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A Statistical Model for Predicting Yarn Evenness of Cotton Sirospun Yarns

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Abstract

Raw material costs constitute the majority of the yarn production costs, therefore it is critically important to select the suitable cotton blend and to know required fibre characteristics for spinning. This article is a part of a comprehensive work including the experimental research and the modeling of the physical and mechanical properties of the cotton sirospun yarns. In this paper, a model for estimating sirospun yarn evenness from cotton fibre properties was investigated. For this purpose, different cotton blends were selected from different spinning mills in Turkey and their properties were measured with AFIS (Advanced Fibre Information System). Besides some yarn production parameters were also selected as independent variable (predictor) due to their significant effect. Sirospun yarns were produced at Ege University Textile Engineering Department's spinning mill under the same conditions. Linear multiple regression method were performed and statistical evaluation showed that generated equations for predicting yarn evenness had a large R2 and adjusted R2 values.

Key words

AFIS, Estimation, Multiple regression analysis, Prediction, Sirospun, Yarn evenness

1. INTRODUCTION

Yarn production is a sequence of processes that convert fibres into yarn, which will be used in various end products. Basic interest of every spinner is to reduce costs and to optimize the spinning process as well as to reach the desirable yarn quality. Raw material costs are more than half of the total manufacturing costs in a spinning mill, therefore knowing and monitoring the quality characteristics of the fibers, with the purpose of reducing costs and optimizing the spinning process, have great importance for the spinners.

For many years, the spinning machinery manufacturers enhanced the spinning process and reduced the mass variation of yarns, rovings and slivers thanks to precise measurement. This improvement provides an opportunity to increase productivity and to reduce considerably the raw material costs [1].

As much as spinners would like to produce an absolutely regular yarn, it is unachievable because of cross sectional fibre variation and the mechanical constraints. Accordingly, there are limits to achievable yarn evenness. According to Martindale, in the best possible conditions, the following evenness limit could be achieved for ring-spun yarns:

$$U_{lim} \frac{80}{\sqrt{n}} \times \sqrt{1+0,0004CV_D{}^2} \quad \text{or} \quad CV_{lim} \frac{100}{\sqrt{n}} \times \sqrt{1+0,0004CV_D{}^2} \qquad (1)$$

n is the number of fibers in the yarn cross section

CV_D is the coefficient of variation of the fiber diameter

Since the variation of the fibre diameter is small enough to be ignored in industrial use, the equations reduce to:

$$U_{lim}\frac{80}{\sqrt{n}} \quad \text{or} \quad CV_{lim}\frac{100}{\sqrt{n}} \tag{2}$$

This can be expressed approximately as CV~= 1.25U. In the evaluation of the achieved evenness, the unevenness index I is commonly used which is defined as [2]:

$$I = \frac{CV_{actual}}{CV_{lim}} \tag{3}$$

In recent years, prediction of the yarn quality characteristics from process parameters and fibre properties is one of the favorite research subjects for the engineers. Consequently researchers have been developed various mathematical, statistical and empirical models which are considerably important for the spinners in terms of raw material selection [3-9].Especially, Hunter [8] and Ethridge et. al. [9] has investigated models for predicting yarn irregularity by using fibre parameters. Most of the researchers are focused on modeling of ring spun and rotor spun yarn properties but there is a few study on modeling sirospun yarn characteristics.

It is authenticated that, yarn properties are particularly influenced from fibre properties and this effect becomes more influential in the case of finer yarns. This paper is a part of a work concerning the experimental research and determination of the equations and models for estimating the sirospun yarn quality characteristics from the yarn production parameters and cotton fiber properties which are measured by the HVI and AFIS systems. As a result, equations were derived for the prediction of yarn tenacity, breaking elongation, unevenness and hairiness by using fiber and yarn properties. Some of the results are given in previous papers [10-13]. Regressional estimation of cotton sirospun yarn properties from fibre properties measured with HVI [11], regressional estimation of yarn hairiness of cotton sirospun yarns from AFIS fiber properties [12] and the prediction of yarn strength of cotton sirospun yarns from AFIS fiber properties by using linear regression analysis [13] were investigated previously.

2. EXPERIMENTAL

2.1. Materials

As the raw material represents about 50-75% of the manufacturing cost of a short-staple yarn and it has a significant effect on productivity and quality, yarn producers focus on the suitable blend [14].

In order to investigate the effect of fibre properties, various cotton blends were supplied from spinning mills in different regions of Turkey. Cotton fibres properties were analyzed with Advanced Fibre Information System (AFIS) which is developed for the measurement of individual fibres. The features provided with the USTER are given in Table 1 [15].

Table 1. Fibre properties that can be measured with AFIS.

Nep Classification:	Fiber and seed coat nep count per gram and size (m) distribution.
Length:	Fiber length by number and by weight distributions; short fiber content by number and by weight (%).
Maturity:	Maturity, immature fiber content (%) and fineness (mtex) distribution.
Trash:	Dust and trash count per gram and size (m) distribution; visible foreign matter content (%).

AFIS can be used for blend composition, analysis of changes in fibre properties during processing, optimization of the process parameters and predicting the produced yarn quality [16]. Different blends are coded from B1 to B11 and fibre properties measured with AFIS are given in Table 2.

Table 2. Fibre properties of different blends measured with AFIS.

Fibre properties	Abbreviation	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11

Fiber nep count per gram	Nep Cnt/g	4	19	24	8	5	7	152	12	19	25	17
Mean length by weight	L(W) (mm)	29,5	28,1	25	30,3	26,8	27	24,8	26,1	26,3	28	25,5
Upper Quartile Length by weight	UQL (w)	35,2	33,9	30,7	36,6	32	32,6	30,9	31	31,2	33,9	30,6
Short fibre content by weight	SFC (w) %	2,3	3,7	6,2	2,4	3,8	4,6	9,9	3,7	4,6	3,9	5,1
Mean length by number	L(n) (mm)	25,8	24,2	21,5	26,4	23	23,3	20,2	22,9	22,7	24,3	22,2
Length variation by number	L(n) %cv	37,6	40,3	40,3	38,9	38,4	40	48,5	37,8	39,6	39,2	38,7
Short fibre content by number	SFC (n) %	8,5	11,6	15,1	9	11,3	13,2	25,5	11	12,8	11,4	14,2
5% Length by number	5.0% (mm)	40,9	39,9	36,7	42,4	37,3	38,2	35,6	36,1	36,9	39,1	35
Total trash count per gram*	Total Cnt/g	8	11	14	7	29	16	84	5	14	9	9
Trash count per gram	Trash Cnt/g	0	0	0	0	0	0	11	0	2	0	2

* dust particles included

Upper quartile length by weight and 5% length by number values of the different blends are given in Figure 1. B4 blend has the highest values, whereas B11 has the lowest length values.

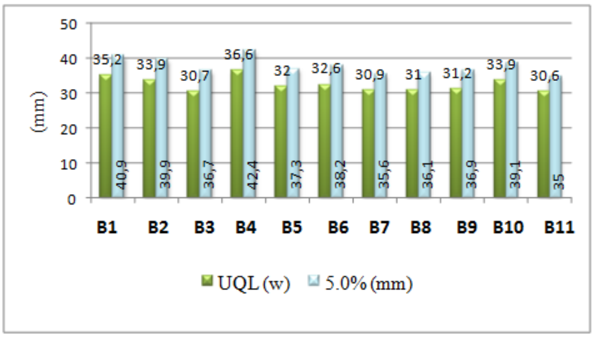

Figure 1. UQL (w) and 5.0% (mm) values of the different blends

Short fibre content by number and by weight values of the different blends are given in Figure 2. B1 and B4 blends have the lowest short fibre content while B3 and B7 blends have the highest ratios.

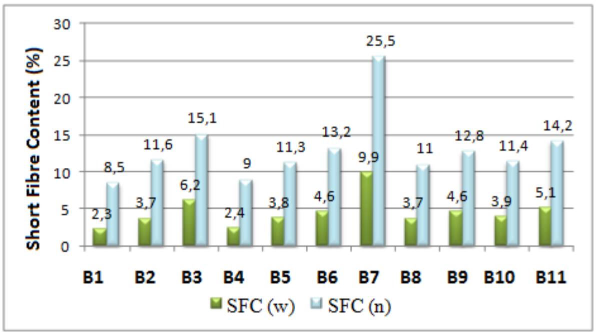

Figure 2. Short fibre content by weight and short fibre content by number values of the different blends

2.2. Methods

Yarn production parameters, as is known, have significant effect on yarn properties. Accordingly, yarn count, twist coefficient and strand spacing, which is defined as the distance between the two parallel roving strands fed through the drafting system, were also selected as predictors. As the sirospun yarns are produced with two rovings, spinners have to produce finer rovings and increase the creel capacity of the spinning frame. Besides, a double roving sirospun guides and condensers must be used in siro-spinning, which is mounted on the rail and disconnected from the traverse mechanism.

According to experimental design, it is planned to spun in four yarn counts (11.81, 14.77, 19.69 and 29.53 tex), at three twist coefficients and three strand spacing values, for each blend. More clearly, each linear density was spun at 3, 6 and 9 mm strand spacing, and at three different twist multipliers (α_{Tt} 3831, α_{Tt} 4310 and α_{Tt} 4789). Cotton sirospun yarns were produced on a Rieter Model G30 ring spinning machine by keeping the spinning conditions constant. Some samples cannot be produced because of the raw material quality and drafting limits of the machine. For each yarn type, ten samples were produced and tested. Comparison was made between the yarns of different linear density, different twist factor and strand spacing. Experimental plan for each blend and yarn codes are given in Figure 3 and Table 3, respectively.

Subsequently yarn quality characteristics was measured and Uster Tester 5 was used for determining of the yarn unevenness, number of thin places, number of thick places, number of nep.

Final step is determining the equations and models for estimating the sirospun yarn uneveness from the yarn production parameters and cotton fiber properties which are measured by AFIS instrument. For this purpose, multivariate linear regression methods were performed. Statistical analyses were performed using Gretl (GNU Regression, Econometrics and Time-series Library) software.

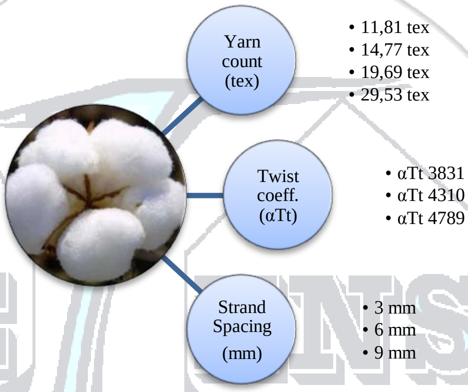

Figure 3. Experimental plan.

Table 3. Yarn code matris.

Twist coeff.	Strand spacing	Yarn count			
		11,81 tex	**14,77 tex**	**19,69 tex**	**29,53 tex**
α_{Tt} 3831	3 mm	**28**	**1**	**10**	**19**
	6 mm	**29**	**2**	**11**	**20**
	9 mm	**30**	**3**	**12**	**21**
α_{Tt} 4310	3 mm	**31**	**4**	**13**	**22**
	6 mm	**32**	**5**	**14**	**23**
	9 mm	**33**	**6**	**15**	**24**
α_{Tt} 4789	3 mm	**34**	**7**	**16**	**25**
	6 mm	**35**	**8**	**17**	**26**
	9 mm	**36**	**9**	**18**	**27**

3. RESULTS AND DISCUSSION

Yarn unevenness, number of thin places, number of thick places, number of nep were measured with Uster Tester 5. According to the Figure 4, it is found that yarn unevenness is higher for finer yarns and increases with the increasing of the twist coefficient and strand spacing. For some blends, some yarn types cannot be produced because of poor spinning stability depending on the fibre quality, strand spacing and yarn count.

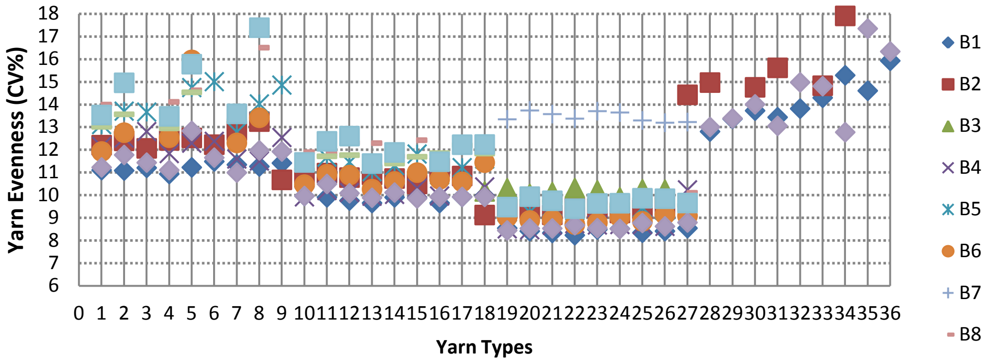

Figure 4. Yarn uneveness values (CV%).

Regression analysis is used for the investigation of relationships between two groups of variables. The obtained model can be used to describe the relationship between dependent and independent variables and to predict new values. As the yarn characteristics are influenced by fibre properties, production parameters, the spinning conditions, etc. the multiple regression analysis and ordinary least-squares methods were selected. The types of relationship between selected parameters and yarn properties were checked by curve estimation and correlation analysis. Based on statistical analysis, a nearly linear relationship between fibre properties measured with AFIS and yarn properties was found, therefore, the linear multiple regression analysis method was chosen for this study [7].

Table 4. Pearson correlation coefficients between fibre properties measured with AFIS.

	Nep	L_w	SFC_w	UQL_w	L_n	SFC_n	$\%5L_n$	Total	Trash
Nep	1	-0,366**	0,788**	-0,256**	-0,493**	0,838**	-0,283**	0,778**	0,901**
L_w	-0,366**	1	-0,804**	0,986**	0,986**	-0,739**	0,973**	-0,386**	-0,451**
SFC_w	0,788**	-0,804**	1	-0,709**	-0,885**	0,989**	-0,706**	0,706**	0,786**
UQL_w	-0,256**	0,986**	-0,709**	1	0,953**	-0,640**	0,985**	-0,309**	-0,383**
L_n	-0,493**	0,986**	-0,885**	0,953**	1	-0,833**	0,935**	-0,489**	-0,556**
SFC_n	0,838**	-0,739**	0,989**	-0,640**	-0,833**	1	-0,645**	0,754**	0,843**
$\%5\ L_n$	-0,283**	0,973**	-0,706**	0,985**	0,935**	-0,645**	1	-0,314**	-0,420**
Total	0,778**	-0,386**	0,706**	-0,309**	-0,489**	0,754**	-0,314**	1	0,783**
Trash	0,901**	-0,451**	0,786**	-0,383**	-0,556**	0,843**	-0,420**	0,783**	1

***Correlation is significant at 0.01 level (two-tailed).*

According to Pearson correlation coefficients, there is high correlation between number based and weight based measurements (r>0,98). Besides, correlation between fibre length measurements ($UQL_{(w)}$-$L_{(w)}$) were also high (Table 4). As a result, for regression analysis, fibre properties that have a higher correlation with yarn unevenness were used: nep /gr, $L_{(w)}$, $SFC_{(w)}$, Total cnt, Trash cnt. Besides these, yarn count, twist coefficient and strand spacing were also chosen as independent variables.

A polynomial relation was found between short fibre content and yarn unevenness, due to curve estimation. Apart from that, there is a linear relationship between fibre properties and yarn properties. Following the curve estimation and collinearity tests, Best Subsets Regression method was used for determining which independent variables should be included in the model. To analyze the model in details, Stepwise regression was used. Models with higher adjusted R2, but lower Akaike and Schwarz values were determined. Finally, heteroskedasticiy is tested with White test, it is found and a new model was established. Otherwise, it can invalidate statistical tests of significance that assume that the modelling errors are uncorrelated and normally distributed and that their variances do not vary with the effects being modelled.

Regression coefficients of variables, t-values and significance level of each variable of the final model are given in Table 5. Regression coefficients, which are constants, represent the rate of change of the yarn unevenness as a function of changes in the fibre properties and yarn parameters. Signs (+ or -) of regression coefficients of variables indicate the direction of influence P-value indicate the statistically significance. If the p-value is less than the significance level α, the null hypothesis is rejected and the result is statistically significant.

Table 5. Regression coefficients, t-values and significance level of t-values of linear regression model for yarn unevenness.

	Coefficient	Std. error	t-ratio	p-value
Constant	19.977	0.505	39.556	<0.00001***
Strand spacing (mm)	0.028	0.004	7.932	<0.00001***
Yarn count (Ne)	0.181	0.001	151.054	<0.00001***
Twist coefficient (α_e)	0.058	0.019	3.036	0.00242**
L_w	-0.529	0.013	-39.271	<0.00001***
SFC_w	0.378	0.117	3.228	0.00126***
SFC_w^2	-0.191	0.021	-8.964	<0.00001***
SFC_w^3	0.018	0.001	15.025	<0.00001***
Trash cnt	0.023	0.011	2.084	0.0373**
R^2	**0.9272**	**Adjusted R^2**	**0.9269**	

Yarn unevenness (CV%) = 19,977 + 0,028 F.A.M. + 0,181 Yarn count (Ne) + 0,058 (α_e) – 0,529 L_w+ 0,378 SFC_w -0,191 SFC_w^2 + 0,018 SFC_w^3 + 0.023 Trash cnt

** *is significant for α=0.05.*
*** *is significant for α=0,01.*

All of the regression coefficients in the model are statistically significant. According to the equation, yarn unevenness increases with the increase of yarn fineness, twist coefficient and strand spacing. Among fibre properties, fibre length and short fibre content have greater influence on yarn evenness. As fibre length increases and trash count decreases, yarn unevenness decreases. Short fibre content has a polynomial relation, yarn uneveness increase with the increase of short fibre content, up to a limit, after that decrease and increase again.

Figure 5 shows the scatter plot of predicted yarn unevenness values versus actual yarn unevenness values and regression line of the models. A high correlation (r=0,95) was found between actual and predicted values.

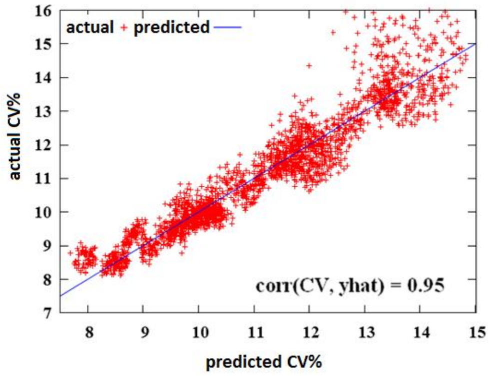

Figure 5. Predicted versus actual values of yarn evenness.

4. CONCLUSION

As the raw material costs are more than half of the total manufacturing costs in a short staple spinning mill, therefore knowing and monitoring the quality characteristics of the fibers, have great importance for the spinners. In this paper, a model for estimating sirospun yarn evenness from cotton fibre properties was investigated. This article is a part of a comprehensive work and some of the results are given in previous papers. Cotton fibre properties, measured with AFIS and some yarn production parameters such as yarn count, twist coefficient and strand spacing were selected as predictors. Linear multiple regression method were performed and statistical evaluation showed that generated equations for predicting yarn evenness had a large R2 and adjusted R2 values. Prediction ability of our model is very high as shown in Figure 5. Yarn unevenness increases with the increase of yarn fineness, twist coefficient and strand spacing. Fibre length and short fibre content are most important fibre properties for yarn unevenness. As fibre length increases and trash count decreases, yarn unevenness decreases.

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