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The Prediction of Cotton Ring Yarn Properties from AFIS Fibre Properties by Using Linear Regression Models

Abstract
In this paper some models for predicting the most important ring yarn quality characteristics were built by using AFIS (Advanced Fibre Information System) data. Yarn count, twist and roving properties were also selected as predictors because of their great effect on the yarn properties. A total of 180 ring yarns were produced from 15 different cotton blends on the same ring spinning machine, on the same spinning positions and under the same conditions at Ege University Textile and Apparel Research-Application Centre. Each blend was spun in four yarn counts (29.53 tex, 23.63 tex, 19.69 tex, and 16.88 tex) at three different coefficients of twist (α_{Tt} 3639, α_{Tt} 4022, and α_{Tt} 4404). Linear multiple regression methods were used for the estimation of the yarn quality characteristics. The goodness of fit statistics showed that our equations had very large R^2 (coefficient of multiple determination) and adjusted R^2 values.

Key words: *cotton yarn, cotton fibre, AFIS, ring spinning, regression analysis, yarn quality.*

Introduction

In addition to spinning technique, machine parameters, operation stages, processing conditions and the physical characteristics of fibre determine its processing behaviour, production efficiency and final yarn and fabric quality. Therefore, predicting the quality characteristics of yarns, especially tensile properties, has been the main target of many studies in the last century. Generally, two approaches were used in these studies for predicting yarn quality from fibre and yarn characteristics: an empirical, statistical approach and a theoretical or analytical approach.

One of the most common statistical approaches is the multiple regression method. Such an approach is used to investigate the interdependence of different fibre properties and to estimate the relative contribution of each fibre property to the overall yarn properties. Several researchers [1 - 5] have established various regression equations using this method.

The theoretical approach is based on physical and mechanical principles. These models usually give us good information about interactions between different fibre properties and yarn characteristics. However, practical applications are almost impossible because of the complexities of the models. They are usually based on certain assumptions and their success is determined by the feasibility of these assumptions [4, 6].

In recent years some researchers [2, 4, 7, 8] have shown an interest in the use of artificial neural networks (ANN) to predict yarn characteristics. This analytical system is also useful for discovering relationships between variables [8].

AFIS (Advanced Fibre Information System) instrument is used for the measurement of individual fibres. The AFIS test provides detailed information regarding important fibre properties including fibre diameter, neps, trash, dust counts and several length parameters. AFIS is one of the instruments of choice for cotton spinning industry specialists since it provides them with both average fibre values and distributions. Although it is of great importance, very little research can be found related to the estimation of yarn properties by using AFIS test results. Chanselma et al. [9] used AFIS test results to predict yarn evenness and imperfections and Zhu and Ethridge [8] to predict yarn hairiness.

The main aim of this investigation was to determine the relationship between ring yarn properties and the fibre measurements obtained by the AFIS instruments and to design appropriate models for predicting yarn properties. In addition to AFIS fibre properties, we also used roving properties, yarn count and yarn twist to model yarn properties.

Materials and test methods

In this work, fifteen different cotton samples were collected in roving form from various spinning mills in Turkey. Spinning operations can affect fibre properties in different ways, depending on the machinery line and adjustments etc. For the elimination of these effects, fibre properties were measured from finisher drawframe slivers by using an Uster AFIS instrument. The main test results of fibre properties are given in Table 1 (see page 64).

All samples were spun into yarns on a ring spinning machine (Rieter Model G30) at a yarn count of 29.53 tex, 23.63 tex, 19.69 tex, and 16.88 tex. Each yarn count was spun at three different twist multipliers (α_{Tt} 3639, α_{Tt} 4022, and α_{Tt} 4404). A total of 180 spinning trials were done. Appropriate drafting ratios were adjusted on the ring spinning machine for each sample. Other spinning conditions were kept constant. Orbit rings (42 mm diameter) and travellers (suitable weights were selected for each yarn count) were used. For each yarn sample ten cops were produced and tested.

The tensile properties of the yarns were evaluated on an Uster Tensorapid tensile testing machine. Unevenness and hairiness tests were performed on an Uster Tester 3.

Rovings were tested on Uster Tester 3. Measurements of the main properties are shown in Table 2 (see page 64).

***Table 1.** Main fibre properties of cotton samples.*

Property	Abbreviations and Unit	Cotton Sample No.														
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15
Neps	Cnt/g	8	40	45	3	29	16	16	158	56	24	17	34	8	15	39
Mean length by weight	L(w), mm	27.1	29.4	26.2	27.4	24.8	26.9	31.4	26.6	26.9	27.3	25.5	27.5	27.4	28.2	24.7
Short fibre content by weight	SFC (w), %	3.2	3.7	4.4	3	6.1	3	1.7	5.8	5.1	2.2	5.2	4.5	3.4	2.8	8.6
Upper quartile length by weight	UQL (w), mm	32.3	35.8	31.5	32.6	29.6	31.6	37.4	32.2	31.9	32	30.5	32.6	32.6	33.3	30.5
Mean length by number	L(n), mm	24	24.9	23.1	24.6	21.3	24.4	27.7	22.5	23.3	24.9	22.2	24	24.4	25.3	20.4
Short fibre content by number	SFC (n), %	9.9	13.4	11.9	8.6	16.4	8.4	7.3	18.1	15.2	6.7	14.5	13.8	9.7	8.4	22.8
Upper quartile length by number	UQL (n), mm	29.9	32.4	29.5	30.4	27	29.9	34.8	29.7	29.9	30.3	28	30.7	30.5	31.2	27.2
Fibre diameter	D(n), µm	14.3	12.4	14.5	14.6	14.1	14.5	12.7	14.3	14.5	14.6	14.4	14.5	14.5	13.7	14.4
2,5% Length by number	mm	41.8	46.3	39.3	41.2	40	39.8	47.4	40.5	40.4	40.5	39.3	40.9	41.3	43	39.6
Dust	Cnt/g	7	21	22	13	12	28	10	178	52	16	16	77	9	15	89
Trash	Cnt/g	0	1	2	0	1	1	2	29	4	0	0	0	1	0	4
Total	Cnt/g	7	22	24	13	13	29	12	207	56	16	16	77	10	15	93
Visible foreign matter	V.F.M., %	0.001	0.019	0.022	0.008	0.01	0.014	0.013	0.467	0.058	0.007	0.009	0.059	0.015	0.009	0.099

***Table 2.** Main properties of rovings.*

Property	Sample No.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Roving Cnt., tex	542.39	544.9	896.31	634.44	483.76	485.75	531.65	665.92	564.69	587.73	584.24	580.79	590.67	657.03	593.04
Um, %	4.11	4.95	3.23	4.00	4.68	3.90	5.24	5.35	4.90	4.42	3.91	5.72	5.06	3.61	4.98
CVm, %	5.06	6.29	4.06	5.07	5.92	4.91	6.69	6.77	6.16	5.56	4.93	7.24	6.42	4.56	6.29
CVm (1 m), %	2.96	2.82	2.17	2.48	3.01	1.96	4.06	3.04	2.31	1.61	2.68	2.82	4.05	1.46	2.02

Statistical method

Regression analysis is the most common statistical method for estimation of the relationship between a dependent variable and one or more independent variables. This method has the advantage of simplicity in describing the quantitative relationship between textile material properties. Therefore, the multiple regression analysis method was selected for establishing the relationships between fibre and yarn properties. At the beginning, the types of relationship between selected properties (independent variables) and yarn properties (dependent variables) were checked individually by using curve estimation and correlation analysis. Statistical analysis indicated that there was a nearly linear relationship between fibre properties and yarn properties. Hence, the linear multiple regression analysis method was chosen for this study, and the forward stepwise method was selected for linear regression analysis.

Before the regression analysis, we tested for collinearity within each variable. The results suggest that there is a strong correlation between length measurements by weight and number based values. It was also found that all length measurements have good correlation coefficients with yarn properties, but autocorrelation between fibre length measurements can cause some illogical signs on significant variables of the regression equations. Therefore, the regression equations using these explanatory variables are very unstable, and their use may give mistaken results in individual cases. As a result, we neglected length measurements by number (L(n), UQL(n) and SFC(n)). We also excluded visible foreign matter (VFM) from the group of variables because of the same reason (it highly correlated with the trash count).

Statistical analyses were performed using SPSS 11.0.1 software.

Results and discussion

Predicting yarn tenacity

The tensile properties of a spun yarn have always been very important in determining the quality of the yarn, since they directly affect the winding and knitting efficiency as well as warp and weft breakages during weaving. It is, therefore, important to establish which fibre and yarn parameters influence yarn tensile properties and if possible, to derive the functional relationship between them. So far, numerous mathematical and empirical models have been established for the estimation of single yarn tenacity [3, 10, 11] and CSP (Count Strength Product) [1, 3, 12, 13] using fibre properties and some yarn parameters.

Hearle [14] reviewed various mathematical and empirical studies concerning yarn strength, which were published between 1926 and 1965. Hunter [6] stated that more than 200 papers had published about the prediction of yarn quality parameters, particularly tensile properties, up to 2004.

Obviously, fibre strength is the most important factor for yarn tenacity, but fibre strength can not be measured by AFIS. Instead of strength, fibre diameter becomes the foremost property among those of AFIS , in addition we found very high negative correlation coefficient between fibre diameter and yarn tenacity (R = -0.929). This negative correlation means that the lower the diameter of fibre (i.e. higher number of fibres in the yarn cross-section), the higher the yarn tenacity. Our regression analysis expresses this relationship clearly. Table 3 shows regression coefficients of variables, t-values and significance level of each variable. Arrangement of variables in the table indicates their relative importance for the model. Signs (+ or -) of regression coefficients of variables indicate the direction of influence. Neps count, upper quartile length and dust count are other important fibre parameters for yarn tenacity, in addition to fibre diameter. Increased neps and dust count reduced yarn tenacity. As expected increased upper quartile length increased tenacity.

Figure 1 shows the scatter plot of predicted values versus experimental values and regression line of our model.

Predicting yarn elongation

Prediction models dealing with the breaking elongation of cotton yarns are few in number. Mathematical models have been proposed by Aggarwal [15, 16], Frydrych [10], and Żurek *et al*. [17]. Statistical models have been developed by Hunter [3] and ANN models produced by Majumdar [4].

In linear regression analysis the relationship between dependent variable and each independent variable should be linear. Our curve estimation analysis showed that the roving count (tex) value will relate linear to yarn elongation by the following quadratic form:

$$Q_{Rv} = 10.16 - 0.015Rv + 0.000012Rv^2 \quad (1)$$

where:
Q_{Rv} - Quadratic (Roving Count)
Rv - Roving Count

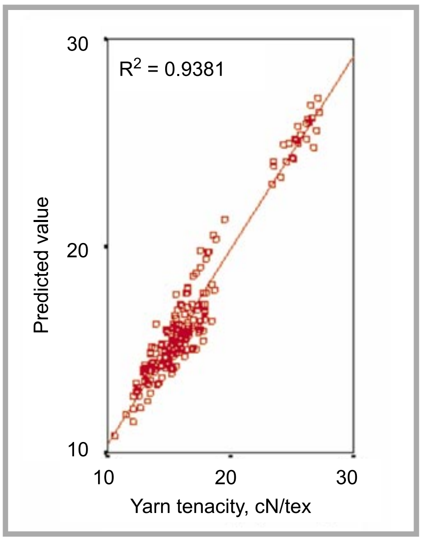

Figure 1. *Predicted versus observed yarn tenacity values.*

Table 3. *Regression coefficients, t-values and significance level of t-values of our linear regression model for yarn tenacity; * Partial Regression Coefficient.*

Statist. param.	Constant	D(n), µm	Neps, Cnt/g	Yarn Cnt., tex	Yarn twist, t.p.m.	UQL (w), mm	Dust, Cnt/g
B*	61.515	-4.577	-0.017	0.303	0.010	0.175	-0.009
Std. Error	4.800	0.194	0.005	0.023	0.001	0.065	0.004
T	12.815	-23.568	-3.594	13.368	9.619	2.709	-2.201
Sig.	0.000	0.000	0.000	0.000	0.000	0.007	0.029

Table 4. *Regression coefficients, t-values and significance level of t-values of our linear regression model for yarn elongation; * Partial Regression Coefficient.*

Statist. param.	Constant	Yarn Cnt., tex	Quad (Roving Cnt.)	UQL (w)	Yarn twist, t.p.m.	Roving CVm, %	D(n), µm
B*	-5.039	0.167	0.970	0.089	0.003	-0.203	-0.211
Std. Error	2.567	0.011	0.183	0.031	0.000	0.046	0.087
t	-1.963	15.578	5.310	2.913	6.878	-4.437	-2.433
Sig.	0.051	0.000	0.000	0.004	0.000	0.000	0.016

Table 5. *Regression coefficients, t-values and significance level of variables of our linear regression model for yarn unevenness; * Partial Regression Coefficient.*

Statist. param.	Constant	Dust, Cnt/g	Neps, Cnt/g	D(n), µm	SFC(w)	Roving Cnt., tex	Roving CVm, %	Yarn Cnt., tex
B*	-7.737	0.011	0.015	1.557	0.162	0.002	0.577	-0.245
Std. Error	2.009	0.004	0.004	0.114	0.044	0.001	0.105	0.013
t	-3.851	2.719	3.336	13.720	3.682	1.987	5.488	-19.536
Sig.	0.000	0.007	0.001	0.000	0.000	0.049	0.000	0.000

We disregarded roving count from the group of variables and added Q_{Rv} value. Table 4 shows our multiple linear regression analysis results. The breaking elongation is mostly influenced by yarn count. Upper quartile length and fibre diameter are the most important fibre properties for the yarn breaking elongation. Other important parameters are yarn twist, roving count and roving unevenness. All parameters have positive effect except roving unevenness and fibre diameter.

Several researchers [3 - 5] concluded that yarn elongation is chiefly influenced by fibre elongation and fibre strength. We can not measure fibre elongation and strength on an AFIS instrument. Therefore the R^2 value and predictive power of the model is relatively low. Figure 2 shows the wide spread of values around the regression line.

Predicting yarn unevenness

Cross sectional fibre variation is the basic reason for yarn unevenness. The Spinning method, yarn count and some fibre parameters have a decisive influence on the unevenness of yarn in addition to machine parameters. Hunter [3] and Ethridge et. al. [2] have developed some models to determine yarn irregularity by using fibre parameters.

In Table 5 linear regression analysis results are presented. Our analyses show that yarn unevenness is mainly affected by dust and neps count. The direction of impact for dust, neps, fibre diameter, short fibre content, roving unevenness and roving count is positive. That is, increased parameters increased the yarn evenness. Fibre diameter designates the number of fibre in yarn cross section. Decreased fibre diameter increased the number of fibre in cross section, and thus increased regularity. Hunter [3]

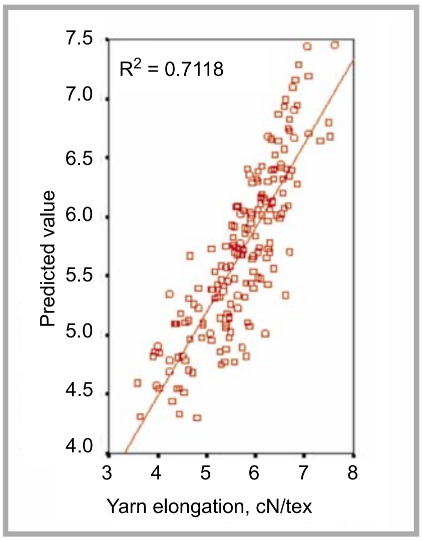

Figure 2. *Predicted versus observed yarn elongation values.*

showed that increases in short fibre content increase thin places in yarn. Roving count determines the draft ratio on ring spinning. We see that decreased roving count (lower draft) decreased yarn unevenness. But it must be noted that in this research drafting ratio ranged from 18.80 to 54.20.

Prediction ability of our model is very high as shown in Figure 3.

Predicting yarn hairiness

Hairiness, another measurable yarn characteristic, is usually an undesirable property. Acceptable measuring devices for the determination of hairiness, such as the Uster Tester and the Zweigle Hairiness Tester are relatively new and therefore fewer research articles have been published on the estimation of hairiness by using fibre parameters.

Regression coefficients, t-values and significance level of the variables of our model are given in Table 6. We see that the most important fibre property influencing yarn hairiness is fibre diameter. Finer cottons create less yarn hairiness. Increased nep content, roving unevenness, yarn count (tex) and roving count (tex) increased yarn hairiness. Upper quartile length and yarn twist reduced yarn hairiness. Long fibres have less chance to protrude from the yarn body and become a hair.

Figure 4 shows the scatter plot of predicted values versus experimental values and regression line of our model.

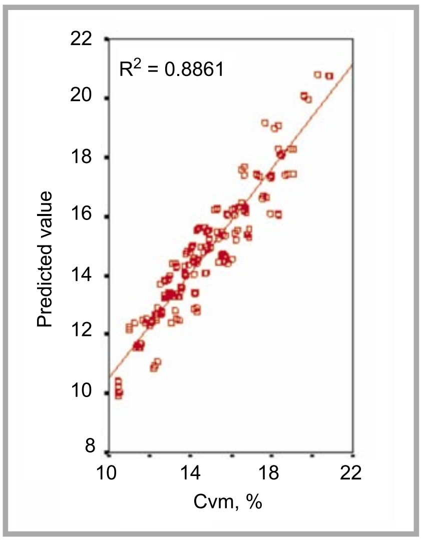

Figure 3. *Predicted versus observed yarn unevenness values.*

Table 6. *Regression coefficients, t-values and significance level of variables of our linear regression model for yarn hairiness; * Partial Regression Coefficient.*

Statist. param.	Constant	Yarn twist t.p.m.	D(n), µm	Neps, Cnt/g	Roving CVm, %	Roving Cnt., tex	Yarn Cnt., tex	UQL (w)
B*	-0.361	-0.003	0.560	0.005	0.311	0.001	0.021	-0.058
Std. Error	1.793	0.000	0.075	0.001	0.046	0.000	0.009	0.027
t	-0.201	-8.641	7.477	4.523	6.813	3.316	2.467	-2.128
Sig.	0.841	0.000	0.000	0.000	0.000	0.001	0.015	0.035

Table 7. *Goodness of fit statistics of models; * Standart Error of the Estimate.*

Statist. parameter	Tenacity	Elongation	Unevenness	Hairiness
R	0.969	0.844	0.942	0.894
R^2	0.938	0.712	0.887	0.799
Adj. R^2	0.936	0.702	0.882	0.790
SEE*	0.967	0.457	0.809	0.367

Summary and conclusions

In this study we have tried to predict the most important yarn parameters of ring spun cotton yarns by using AFIS fibre properties, roving and yarn properties with linear multiple regression analysis. For this aim fifteen cotton samples were selected and yarns of 16.88, 19.69, 23.63, and 29.53 tex were spun with α_{Tt} of 3639, 4022, and 4404. Cotton fibres were tested on an Uster AFIS instrument. In the first part of the work we tested the type of relationship between yarn properties and independent variables (i.e. fibre, roving and yarn properties) one by one. These curve estimation tests indicated that the relationships between variables and yarn properties are nearly linear for each yarn property. Therefore, we chose multiple linear regression models for statistical analysis.

Table 7 shows the following goodness of fit statistics of our models: multiple R, R^2, adjusted R^2 and standard error of the estimate (SEE). From the table we can see that all our models have very high R^2 values and low SEE values.

In order to control the fitness of the regression equations, analyses of variance (ANOVA) were performed. Table 8 shows the ANOVA test results for all models. This table includes regression and residual sums of squares, mean squares, F values and significance level of regression (p value). Goodness of fit statistics and ANOVA tables prove that the predictive powers of our models are very high and important at the $\alpha = 0.01$ significance level. The good performance of linear regression models in explaining yarn properties indicates that the relationships between our variables (fibre properties, roving properties, yarn count and twist) and yarn properties are very nearly linear.

Our models pointed out that roving properties have a great effect on all yarn properties. Yarn count and twist are most decisive factors for yarn properties. Among fibre properties fibre diameter is the most important parameter as it is the only variable that maintains significance in every regression equation. Upper quartile length, short fibre content, dust and neps count are other important fibre parameters for yarn properties.

Our work showed that AFIS fibre properties can be used for the prediction of yarn properties successfully.

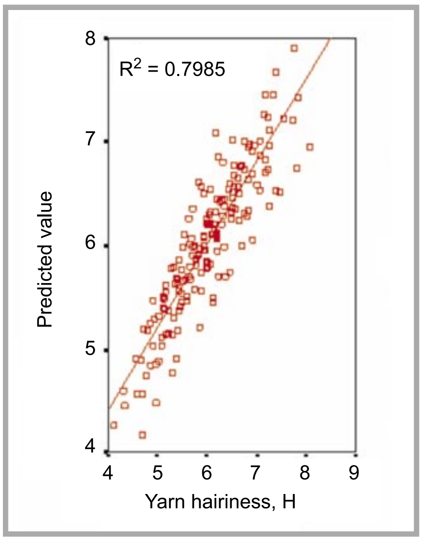

Figure 4. *Predicted versus observed yarn hairiness values.*

Table 8. Analysis of variance (ANOVA) results.

	Quantity	Sum of Squares	df	Mean Square	F	p (Sig.)
Tenacity	Regression	2448.409	6	408.068	436.773	0.000
	Residual	161.631	173	0.934		
	Total	2610.039	179			
Elongation	Regression	89.218	6	14.870	71.228	0.000
	Residual	36.116	173	0.209		
	Total	125.334	179			
Unevenness	Regression	878.105	7	125.444	191.08452	0.000
	Residual	112.915	172	0.656		
	Total	991.020	179			
Hairiness	Regression	91.841	7	13.120	97.386	0.000
	Residual	23.172	172	0.135		
	Total	115.013	179			

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