Influence of cotton quality and construction parameters on the strength of rotor yarns

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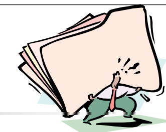


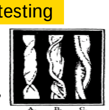
- . Expression of cotton fibers quality focused on yarn strength
- Comparison of some approaches to prediction of cotton yarn strength
- Presentation of yarn strength model based on the correction factors product (utilization factors)
- Description of graphically oriented method for creation of yarn strength stochastic models.
- Application of statistical analysis for prediction of yarn strength from cotton fibers data obtained by HVI

Cotton fibers parameters

Classical low volume instruments (LVI)

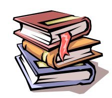
Fineness (expressed as micronaire value - MI or directly in Tex), **length (**expressed as mean length - LM), **maturity** (expressed e.g. as maturity index - IM from polarization microscope) and **strength of individual fibers** (SI) or **bundle strength** (expressed by Pressley index – PI or Stelometer - ST).

HVI (high volume instrument) testing



Spinlab 900
fineness (MIC),
length (UHM),
length uniformity (UI),
elongation (EL),
strength (STR),
reflectance (RD).
Yellowness and trash grade

Utility value concept



Let we have K utility properties R_1 ,...,R_K (cotton fiber properties measured by HVI). Based on the direct or indirect measurements it is possible to obtain some **quality characteristics** x_1 ,...,x_K (mean value, variance, quantiles etc.). These characteristics represent utility properties. Functional transformation of quality characteristics (based often on the psycho physical laws) lead to partial utility functions

$$u_i = f(x_i, L, H)$$

L is value of characteristic for just non acceptable cotton ($u_i = 0.1$) and *H* is value of characteristic for just fully acceptable product ($u_i = 1$)

Quality index *QI* (utility value) is weighted average of u_i with weights β_i

$$QI = ave(u_i, \beta_i)$$

Prediction of yarn strength σ_y [N/tex]

$$\sigma_y = \sigma_f \phi_{fy} = \sigma_b \phi_{by} = \delta_f \phi_{fb} \phi_{by}$$

$\phi_{fy} = f_n f_l f_\alpha \psi$	**Solovev**	**fiber**	
$\phi_{fy} = \varphi\phi\chi\varpi$	**Neckar**	**bundle**	ϕ_{fb}
$\phi_{by} = V_f n_\beta$	**Pan**	**yarn**	ϕ_{by}

σ_f – fiber strength [N/tex], σ_b – fiber bundle strength [N/tex], ϕ_{fb} – utilization of fiber strength in bundle, ϕ_{by} – utilization of fiber bundle strength y in yarn, ϕ_{fz} – utilization of fiber strength in yarn

Pan Model

$$F(\sigma) = 1 - \exp\left(-l_y \alpha_y \beta_y \sigma_v^{\beta_y}\right)$$

$$\overline{\sigma_f} = (l_y \alpha_y)^{-\frac{1}{\beta_y}} \Gamma\left(1 + \frac{1}{\beta_y}\right)$$

$$s_{\overline{\sigma_f}} = \overline{\delta_v}\left(\frac{\Gamma\left(1+\frac{2}{\beta_y}\right)}{\Gamma^2\left(1+\frac{1}{\beta_y}\right)} - 1\right)^{\frac{1}{2}}$$

Fiber strength

Daniel's result

$$H(\sigma_s) = \frac{1}{\sqrt{2\pi}\, s_{\overline{\sigma_s}}} \exp\left[-\frac{(\sigma_s - \overline{\sigma_s})^2}{2 s_{\overline{\sigma_s}}^2}\right]$$

$$\overline{\sigma_b} = (l_y \alpha_y \beta_y)^{-\frac{1}{\beta_y}} \exp\left(-\frac{1}{\beta_y}\right)$$

$$s_{\overline{\sigma_b}} = (l_y \alpha_y \beta_y)^{-\frac{2}{\beta_y}} \exp\left(-\frac{1}{\beta_y}\right)\left(1 - \exp\left(-\frac{1}{\beta_y}\right)\right) n^{-1}$$

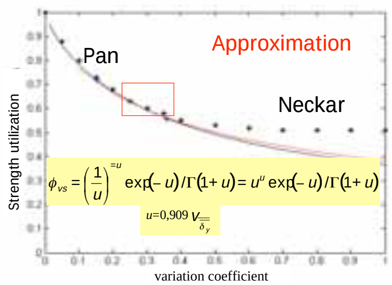
Bundle strength

$$\phi_{fb} = \frac{\overline{\sigma_b}}{\overline{\sigma_f}} = (\beta_y)^{-\frac{1}{\beta_y}} \exp\left(-\frac{1}{\beta_y}\right) / \Gamma\left(1 + \frac{1}{\beta_y}\right)$$

$$v_{\overline{\sigma_f}} = \frac{s_{\overline{\sigma_f}}}{\overline{\sigma_f}} = \left(\frac{\Gamma\left(1+\frac{2}{\beta_y}\right)}{\Gamma^2\left(1+\frac{1}{\beta_y}\right)} - 1\right)^{\frac{1}{2}}$$

Utilization of fiber strength in bundle

Utilization of fiber strength in bundle strength

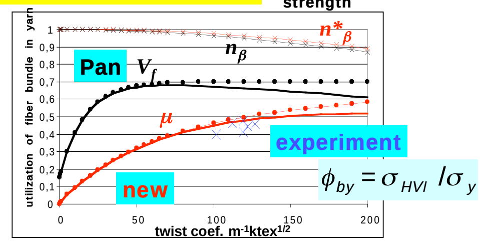


$$\phi_{vs} = \left(\frac{1}{u}\right)^{=u} \exp(-u)/\Gamma(1+u) = u^u \exp(-u)/\Gamma(1+u)$$

Yarn strength

$$\sigma_y = \sigma_{HVI}\phi^*_{by} = \sigma_{HVI}\,\mu\, n^*_\beta$$

n^*_β orientation factor
μ packing density
σ_{HVI} fiber bundle strength



$$\phi_{by} = \sigma_{HVI} / \sigma_y$$

Cotton yarn strength I

Generally is cotton yarn strength dependent on the

- parameters of fiber (fiber strength, fineness and fiber uniformity mainly)
- parameters of yarn formation (yarn fineness, twist etc.)
- spinning technology.

The theoretical predictive models are based on the mechanisms of yarn formation or concept of strength utilization factors (i.e. lowering of fiber strength due to bundle utilization, orientation , number of fibers bearing load and limit arrangement of fibers in yarns.

Cotton yarn strength II

Classical approach to prediction cotton yarn strength is based on the regression approach. This approach has some serious limitations:

- Regression models are additive - sum of possibly nonlinear contributions from all selected fiber properties and yarn construction parameters denoted as factors
- Some factors are mutually connected (i.e. yarn twist and fineness) but in the models are separated
- There is a logical nonsense in direct combination of properties responsible for fibrous bundle strength (measured by HVI, Pressley or Stelometer) and geometric characteristics of yarns (dependent on yarn formation parameters).

The pure statistical approach without creation of model in explicit forms is represented by neural network regression.

Cotton yarn strength III

The main problems in yarn strength predictive model building are:

- Limited range of some factors (due to improper experiment or non ability to change all factors). This problem is typical for cotton fiber properties where it is impossible to change properties arbitrarily.
- Small data sets not sufficient for inclusion of all important contributions
- Proper selection of technological parameters of yarn creation (interdependence of twist, fineness and spinning technology etc.).

  Some experimental data sets allow creating models having some important factor constant. Typical example is investigation of cotton fiber influence on cotton yarn strength where are formation parameters and yarn geometry constant.

Predictive models

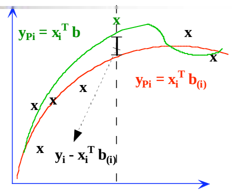
The construction of predictive models has the two main kind of problems:

- a) *Selection of the regression model form* (linear, nonlinear, interaction),
- b) *Specification of the criterion* for selection of the best predictive model.

The suitable model can be selected from the set of provisional models or adaptively created based on the special graphical aids (partial regression graphs). As criterion for both approaches the predictive ability characteristics are selected.

Regression quality

- Prediction ability of regression model can be characterized by quadratic error of prediction (MEP) and predicted correlation coefficient (PR)



$$MEP = \sum_{i=1}^{n} (y_i - x_i^T b_{(i)})^2 / n$$

$$\mathbf{b}_{(i)} = \mathbf{b} - [(\mathbf{X}^T\mathbf{X})^{-1} \mathbf{x}_i e_i] / [1 - H_{ii}]$$

H_{ii} is a diagonal element of projection matrix **H**

Predicted correlation coefficient (PR) $$PR^2 = 1 - \frac{n * MEP}{\sum (y_i - \sum y_i / n)^2}$$

Program MULLREG

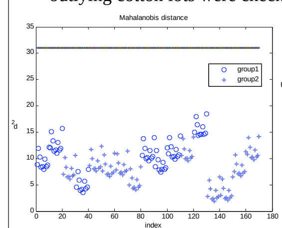
- MULLREG serves for creation of linear and linearized regression models in **MATLAB**
- The least squares is the only special case among a series of biased parameter estimators.
- Before computation, the data can be transformed to a Taylor expansion (up to quadratic terms) or generally.
- A numerically stable SVD based algorithm is used
- Variety of regression characteristics including partial regression graphs are offered computed.
- For diagnostic purposes, the characteristics and graphs for proving the assumptions about data, models and least squares criterion are included

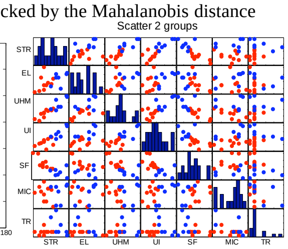
Experiments

- The 170 rotor yarns were prepared under comparable conditions.
- Seventeen kinds of cottons commonly used in Czech Republic were selected.
- The 100% cotton yarns (composed from pure cotton lots) were produced in five levels of yarn count *Jem* (16,5tex, 20tex, 27tex, 37tex, and 50tex) and ten Phrix twist coefficient *alf* (two levels for each yarn count).
- The HVI system was used for determining fibre parameters. Fibre length parameters *UHM*, *UI*, *SF*, fibre bundle strength *STR*, elongation *EL*, micronaire *MIC* and trash content *TR* were measured.
- The yarn strength was measured on the Tensorapid tensile testing machine standard conditions. The yarn strength *YS* is mean value from 50 measurements

Raw cottons

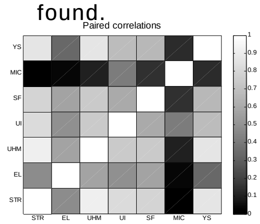
- The cluster analysis identified two groups of yarns. The possible outlying cotton lots were checked by the Mahalanobis distance

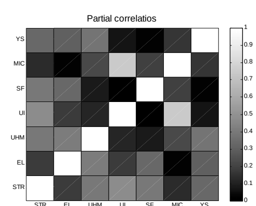




Interdependencies

- The significant partial correlations between *STR*, *EL*, *UHM*, *MIC* and yarn strength were found.





Regression models

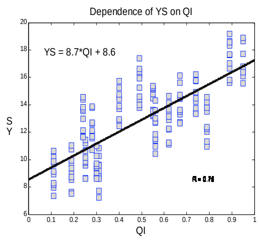
- The standard linear regression method was used for prediction of *YS* and estimation of influence of various factors on *YS*. Response variable is equal to *y* and explanatory variable is equal to *x* in regression line model $y = a + bx$. Prediction ability in linear regression model can be characterized by predicted multiple

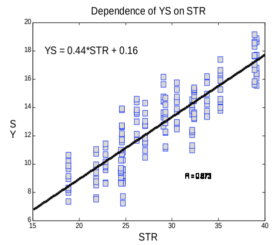
Predictive performance of line regression models

response	explanatory	PR
YS	*QI*	0.754
YS	*STR*	0.870
YS	*ORI*	0.0
YS	*Ym*	0.760
Yload	*Fload*	0.981
Yload	*Floadk*	0.977

Influence of fiber characteristics

- The influence of *QI* and *STR* on the *YS*





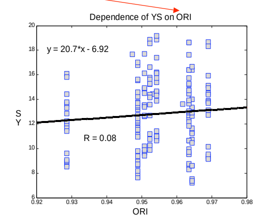
Comparison with yarn strength model

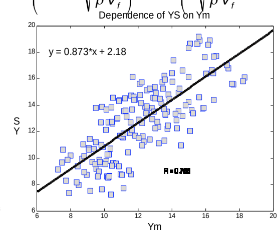
$$\phi_{by} = V_f \eta_\beta \qquad Ym = STR\ \phi_{by}$$

$$V_f[-] = 0,7(1 - 0,78\exp(-0,195K_y))$$

$$\eta_\beta = \frac{2\beta_D(1-\eta)+(1+\eta)\sin 2\beta_D}{4\beta_D}$$

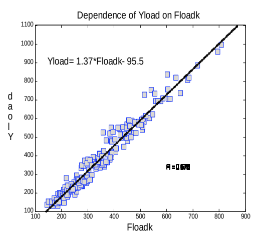
$$\beta_D = arctg\left(10^{-1}K_y\sqrt{\frac{4\pi}{\rho V_f}}\right) = arctg\left(\alpha\sqrt{\frac{4\pi}{\rho V_f}}/\sqrt{10^3}\right)$$

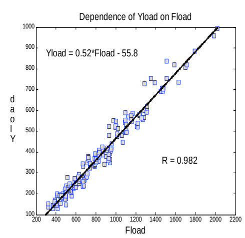




Loads to break

- Yarn maximum load *Yload = YS*Jem*
- Load beared by all fibers *Fload = STR*Jem*
- Corrected load beared by all fibers *Floadk = STR*Jem * ORI*





Conclusion

- It was found that yarn strength is critically dependent on the fibre strength.
- The simple models for yarn strength *YS* prediction based on the reduction of fibre strength by the multiplicative factors from orientation, Poisson ratio and volume fraction combined with linear regression is useful as well.
- The influence of process parameters are hidden in yarn fineness and are not as important as fibre strength *STR*.
- These results are valid for rotor yarns only and probably will be not directly extendable for another spinning systems.