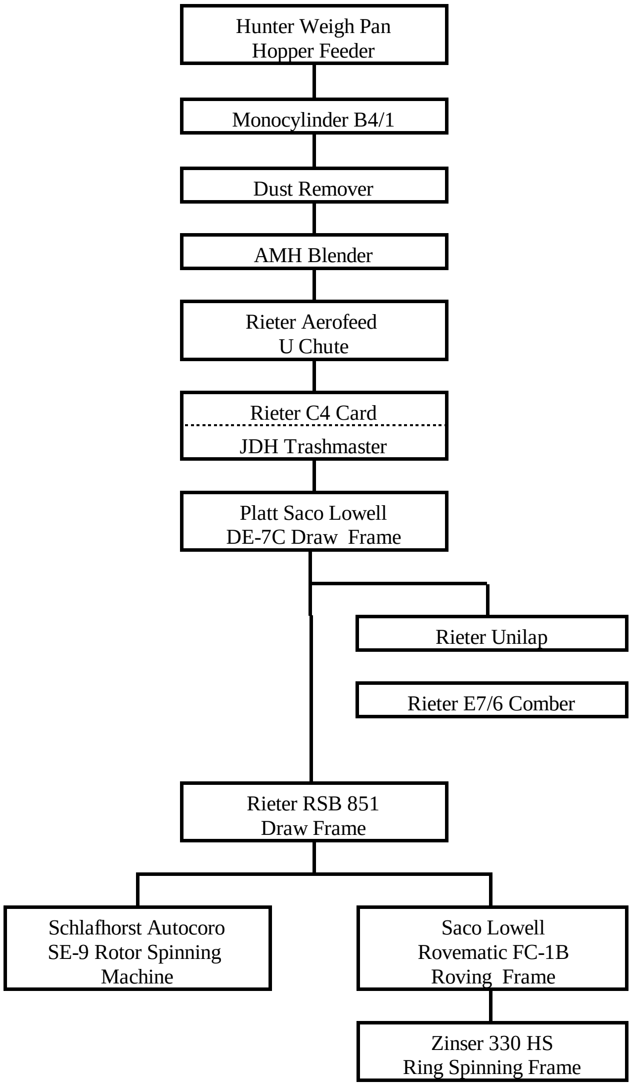


Figure 1: Processing Flows for ELS Cotton

Table 2. Machine Operating Parameters

Figur	Operating Parameters
Monocylinder Cleaner	Roll Speed = 750 rpm
Card	Production Rate = 60 lb/hr Sliver Weight = 60 gr/yd
Opening Draw Frame	Delivery Speed = 570 ft/min Sliver Weight = 55 gr/yd
Combing Machine	Nipping rate = 280 nips/min
Finishing Draw Frame	Delivery Speed = 990 ft/min Sliver Weight = 55 gr/yd
Rotor Spinning Frame	Rotor Speed = 106,000 rpm Rotor Diameter = 31 mm
Ring Spinning Frame	Combed Spindle Speed = 19,000 rpm Carded Spindle Speed = 18,000 rpm Ring Diameter = 36 mm

Table 3. Statistical Measures of Raw Fiber Properties for 50 ELS Cotton Samples

Property	Mean	Std. Dev.	Min.	Max.	Skewness
S	39.1	2.25	34.5	44.4	-0.13
E	6.8	0.56	5.8	7.9	0.02
L	1.36	0.06	1.21	1.50	-0.32
U	85.6	1.59	80.8	88.3	-0.82
M	3.8	0.42	3.0	4.6	-0.13
R	69.3	3.96	63.4	79.3	1.04
Y	11.1	1.38	8.3	14.1	0.24
SF	4.6	1.12	2.9	8.4	1.27
D	10.9	0.53	9.5	12.1	-0.35
T	736.1	355.78	202	1,754	1.2
N	174.2	108.18	80	606	1.9

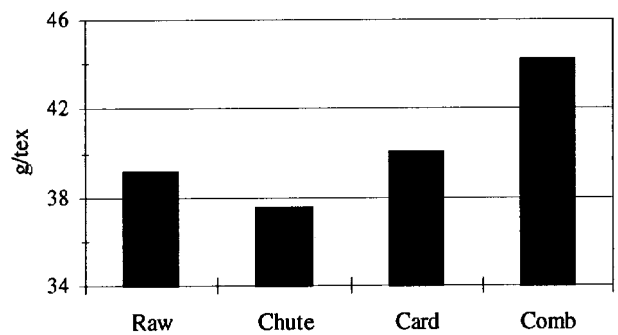


Figure 2 Average Strength Values at Different Stage

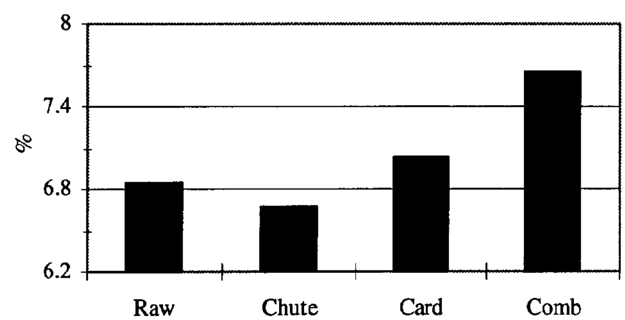


Figure 3. Average Elongation Values at Different Stages.

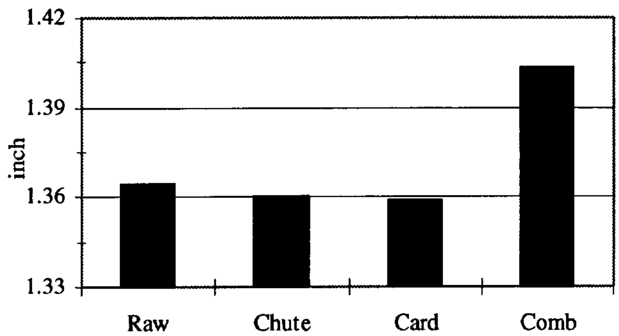


Figure 4. Average Length Values at Different Satges

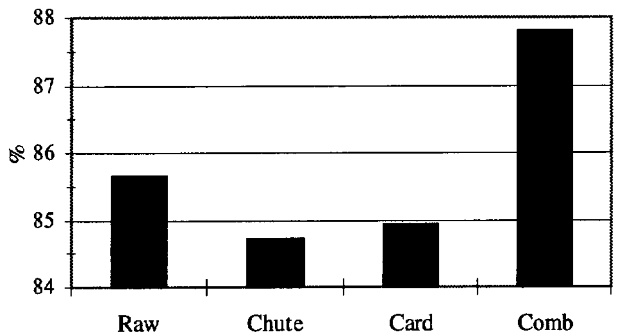


Figure 5. Average Length Uniformity Values at different levels

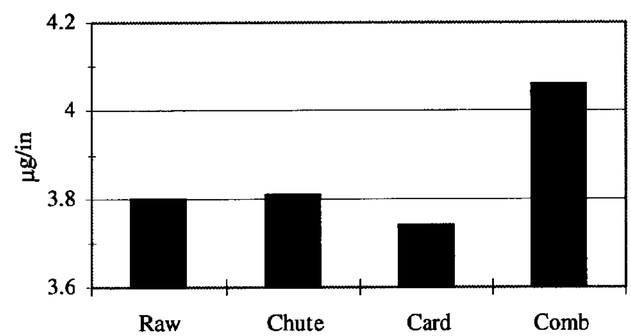


Figure 6. Average Micronaire Values at Different Stages

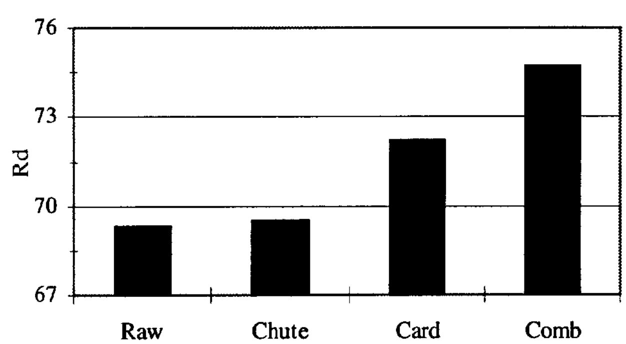


Figure 7. Average Reflectance Values at Different Stage

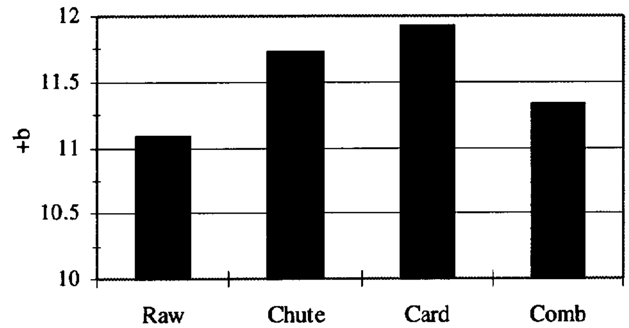
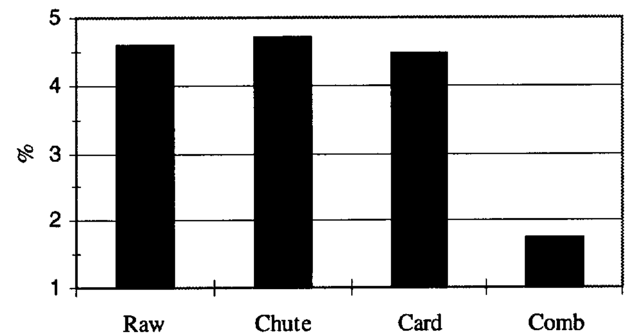


Figure 8. Average Yellowness Value at Different Stages



Figures 9. Average Short Fiber Content Values at Different Stages

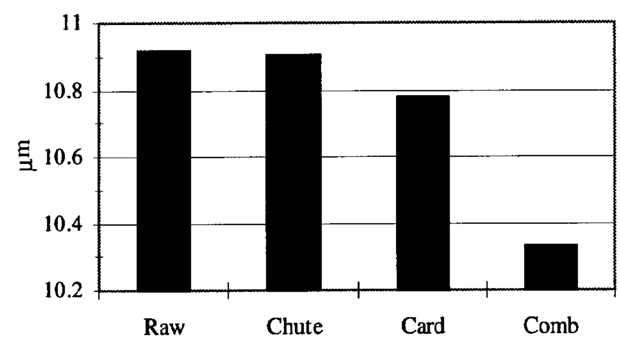


Figure 10. Average Diameter values at Different Stages

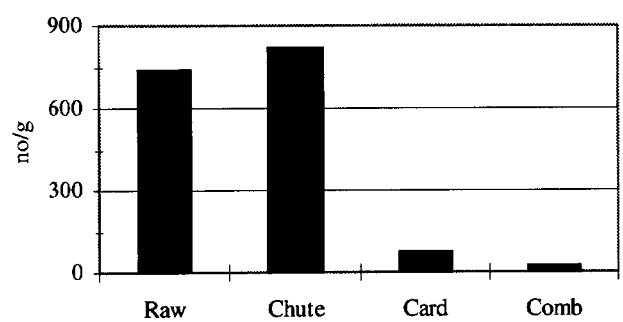


Figure 11. Average Trash Values at Different Stages

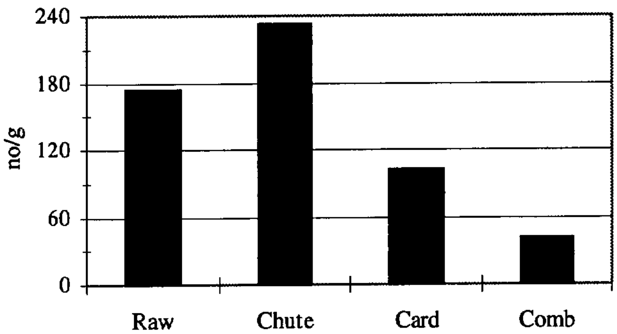


Figure 12 Average Nep Values at Different Stages

Table 4. Simple Correlation Coefficients Between Raw Fiber Properties of 50 ELS Cotton Samples

	E	L	U	M	R	Y	SF	D	T	N
S	**0.63**	**0.40**	**0.69**	0.24	**-0.36**	0.12	**-0.38**	0.08	0.15	**-0.56**
E		0.10	**0.70**	**0.54**	-0.31	0.06	**-0.71**	**0.35**	0.02	**-0.72**
L			**0.44**	-0.17	-0.35	0.31	0.01	**-0.39**	-0.07	0.06
U				**0.38**	-0.34	0.03	**-0.58**	0.13	0.11	**-0.72**
M					0.01	-0.11	**-0.57**	**0.78**	0.03	**-0.53**
R						**-0.76**	0.22	0.01	-0.15	0.19
Y							-0.07	0.04	0.09	0.21
SF								**-0.42**	-0.23	**0.73**
D									-0.06	-0.25
T										-0.15

Note: Bold numbers indicate statistical significance at the 95% confidence level.

Table 5. Simple Correlation Coefficients Between Chute Fiber Properties of 50 ELS Cotton Samples

	E	L	U	M	R	Y	SF	D	T	N
S	**0.54**	**0.44**	**0.38**	0.25	-0.32	0.05	**-0.47**	-0.19	0.25	**-0.40**
E		0.04	**0.45**	**0.58**	-0.05	-0.07	**-0.54**	0.03	0.23	**-0.42**
L			**0.61**	-0.14	-0.30	0.11	-0.07	**-0.44**	0.19	0.11
U				**0.46**	-0.05	-0.07	**-0.54**	0.00	0.23	**-0.42**
M					0.08	-0.11	**-0.69**	**0.67**	0.22	**-0.65**
R						**-0.74**	0.13	0.07	-0.19	0.09
Y							-0.11	0.03	0.18	-0.09
SF								-0.20	-0.21	**0.74**
D									-0.07	-0.21
T										-0.31

Note: Bold numbers indicate statistical significance at the 95% confidence level.

Table 6. Simple Correlation Coefficients Between Card Sliver Fiber Properties of 50 ELS Cotton Samples

	E	L	U	M	R	Y	SF	D	T	N
S	**0.58**	0.34	0.33	0.29	-0.29	0.08	-0.31	-0.11	**0.40**	-0.31
E		0.05	**0.51**	**0.65**	-0.26	0.14	**-0.51**	**0.36**	0.23	**-0.60**
L			**0.43**	0.14	-0.21	0.15	-0.04	**-0.43**	0.21	0.27
U				**0.50**	0.08	-0.17	**-0.56**	0.28	0.02	**-0.41**
M					-0.02	-0.10	**-0.67**	**0.76**	0.12	**-0.77**
R						**-0.93**	0.09	0.04	-0.19	-0.04
Y							-0.05	-0.06	0.08	0.12
SF								-0.34	-0.08	**0.57**
D									-0.07	**-0.54**
T										-0.08

Note: Bold numbers indicate statistical significance at the 95% confidence level.

Table 7. Simple Correlation Coefficients Between Comb Sliver Fiber Properties of 50 ELS Cotton Samples

	E	L	U	M	R	Y	SF	D	T	N
S	**0.65**	0.31	0.23	0.07	-0.21	0.16	**-0.37**	-0.33	0.32	-0.28
E		0.22	**0.39**	**0.51**	-0.29	0.12	**-0.57**	0.15	0.28	**-0.67**
L			**0.80**	0.10	-0.24	0.23	-0.07	**-0.45**	0.11	0.18
U				0.18	-0.18	0.12	-0.19	-0.11	0.08	-0.16
M					-0.04	-0.16	**-0.50**	**0.77**	0.21	**-0.72**
R						**-0.93**	0.17	-0.03	-0.11	0.05
Y							-0.09	-0.08	0.01	0.15
SF								-0.31	-0.14	**0.74**
D									-0.08	**-0.50**
T										-0.21

Note: Bold numbers indicate statistical significance at the 95% confidence level.

Table 8. Multiple Regression of Ne 50 Ring Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	**Raw**	**Chute**	**Card**	**Comb**
F Value:	13.973	24.849	16.251	170.495
R^2:	0.80	0.88	0.83	0.98
Independent Variables				
S	**70.578**	**113.066**	**79.745**	**83.09**
E	-101.356	**-163.813**	-116.819	**-155.92**
L	712.102	-438.689	294.307	**2,800.9**
U	-5.789	54.246	44.565	-15.430
M	**-261.896**	**-392.407**	-188.942	**-242.66**
R	3.210	6.303	24.745	-0.437
Y	33.320	36.810	116.373	3.336
SF	22.889	**-107.747**	-29.567	**-286.52**
D	-127.659	-121.927	**-260.491**	-73.88
T	0.087	**0.102**	1.364	2.739
N	**-1.220**	0.433	-0.976	-0.247
Constant	3,184.602	-987.316	-2,220.712	1,022.493

Dependent Yarn Variable: CV%

Stage:	**Raw**	**Chute**	**Card**	**Comb**
F Value:	1.230	0.908	16.970	9,610.4
R^2:	0.26	0.21	0.84	0.9997
Independent Variables				
S	0.026	-0.033	0.029	-0.1568
E	0.095	0.310	-0.107	**16.929**
L	-4.931	-7.278	**-4.269**	-260.98
U	0.578	0.231	0.064	**8.502**
M	0.398	0.135	**1.107**	10.828
R	-0.042	-0.061	0.055	**-5.201**
Y	-0.623	-0.630	0.138	**-18.799**
SF	-0.208	-0.254	**0.112**	**-30.545**
D	0.333	0.323	0.521	0.694
T	-0.0005	0.0003	-0.003	0.054
N	0.0104	0.003	**0.011**	**0.963**
Constant	-26.992	10.568	-3.229	73.095

Note: Bold numbers indicate statistical significance at the 95% confidence level.

Table 9. Multiple Regression of Ne 36 Ring Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	**Raw**	**Chute**	**Card**
F Value:	9.815	18.064	13.410
R^2:	0.74	0.84	0.80
Independent Variables			
S	**67.826**	**118.892**	**79.405**
E	-53.563	**-172.005**	-76.381
L	842.998	-800.972	-8.545
U	-9.737	**90.803**	89.976
M	-155.332	-240.737	-22.137
R	8.247	14.124	38.628
Y	27.273	**53.460**	**157.181**
SF	14.787	**-88.536**	**9.978**
D	-89.117	-88.629	**-281.600**
T	0.067	**0.095**	0.749
N	**-1.256**	0.335	-1.469
Constant	2,146.575	-5,423.771	-7,807.049

Dependent Yarn Variable: CV%

Stage:	**Raw**	**Chute**	**Card**
F Value:	5.322	4.971	14.709
R^2:	0.61	0.60	0.81
Independent Variables			
S	0.116	-0.035	0.074
E	-0.402	-0.528	**-0.536**
L	-1.217	-0.275	-2.382
U	0.010	-0.285	-0.181
M	-0.442	0.876	0.690
R	-0.028	-0.050	-0.021
Y	-0.184	-0.211	-0.154
SF	0.012	-0.268	0.075
D	0.657	-0.071	**0.798**
T	-0.0002	-0.0001	-0.002
N	**0.006**	0.003	**0.019**
Constant	11.027	**45.390**	23.974

Note: Bold numbers indicate statistical significance at the 95% confidence level.

Table 10. Multiple Regression of Ne 36 Rotor Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	**Raw**	**Chute**	**Card**
F Value:	6.832	7.777	7.051
R^2:	0.65	0.70	0.68
Independent Variables			
S	**33.040**	**58.586**	**45.203**
E	-41.698	**-135.241**	-82.252
L	214.253	-787.773	-508.682
U	-20.200	37.801	**63.977**
M	-106.039	-15.745	126.585
R	8.483	9.673	**29.666**
Y	30.922	**42.182**	**120.020**
SF	23.954	-40.903	**67.522**
D	-2.725	-57.453	**-162.325**
T	0.062	**0.079**	0.453
N	**-1.121**	0.235	**-1.031**
Constant	2,674.453	-1,023.601	-5,789.959

Dependent Yarn Variable: CV%

Stage:	**Raw**	**Chute**	**Card**
F Value:	9.362	10.485	19.622
R^2:	0.73	0.76	0.85
Independent Variables			
S	0.011	-0.010	0.002
E	-0.099	-0.243	-0.152
L	0.065	0.137	0.018
U	0.018	0.016	-0.003
M	**0.644**	**0.952**	**0.857**
R	-0.002	-0.002	0.012
Y	-0.022	0.005	0.057
SF	0.068	0.054	-0.027
D	**0.328**	**0.283**	**0.466**
T	-0.000015	0.0002	0.0002
N	**0.002**	0.001	**0.004**
Constant	7.401	7.832	5.645

Note: Bold numbers indicate statistical significance at the 95% confidence level.

Table 11. Stepwise Multiple Regression of Ne 50 Ring Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	Raw	Chute	Card	Comb
F Value:	40.27	44.29	39.28	321.77
R^2:	0.72	0.80	0.78	0.98
Independent Variables				
S	65.895	109.085	78.768	82.262
E		-153.02		-166.131
L				2,466.708
U				
M				-200.636
R	-13.369		29.545	
Y		44.956	123.567	
SF				-353.382
D	-321.502	-121.927	-342.565	-115.07
T				
N				
Constant	5744.351	3163.507	814.411	675.743

Dependent Yarn Variable: CV%

Stage:	Raw	Chute	Card	Comb
F Value:	5.06	7.09	32.56	14,261.7
R^2:	0.10	0.13	0.82	0.9996
Independent Variables				
S				
E				16.182
L			-3.385	-265.913
U				8.565
M			0.776	12.226
R			0.055	-5.235
Y	-0.408	-0.513		-18.824
SF				-30.312
D			0.633	
T			-0.002	
N			0.011	0.964
Constant	17.858	19.332	6.149	78.261

Table 12. Stepwise Multiple Regression of Ne 36 Ring Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	Raw	Chute	Card
F Value:	34.51	30.99	25.75
R^2:	0.69	0.82	0.79
Independent Variables			
S	64.863	101.363	74.498
E		-131.417	
L			
U		57.509	70.743
M		-376.985	
R			37.453
Y			146.764
SF		-112.377	
D	-229.627		-304.202
T		0.091	
N	-0.663		-1.076
Constant	4,042.487	-1,945.626	-6,097.33

Dependent Yarn Variable: CV%

Stage:	Raw	Chute	Card
F Value:	47.86	15.24	37.38
R^2:	0.50	0.50	0.77
Independent Variables			
S			
E			
L			
U		0.372	-0.309
M			
R			
Y		-0.178	-0.160
SF			
D			1.024
T			
N	0.006	0.004	0.018
Constant	13.475	47.197	29.805

Table 13. Stepwise Multiple Regression of Ne 36 Rotor Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	**Raw**	**Chute**	**Card**
F Value:	15.58	14.25	17.85
R^2:	0.58	0.62	0.54
Independent Variables			
S	31.64	58.586	29.965
E	-77.134	-135.241	
L			
U			
M			
R			
Y			
SF		-45.427	
D	-68.877	-59.511	-117.683
T		0.075	
N	-0.635		-0.941
Constant	2,854.804	2,663.462	2,865.398

Dependent Yarn Variable: CV%

Stage:	**Raw**	**Chute**	**Card**
F Value:	39.09	32.73	60.73
R^2:	0.72	0.75	0.85
Independent Variables			
S			
E		-0.257	-0.131
L			
U			
M	0.677	0.869	0.859
R			
Y			
SF			
D	0.304	0.313	0.462
T			
N	0.002	0.001	0.004
Constant	8.296	9.189	6.798

Table 14. Modified** Stepwise Multiple Regression of Ne 50 Ring Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	**Raw**	**Chute**	**Card**	**Comb**
F Value:	40.27	56.18	39.28	335.23
R^2:	0.72	0.84	0.78	0.97
Independent Variables				
S	65.895	92.694	78.768	63.608
L		853.542		2,227.533
U				
M		-583.987		-260.667
R	-13.369		29.545	
Y			123.567	
SF		-128.409		-322.812
D	-321.502		-342.565	-134.500
N				
Constant	5,744.351	2,075.276	814.411	954.836

Dependent Yarn Variable: CV%

Stage:	**Raw**	**Chute**	**Card**	**Comb**
F Value:	5.06	7.09	36.29	20,711.4
R^2:	0.10	0.13	0.81	0.9993
Independent Variables				
S				
L			-3.523	
U				
M			0.707	42.614
R			0.022	
Y	-0.408	-0.513		
SF				-47.864
D			0.674	
N			0.011	1.124
Constant	17.858	19.332	5.777	-122.105

**Modified by the exclusion of fiber elongation (E) and trash (T) as independent variables.

Table 15. Modified** Stepwise Multiple Regression of Ne 36 Ring Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	Raw	Chute	Card
F Value:	34.51	39.89	25.75
R^2:	0.69	0.78	0.79
Independent Variables			
S	64.863	95.179	74.498
L			
U		57.962	70.743
M		-415.955	
R			37.453
Y			146.764
SF		-105.759	
D	-229.627		-304.202
N	-0.663		-1.076
Constant	4,042.487	-2,444.03	-6,097.33

Dependent Yarn Variable: CV%

Stage:	Raw	Chute	Card
F Value:	47.86	15.24	37.38
R^2:	0.50	0.50	0.77
Independent Variables			
S			
E			
L			
U		0.372	-0.309
M			
R			
Y		-0.178	-0.160
SF			
D			1.024
N	0.006	0.004	0.018
Constant	13.475	47.197	29.805

**Modified by the exclusion of fiber elongation (E) and trash (T) as independent variables.

Table 16. Modified** Stepwise Multiple Regression of Ne 36 Rotor Spun Yarn Properties on All Fiber Properties Measured at Each Processing Stage

Dependent Yarn Variable: CSP

Stage:	Raw	Chute	Card
F Value:	18.5	17.59	17.85
R^2:	0.55	0.54	0.54
Independent Variables			
S	23.634	35.005	29.955
L			
U			
M			
R			
Y			
SF		-35.592	
D	-92.255	-74.162	-117.683
N	-0.469		-0.941
Constant	2,854.804	2,365.232	2,865.398

Dependent Yarn Variable: CV%

Stage:	Raw	Chute	Card
F Value:	39.09	37.73	75.32
R^2:	0.72	0.72	0.83
Independent Variables			
S			
L			
U			
M	0.677	0.726	0.729
R			
Y			
SF			
D	0.304	0.344	0.502
N	0.002	0.001	0.005
Constant	8.296	7.621	5.893

**Modified by the exclusion of fiber elongation (E) and trash (T) as independent variables.