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SIMPLE PREDICTION OF ROTOR YARN STRENGTH

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Yarn mechanical and geometrical properties are dependent on the cotton fibres quality and technology of yarn production. The main factors influencing on these properties are: type of fibres, yarn twist, yarn count, blending ratio and yarn production technology. This paper is focuses on investigation of the influence of cotton fibre strength and basic process parameters (fineness and twist) on rotor yarn strength. The HVI (High Volume Instruments) are used for testing of fiber bundle strength.

Seventeen kinds of cottons were selected and 100% cotton yarns were produced in five levels of yarn count and two levels of twist. Total number of tested yarn is 170. For prediction of the yarn strength from fibre strength and process parameters the approach based on reduction of fibre strength by the multiplicative factors combined with linear regression is used. The prediction ability is characterized by predicted correlation coefficient.

Keywords: strength prediction, rotor yarns, cotton strength, yarn production technology.

1. Introduction

Yarn strength is one of the most important yarn parameters, which is used for yarn quality control and design of fabrics. It is usually characterized by the relative strength YS [N/tex]. Yarn strength has great influence on the weaving process and mechanical parameters of textile products. The main factors influencing YS are: type of fibres, yarn twist, yarn count, blending ratio and yarn production technology. This paper focuses in the influence of cotton fibre strength and process parameters of rotor yarn strength.

The theoretical predictive models of yarn strength 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. One simple model of this category is described by Pan [1, 2]. His model for yarn strength is based on the strength of fibrous bundle multiplied by utilization factors connected with bundle orientation (due twist) and bundle packing density in limit configuration. For prediction of bundle strength the well known Daniels result about normality of bundle strength distribution were used.

In this contribution it is shown that for prediction of rotor yarn the model based on the reduction of fibre strength by the multiplicative factors combined with linear regression is attractive.

2. Cotton Fiber Quality

It is generally accepted that rotor yarn strength depends significantly on the properties of fibres (fibre strength mainly), number of fibres in yarn cross section and twist factor. The predictive models are often based on the concept of reduction of fibre strength by the multiplicative factors (strength utilization factors) i.e. due to bundle creation, orientation, number of fibers bearing load and limit arrangement of fibers in yarns

Relative yarn strength σ_y is frequently expressed as product of relative fiber strength σ_f and correction factor ϕ_{fy} expressing utilization of fibers strength in yarn.

$$\sigma_y = \sigma_f \phi_{fy} = \sigma_b \phi_{by} = \sigma_f \phi_{fb} \phi_{by} . \quad (1)$$

Utilization of fibers strength in yarn is product of fiber strength utilization in bundle ϕ_{fb} and utilization of bundle strength in yarn ϕ_{by}. The σ_b denotes bundle strength and is approximately equal to STR. For this case is $\phi_{fb} = 1$. These factors are computed according to the various relations. One of simplest empiric relation for relative yarn strength σ_y was derived by Solovev (see [5]).

$$\varphi_{fy} = f_n f_l f_\alpha \psi . \qquad (2)$$

Factor f_n expresses influence of fiber number, f_l is the factor of fiber length influence, f_α is the factor of yarn twist influence and ψ is factor of technology influence. Neckar [5] proposed another products form. Utilization of bundle strength in yarn was derived by Pan [6]:

$$\varphi_{by} = V_f n_\beta . \qquad (3)$$

Volume ratio V_f and orientation factor n_β are correction factors. The random distribution of helical angles of fibers is used for computation of orientation factor n_β. Migration of fibers is negligible. Fiber volume fraction V_f is computed from equation

$$V_f\left[-\right] = 0,7(1 - 0,78\exp(-0,195 K_y)) , \quad (4)$$

where K_y a is twist coefficient described by relation

$$K_y\left[cm^{-1}tex^{1/2}\right] = 10^{-2}\sqrt{T\left[tex\right]}Z\left[m^{-1}\right] = \alpha\left[m^{-1}ktex^{1/2}\right]\sqrt{1000}/100 . \qquad (5)$$

In eqn. (5) is T yarn fineness, Z is yarn twist and α is a twist coefficient. Orientation factor η_β is function of helix angle β_D and yarn Poisson ratio η [6].

$$\eta_\beta = \frac{2\beta_D\left(1-\eta\right) + \left(1+\eta\right)\sin 2\beta_D}{4\beta_D} . \quad (6)$$

Helix angle β_D is defined according to the equation [6]:

$$\beta_D = \mathrm{arctg}\left(10^{-1} K_y \sqrt{\frac{4\pi}{\rho V_f}}\right) = $$
$$= \mathrm{arctg}\left(\alpha\sqrt{\frac{4\pi}{\rho V_f}} / \sqrt{10^3}\right), \qquad (7)$$

where α is a twist coefficient in [$m^{-1}ktex^{1/2}$], ρ is fiber density in [kgm^{-3}]. Poisson ratio η has the form [3]:

$$\eta = \frac{\sin^5\beta_D}{2\left(1-\cos^3\beta_D\right)\left(\frac{1}{2}\beta_D - \frac{1}{4}\sin 2\beta_D\right)} .(8)$$

3. Experimental Part

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 bundle strength STR. The yarn strength was measured on the Tensorapid tensile testing machine standard conditions. The yarn strength YS is a mean value from 50 measurements

4. Results and Discussion

The standard linear regression method was used for prediction of YS and estimation of influence of various factors on YS [4]. Prediction ability in linear regression model can be characterized by mean quadratic error of prediction (MEP) defined generally by relation

$$MEP = \sum_{i=1}^{n}\left(y_i - x_i^T b_{(i)}\right)^2 / n , \quad (9)$$

where $b_{(i)}$ is the estimate of regression model parameters when all points except the i-th (i-th row x_i of matrix X) are used. The statistics MEP uses a prediction $y_{pi} = x_i^T b_{(i)}$ which was constructed without information about the i-th point. Optimal model has minimal value of MEP. The MEP can be used for definition of the predicted multiple correlation coefficient PR

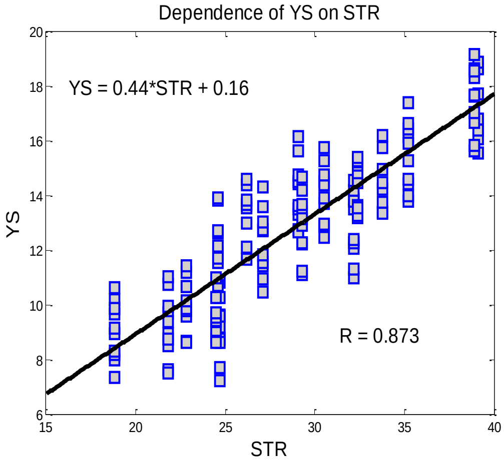
$$PR = \sqrt{1 - n * MEP / \sum_{i=1}^{n} (y_i - \bar{y})^2} . \quad (10)$$

The PR was used as criterion of predicitve performance. Values of PR for all kind of tested dependencies are given in the table I. Response variable is equal to y and explanatory variable is equal to x in the regression line model y = a+bx.

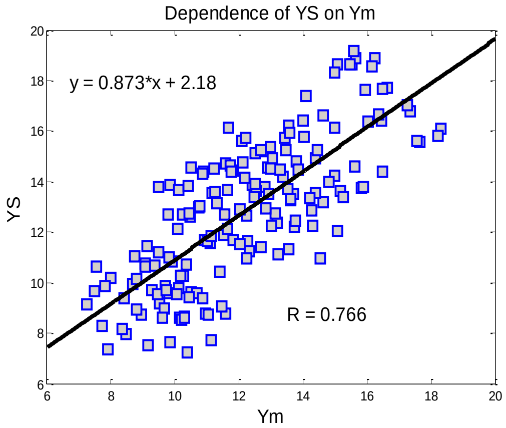
T a b l e I

response	explanatory	PR
YS	STR	0.870
YS	Ym	0.760
Yload	Fload	0.981
Yload	Floadk	0.977

Dependence between YS and STR is shown on the Picture 1-a.



a)



b)

Picture 1. Regression line for dependence of YS on (a) STR and (b). Ym

The very good prediction ability of STR supports the empiric evidence of importance of fibre strength in rotor spinning. The slope 0.44 is equal to the fibre utilization factor in the yarn. The predicted yarn strength Ym was computed from the modified eqn (1)

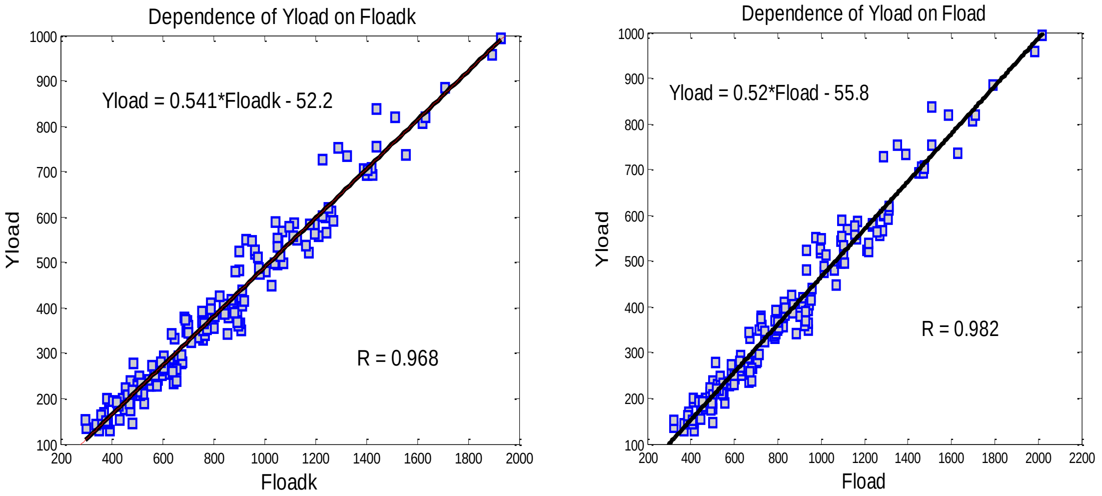
$$Ym = STR\ \phi_{by} , \quad (11)$$

where ϕ_b was computed from eqn (3). The dependence between measured yarn strength YS and predicted yarn strength Ym is shown on the fig. 1b. The prediction ability of this model is lower in comparison with prediction ability of STR only.

Relative yarn strength is in fact maximum load Yload = YS*Jem bearing by yarn divided by yarn finenness Jem. This value can be related to the load beared by all fibers Fload. After simple rearrangements we can compute this quantity as Fload = STR*Jem (it is maximum load of mean fibre in bundle divided by number of fibers in yarn cros section). Dependence of Yload on Fload is shown on the Picture 2-a. It is visible that this model has very excellent prediction ability. The factor Fload is composed from influence of fiber strength and yarn fineness. Yarn fineness is dependent on the twist level as well.

For including of orientation factor into predictive model the corrected load beared by all fibers Floadk = STR*Jem * ORI was computed.

The dependence of Yload on Floadk is shown on the Picture 2-b. It is visible that this model has similarly excellent prediction ability as a model without this correction (Picture 2-a).



Picture.2. Regression line for dependence of Yload on (a) Floadk and (b) Fload.

It is evident that this approach is very simple and has relatively good prediction capability. Important is that all models are clearly interpretable and are basically dimensionally homogeneous.

These results are limited due to practical range of technological parameters of yarn creation (yarn count, yarn twist).

The model shown on the Picture 2-b is probably one of the best from the point of view of simplicity and content of important fiber and technology factors. For practical prediction of YS is the best model shown on the fig. 1-a (explanatory is STR only). The slope is here equal to the fiber utilization factor.

These results are valid for rotor yarns only and probably will be not directly extendable for other spinning systems.

5. Conclusions

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.

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