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Modelling the influence of cotton fibre properties on ring spun yarn strength using Monte Carlo techniques

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ABSTRACT

Cotton yarn strength modelling and prediction has remained as the cynosure of research for the textile engineers. The strength of spun yarns is accepted as one of the most important parameters for assessment of yarn quality. Yarn strength decide the performance of post spinning operations; warping, weaving and knitting and the properties of the final textile structure; hence its accurate technical evaluation carries much importance in industrial applications. This paper deals with the modeling and prediction of ring spun cotton yarn strength using a simple Monte Carlo techniques. The prediction accuracy of the model was found to be very encouraging.

KEYWORDS

Cotton yarn;
Cotton fibre;
Ring spinning;
Regression analysis;
Yarn quality;
Monte Carlo.

INTRODUCTION TO YARN STRENGTH

In addition to spinning technique, machine parameters, operation stages, processing conditions and the physical characteristics of fibre determine its processing behaviour, production efficiency, 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, several 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. The strength of a spun yarn have always been very important in determining the quality of the yarn, since it 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 strength 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[5,7,8] and CSP (Count Strength Product)[8,9] using fibre properties and some yarn parameters. Hearle[4] reviewed various mathematical and empirical studies concerning yarn strength, which were published between 1926 and 1965. 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 that include Mogahzy[2], Ethridge[3], Hunter[5], Majumdar[6] and Üreyen[10] have established various regression equations using this method.

MATERIALS AND TEST METHODS

In this work, 108 cotton samples were collected in fibre form from a spinning mill in Kenya. The fibres were tested for selected parameters using manual testing systems. The main testing results for the selected fibre properties are given in TABLE 1

TABLE 1 : Cotton fiber parameters

Variable	Units	Mean	Max	Min	Median
Fibre length	mm	28.51	32.60	23.60	28.80
Short fibre content	%	7.37	11.75	3.50	7.25
Fibre Fineness	(dtex)	1.24	1.85	0.63	1.20
Fibre Elongation	(%)	5.35	15.00	1.20	5.50
Fibre Strength	(g/tex)	31.27	33.80	27.50	31.20
Micronaire Value	Value	2.74	3.30	2.45	2.67
Trash Content	%	7.99	19.85	2.70	7.55

The samples were each spun into yarns using ring spinning technology into different yarn counts and at appropriate drafting ratios. The other spinning conditions were kept constant while the Orbit rings and travellers were selected according to the yarn count. For each yarn sample ten cops were produced and tested. Yarn strength was measured using the Universal strength tester, yarn twist measured using a twist tester while the yarn count was evaluated using the wrap wreel and quadrant balance. The main testing results of the selected yarn parameters are given in TABLE 2.

TABLE 2 : Cotton yarn parameters

Variable	Units	Mean	Max	Min	Median
Yarn Elongation	%	28.04	39.39	6.95	30.44
Yarn Twist	tpi	14.97	24.49	9.07	13.02
Yarn Count	tex	49.92	80.81	19.73	55.61
Yarn Strength	cN/tex	819.31	1401.70	187.60	970.05

Statistical modelling

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 linear regression analysis method was selected for establishing the relationships between fibre and yarn properties.

Monte Carlo simulation

In Monte Carlo simulation, a statistical distribution was identified using the variables in the regression model. This distribution was used as the source for each of the input parameters and random samples from each distribution were drawn, which represented the values of the input variables. For each set of input parameters, a set of output parameters is achieved. The value of each output parameter was achieved from one particular outcome scenario in the simulation run. These output values were collected from a number of simulation runs. Finally, statistical analysis was performed on the values of the output parameters, to make decisions about the model. The sampling statistics of the output parameters was used to characterize the output variation[1].

RESULTS AND DISCUSSION

Statistical analyses were performed using SPSS 19 and Minitab 15 while the Monte Carlo simulation was performed using ModelRisk 3.1 software.

Regression modelling

This study developed a model of the relationship between ring spun yarn strength by using fibre and yarn properties with linear multiple regression analysis. Then results were simulated using the Monte Carlo technique.

TABLE 3 : Goodness of fit statistics

Model Summary				
Model	R	R^2	Adj. R^2	SEE
1	0.946[a]	0.895	0.885	124.69824

a. Predictors: (Constant), tc, fe, fi, sf, ln, st, mi, tp, tx

The goodness of fit statistics of the model shown in TABLE 3 gives the coefficient of correlation (R) of 94.6%.

TABLE 4 : Analyses of variance (ANOVA)

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12935944.728	9	1437327.192	92.435	.000[a]
	Residual	1523865.838	98	15549.651		
	Total	14459810.566	107			

a. Predictors: (Constant), tc, fe, fi, sf, ln, st, mi, tp, tx; b. Dependent Variable: Ys

In order to control the fitness of the regression equations, analyses of variance (ANOVA) were performed. The TABLE 4 shows the ANOVA test results for the model which indicates that the predictive powers of the model was important at $\alpha = 0.01$ significance level.

The regression coefficients are shown in TABLE 5 and indicate the coefficients of variables, t-values and significance level of each variable. Arrangement of variables in the table indicates their relative importance for the model.

TABLE 5 : Linear regression model

Coefficients[a]							
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	1795.666	386.364		4.648	.000	1028.939	2562.394
Tp	-64.183	5.342	-.821	-12.015	.000	-74.784	-53.582
Tx	2.185	1.271	.120	1.718	.089	-.339	4.708
Ln	-6.855	5.393	-.043	-1.271	.207	-17.558	3.848
Sf	-.832	1.532	-.018	-.543	.588	-3.872	2.208
Fi	12.445	35.667	.012	.349	.728	-58.336	83.226
Fe	6.453	6.187	.036	1.043	.300	-5.825	18.731
St	-2.636	7.951	-.012	-.331	.741	-18.415	13.143
Mi	69.508	63.771	.042	1.090	.278	-57.044	196.060
Tc	-7.778	5.214	-.054	-1.492	.139	-18.125	2.569

a. Dependent Variable: Ys

$$Ys = 1795.67 - 64.18tp + 2.19tx - 6.86ln - 0.83sf + 12.45fi + 6.45fe - 2.64st + 69.51mi - 7.78tc \quad (1)$$

Monte Carlo simulation

Monte Carlo Simulation involved the process of using the random numbers generated from the distributions of the input variables in obtaining a probabilistic approximation to the solution of the regression model for the output variable. This process was performed using the features of ModelRisk 3 software. The predictions of yarn strength from the model were evaluated using the histogram plot shown in figure 1.

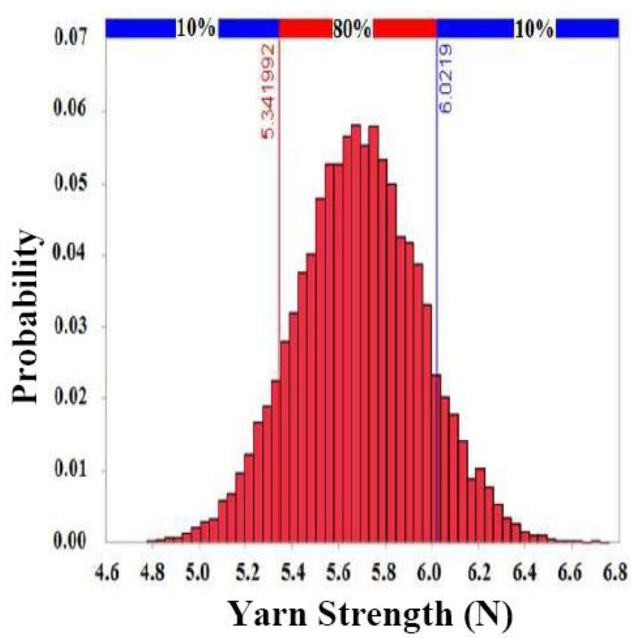

Figure 1 : Histogram plot

According to the histogram plot, the predicted value of the yarn strength at 80% probability is between 5.34N (534cN/tex) and 6.02N (602cN/tex).

Sensitivity analysis

The sensitivity analysis was developed in order to evaluate the relative contribution of each predictor to the overall prediction of the yarn strength and thus the input parameters were ranked according to their coefficients in the model. The beta coefficients of the factors in yarn strength prediction model were applied in the construction of the sensitivity plots.

The tornado sensitivity plot shown in Figure 2 for the yarn strength model (ys) indicates that in terms of yarn parameters; yarn twist (tp) was the most influential variable with the widest range than for any other input variable, the next parameter was yarn linear density (tx). The plot further shows that in terms of fibre parameters the most influential variables are trash content (tc), micronaire value (mi), fibre length (le) and fibre elongation (fe).

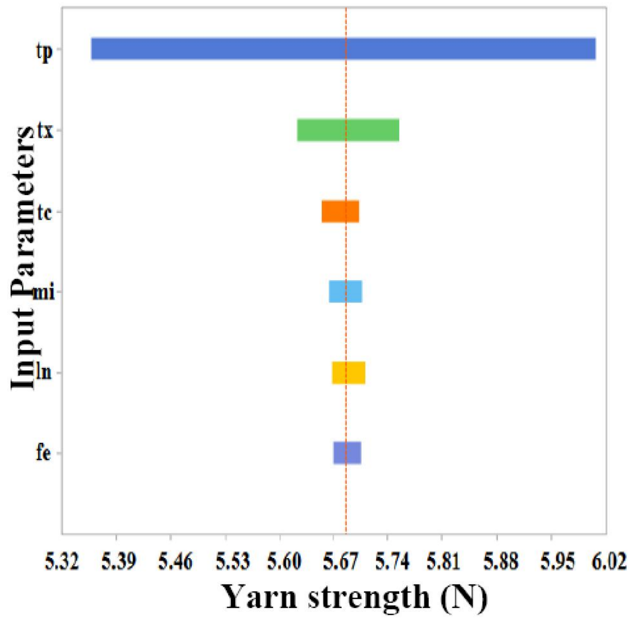

Figure 2 : Tornado plot

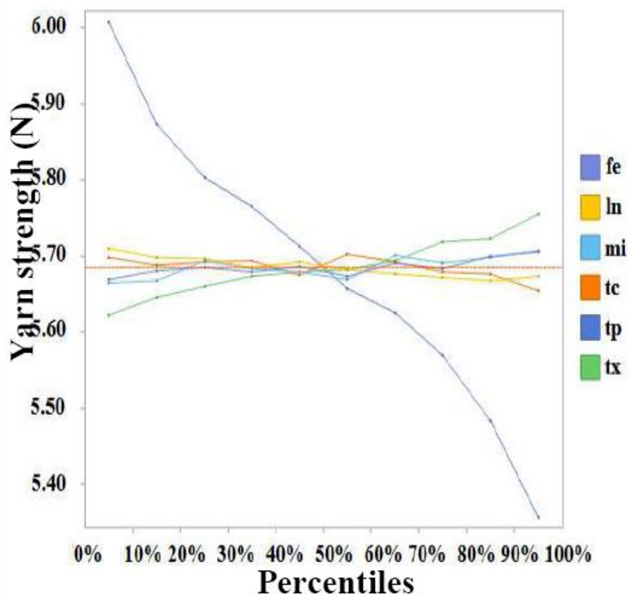

Figure 3 : Spider plot

The spider sensitivity plot shown in Figure 3; indicated that the yarn twist had the dominant influence on the yarn strength model and overshadowed the fibre parameters in the model so that the influence of the fibre parameters in predicting the strength of yarn strength was minimal. This resulted in the elimination of fibre properties such as fineness, short fibre content and strength from the model. This phenomenon could be due to the high correlation between yarn twist and yarn strength as established by Majumdar[6], Moghazy[2], and Hunter[5].

CONCLUSION

The twist of ring spun yarn stands out as the most influential properties which affect yarn strength in ring spun yarn. This phenomenon may probably be due to the fact that the main function of twist is to give coherence to the yarn. In order to develop strength in a twisted strand of fibres the individual fibres must grip each other when the strand is stressed. This cohesion arises mainly from the twist, which presses the fibres together as the stretching force is applied and so develops friction between adjacent fibres. High yarn twist allows for more inter-fiber grip leading to more cohesion between fibers. More fiber cohesion results in higher yarn strength.

The most effective fibre properties on yarn strength were fiber trash content (tc), fibre length (ln), micronaire value (mi) and breaking elongation (fe) for the prediction models. This result is probably due to the fact that trash in the cotton lint could have a negative influence on yarn strength mainly due to problems in spinning process. If the trash in cotton was not removed in the ginning and in the subsequent spinning process, then it will have a negative impact on yarn strength. The fibre length properties affect yarn strength in ring spun yarn because it determines the amount by which fibres can overlap with one another, greater the overlapping; the easier it would be for the fibres to bound together and better would be yarn strength. This means that fibre length have a direct influence on yarn strength and could be negatively affected by shorter span length. Moreover, increasing fibre length results in improved yarn strength because a long fibre generates a greater frictional resistance to an external force, hence the longer the fiber, higher would be the yarn strength. Fibre fineness is also an important fibre character affecting yarn strength. It gives number of fibres in the cross-section of yarn. The better the fineness of cotton more would be the number of fibres per cross-section resulting in higher yarn strength thus fine fibres will produce a yarn of higher strength than coarse fibres. This is because yarns made from fine fibres have more fibres per cross section, which in turn produces stronger yarn. There is a high correlation between the fibre elongation and yarn strength and this could be the reason for its significant influence on the strength of ring spun yarn.

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