IMPROVING THE ACCURACY OF PREDICTING YARN PROPERTIES BY SELECTING PROPER FIBER LENGTH PARAMETERS

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Abstract

Fiber length is a very important factor in yarn production. A study was carried out to investigate the effects of various cotton fiber length parameters (conventional and non-conventional) and their combinations on yarn properties. Linear regression models with different number of fiber length parameters and their combinations were developed to predict different properties of yarns (ring, OE). Our results indicate that, for the models with only length parameters, four-parameter models are more proper models considering their R^2s and Mallow's *Cp* values. If other fiber properties (strength, Mic, etc.) are included, the R^2 can be further increased. Short fiber parameters and length CV are important for improving prediction accuracy of yarn properties. Lower Half Mean Length (LHML) predicts yarn properties similar to short fiber content (SFC). Best prediction models for different yarns (ring, OE, etc.) and different yarn properties (strength, irregularity, etc.) include different length parameters. Not all yarn properties can be predicted well by linear regression models with length parameters. For yarn properties such as neps, ends-down, elongation, and CV (coefficient of variation) of strength, all models had low R^2s.

Introduction

Fiber length is considered a very important factor in yarn production and yarn quality. A number of length parameters are reported by different devices such as AFIS and HVI. Researchers have developed models to predict yarn properties from cotton fiber property parameters such as Mean Length (ML), Upper Half Mean Length (UHML), Upper Quartile Length (UQL), and Short Fiber Content (SFC). Since many length parameters have been developed and used, each parameter's significance on predicting yarn properties is different, because these different length parameters represent different fiber length characteristics. Though the parameters are all statistics of fiber length distribution, their relationships to yarn properties are not similar. For that reason, it is necessary to investigate the effectiveness of these parameters and their combinations in predicting yarn properties. For predicting different properties of different yarns, the models may need different combinations of length parameters.

Therefore we conducted a study to investigate the effectiveness of these parameters and their combinations in predicting yarn properties. In addition, the quantity of short cotton fibers in a cotton sample is an important cotton quality parameter. It impacts yarn production efficiency, cost, and product quality (Backe 1986, Ethridge and Krifa 2004). There have been discussions on short fiber content (SFC)'s impacts on yarn properties (Thibodeaux *et al* 2008). However, because SFC has certain disadvantages such as very high variation, researchers have proposed different short fiber parameters. Therefore our research also focused on comparing the capability of different short fiber parameters in predicting yarn properties and searching for an optimized parameter.

Materials and Method

We developed linear regression models to use fiber length parameters to predict yarn properties. In these models, only length parameters were included in the models as regressors. We not only compared the R^2 values of the models, but also compared their Mallows' *Cp* values to examine if a model is proper (Mallows 1973). If a model's *Cp* value is close to the number of regressors in that model, the model is considered more proper than a model that has a larger *Cp* value. Step-wise algorithm was used to develop the models.

The fiber length parameters included in our models are: 1) Mean Length by Weight (MLw), 2) CV of Length by Weight (Lw_CV), 3) Upper Quartile Length by Weight (UQLw), 4) Mean Length by Number (MLn), 5) CV of Length by Number (Ln_CV), 6) Upper Quartile Length by Number (UQLn), 7) Upper Half Mean Length (UHML), 8) Uniformity Index (UI).

In addition, we also included different short fiber parameters in the model to compare their different effects, these short fiber parameters were: 1) Short Fiber Content (SFC½"), which is defined as the percentage of fibers (by weight or by number) shorter than ½ inch (ASTM D1440-07); 2) Short Fiber Content (SFC16mm), which is defined as the percentage of fibers (by weight or by number) shorter than 16 mm (GB/T 6098.1-2006); 3) Lower Half Mean Length (LHML), which is defined as the mean length (by number) of the short half of the fibers by weight (Cui *et al* 2009, Cai *et al* 2011); 4) Relative Short Fiber Content (Rel. SFC), which is defined as the percentage of fibers (by weight or by number) shorter than 1/2 of the UHML (Heap 2004); 5) Floating Fiber Proportion (FFP), which is defined as FFP = ($S_{2.5}$/MLn – 0.975) × 100, where $S_{2.5}$ is the 2.5% span length (Hertel and Craven 1960); 6) Floating Fiber Index (FFI), which is defined as FFI = (UQLw/MLw – 1) × 100 (Fransen 1984).

The yarn quality properties predicted by using the models were: strength, CV of strength, elongation, irregularity (or uniformity), thick places, thin places, neps, and ends-down.

The samples used in this study included 28 different cottons that were provided by USDA Agriculture Marketing Service (AMS) for a short fiber study. The samples were measured on HVI and AFIS. Ten samples were taken from each bale, and 5 replicates for each sample were tested. Each rep had 5,000 individual fibers tested on AFIS. SFC_{16mm}, LHML, Rel. SFC, FFP, and FFI were calculated from fiber length distributions obtained from AFIS. Other length parameters values were directly obtained from AFIS. The properties of these samples cover wide ranges (Table 1). Those samples were made into open-end, ring, and vortex spun yarns at USDA ARS Cotton Quality Research Station (CQRS) at Clemson, SC.

Table 1. The range of properties of the samples

ML_W (inch)	UQL_W (inch)	$SFC_{W1/2"}$(%)	Micronaire	Maturity Ratio
0.74 – 1.07	0.897-1.29	4.89 – 19.17	2.92 – 5.52	0.84 – 0.99

Results and Discussion

The following Tables 2-6 report the comparisons of models that predict OE spun yarn strength from length parameters. Each model contains one to five length parameters respectively. In each of the tables, the models are sorted by their R^2 values. The comparisons of R^2 and *Cp* between these models clearly indicate that, when using length parameters to predict the yarn strength, four-parameter models performs much better than models with less parameter. As the number of parameters in a model increases, the R^2 increases in general. When the number of the input length parameters is more than four, the increase of R^2 becomes minimal, the model becomes more complicated and the *Cp* moves away from the number of input parameters, which indicates the model deteriorates. Models for predicting ring spun yarn showed similar properties. Generally, a model with four parameters yields the best predictions overall. We found that the length parameters included in the best prediction models for different yarns (ring or OE) were different. In addition, models for predicting different properties also included different length parameters.

Table 2. One-parameter models for OE spun yarn strength

Model	R^2	Model	R^2
-2.27+14.59 MLw	0.715	16.03-0.19 $SFC_{N½”}$	0.488
-1.49+12.36 UQLn	0.698	18.48-0.22 Lw_CV	0.129
-2.70+12.22 UHML	0.688	16.22-6.17 FFP	0.128
-2.47+12.16 UQLw	0.680	-18.79+0.37 UI	0.113
0.47+13.86 MLn	0.614	13.68-0.18 Rel_SFCw	0.078
0.91+17.67 LHML	0.612	16.00-0.11 Ln_CV	0.051
14.60-0.19 SFC_{W16mm}	0.547	14.71-15.36 FFI	0.051
14.60-0.33 $SFC_{W½”}$	0.531		

Table 3. Two-parameter models for OE spun yarn strength

Length Parameters	R^2	Cp
LHML, Lw_CV	0.770	20.789
SFCn, Lw_CV	0.745	25.478
MLw, UQLn	0.742	26.162
SFCw16, MLw	0.736	27.293
SFCw, MLw	0.720	30.213
LHML, FFP	0.720	30.268
UHML, Ln_CV	0.717	30.694
MLw, Lw_CV	0.717	30.787
LHML, Rel_SFCw	0.717	30.798
UQLw Ln_CV	0.717	30.803

Table 4. Three-parameter models for OE spun yarn strength

Length Parameters	R^2	Cp
SFCw, SFCn, UHML	0.852	7.612
UQLn, Lw_CV, Ln_CV	0.850	7.986
LHML, SFCw16, Lw_CV	0.850	8.075
UQLw, SFCw, SFCn	0.848	8.448
MLw, Lw_CV, Ln_CV	0.847	8.610
LHML, Lw_CV, Ln_CV	0.840	9.851
UQLw, LHML, Lw_CV	0.839	10.066
MLw, SFCw, SFCn	0.839	10.078
LHML, Lw_CV, UHML	0.838	10.319
UHML, Lw_CV, Ln_CV	0.828	12.208

Table 5. Four-parameter models for OE spun yarn strength

Length Parameters	R^2	*Cp*
MLw, SFCn, Lw_CV, Ln_CV	0.882	4.0337
UQLn, SFCn,Lw_CV, Ln_CV	0.879	4.6198
MLw, SFCw, Lw_CV, LnCV	0.879	4.6888
UQLn, SFCw, Lw_CV, Ln_CV	0.876	5.2228
LHML, SFCw16, Lw_CV, FFI	0.874	5.5178
MLw, SFCw16, Lw_CV, Ln_CV	0.871	6.1277
UQLn, SFCw16, Lw_CV, Ln_CV	0.869	6.4173
LHML, Lw_CV, SFCw SFCn	0.869	6.548
LHML, SFCw16, Lw_CV, UQLw	0.868	6.6212
FFP, LHML, SFCw16, Lw_CV	0.868	6.7152

Table 6. Five-parameter models for OE spun yarn strength

Length Parameters	R^2	*Cp*
UQLn, UQLw, LHML, SFCw16, Lw_CV	0.889	4.780
UQLw, Rel_SFCw, SFCw, SFCn, FFI	0.888	4.946
UQLn, UHML, LHML, SFCw16, Lw_CV	0.888	5.000
UHML, Rel_SFCw, SFCw, SFCn, FFI	0.887	5.167
UQLw, MLw, SFCn, Lw_CV, Ln_CV	0.886	5.373
LHML, SFCw16, FFI, Lw_CV, UI	0.885	5.471
MLw, UHML, SFCn, Lw_CV, Ln_CV	0.885	5.526
MLn, MLw, SFCn, Lw_CV, Ln_CV	0.885	5.550
UQLn, MLw, SFCn, Lw_CV, Ln_CV	0.884	5.694
MLw, SFCn, Lw_CV, Ln_CV, UI	0.884	5.762

Linear regression models were also developed to predict yarn properties using different short fiber parameters. Only one short fiber parameter was included in each model. Other length parameters were also included in the models and the best model with highest R^2 is compared. The models are listed in Table 7 and 8. Results indicate that the parameters we proposed, LHML, can perform similarly to SFC in predicting yarn properties.

Table 7. Two-parameter models for OE spun yarn strength with one short fiber parameter

Parameter	Model	R^2
LHML	-18.36+0.38 Lw_CV+28.85 LHML	0.771
$SFC_{N½"}$	1.50+0.63 Lw_CV-0.44 $SFC_{N½"}$	0.746
SFC_{W16mm}	-10.31+21.25 MLw+0.10 SFC_{W16mm}	0.736
$SFC_{W½"}$	-5.59+17.31 MLw+0.08 $SFC_{W½"}$	0.720
FFP	-2.71+14.75 MLw+0.36 FFP	0.715
FFI	-1.98+14.52 MLw-1.02 FFI	0.715
Rel. SFC_W	-2.32+14.61 MLw-0.002 Rel_SFCw	0.715

Table 8. Four-parameter models for OE spun yarn strength with one short fiber parameter

Parameter	Model	R^2
$SFC_{N½"}$	-24.64+1.14 Lw_CV-1.33 Ln_CV+47.18 MLw+0.55 $SFC_{N½"}$	0.882
$SFC_{W½"}$	-21.82+0.88 Lw_CV-0.86 Ln_CV+39.33 MLw+0.58 $SFC_{W½"}$	0.879
SFC_{W16mm}	-20.05+1.05 Lw_CV-0.84 Ln_CV+29.40 UQLn + 0.20SFC_{W16mm}	0.869
LHML	-68.11+1.71 Lw_CV+32.07 UQLn-60.72 UHML + 100.69 LHML	0.863
Rel_SFCw	-9.83+1.19 Lw_CV-0.95 Ln_CV+20.92 UQLn + 0.19 Rel_SFCw	0.855
FFP	-12.35+1.18 Lw_CV-0.88 Ln_CV+20.96 UQLn + 2.76 FFP	0.852
FFI	-13.44+1.25 Lw_CV-0.83 Ln_CV+20.77 UQLn -5.373 FFI	0.851

The results clearly show that the variation in fiber length distribution (LW_CV and Ln_CV) play an important role in predicting yarn properties. In addition, our models indicate that not all yarn properties can be predicted well by linear regression models with length parameters. For neps, ends-down, elongation, and CV of Strength, all models had low R^2s. We attempted to introduce square terms of the regressors, but the R^2 values did not exhibit significant improvement.

Conclusions

A study was carried out to investigate the effects of various cotton fiber length parameters (conventional and non-conventional) and their combinations on yarn properties. Linear regression models with different number of fiber length parameters were developed to predict different properties of yarns (ring, OE). Our results indicate that, for the models with only length parameters, four-parameter models are more proper models considering their R^2s and Mallow's *Cp* values. If other fiber properties (strength, Mic, etc.) are included, the R^2 can be further increased. Short fiber parameters and length CV are important for improving prediction accuracy of yarn properties. LHML predicts yarn properties similar to SFC. Best prediction models for different yarns (ring, OE, etc.) and different yarn properties (strength, irregularity, etc.) include different length parameters. Not all yarn properties can be predicted well by linear regression models with length parameters. For neps, ends-down, elongation, and CV of Strength, all models had low R^2s.

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