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Fibre Number of the Cross-section of Ring-spun Yarn and its Strength Prediction Model

Abstract
A calculation equation of the fibre number on the cross-section of ring-spun yarn was deduced theoretically and verified with test data of 20 representative pure cotton ring spun yarns. The equation is practical and convenient to use by substituting the yarn count, yarn twist, and fibre decitex. On the basis of the above equation, a yarn strength predication model was established. The revising functions of yarn count and twist to yarn strength were deduced in practical tests of the strength of 20 commonly used ring-spun yarns, and were used to revise the yarn strength predication model obtained. Substituting the fibre decitex, fibre strength, yarn count, yarn twist and yarn strength can be precisely calculated with this model.

Key words: *ring-spun yarn, yarn incross section, fibre number, yarn twist, yarn strength predication model.*

Introduction

Strength is the foremost property of yarn which affects the efficiency of spinning, yarn finishing, weaving, fabric finishing, and wearability of clothes. The factors affecting yarn strength include the physical and mechanical properties of fibres constituting the yarn as well as the spinning method and technology. Therefore in the textile industry, yarn strength is the parameter of staple fibre yarns most extensively studied.

There are many studies on the relationship of raw cotton properties with yarn strength conducted through trial spinning with a single batch of cotton and statistical analyses. As early as 1974, Abdel S. El Sourady, *et al* selected several batches of cotton with only one property remarkably different, with others were very similar, in single batch trial spinning under the same technological conditions so as to obtain the influence of the one different cotton fibre property on the yarn strength [1].

There are many reports on the study of the relationship between cotton fibre properties and the strength of ring-spun yarn with multi-statistic analyses. The most prominent researchers are L.A. Fiori and G.L. Louis, who obtained many useful results in this area with single-factor correlation and multi-linear regression analyses [2 - 4].

Since 1980s, there has been the invention and extensive use of high volume instrument cotton fibre testers (HVI), with some reports employing an HVI in cotton fibre property testing. and the technology was almost always single batch spinning. But the data analyses method was also developed and many mathematics methods utilized, such as multi-linear and nonlinear regression, stepwise regression, grey theory, and neural network analyses *etc.* Moreover some practical conclusions were made [5 - 13].

In this paper, starting with the testing of fibre numbers in the cotton ring-spun yarn cross-section, and combining the fibre property, yarn count and twist, a yarn strength prediction model was established. For pure cotton yarn, strength prediction results and practical test data present close linear relations with high precision.

Deduction of fibre numbers in yarn cross-section

An assumption is made that the cross section of ring-spun yarn and fibre are circular, with the yarn cross-section area denoted as S_y in cm^2, the fibre cross-section area S_f in cm^2, the yarn count N_y in tex, the fibre decitex N_{df} in dtex, the yarn specific density ρ_y in g/cm^3, the fibre specific density ρ_f in g/cm^3, fibre numbers in yarn cross section n, the following equations are established.

$$\begin{aligned} N_y &= \rho_y \cdot S_y \cdot 1000 \\ N_{df} &= \rho_f \cdot S_f \cdot 10000 \end{aligned} \tag{1}$$

On assumption that the cross section of the yarn is full of fibres without any interspaces, the equation below is established.

$$n = \frac{S_y}{S_f} = 10 \cdot \frac{N_y}{N_{df}} \cdot \frac{\rho_f}{\rho_y} \tag{2}$$

Actually there are some interspaces among the fibres inside the yarn. Pan proposed a yarn structural parameter, namely, the fibre volume fraction factor V_f in %, i.e. the percentage of the constituting fibre volume over the whole yarn volume [14]. He provides the functions of V_f and T_e in twists/inch as follows.

$$V_f = 0.7\cdot(1 - 0.78\cdot e^{-0.195T_e}) \tag{3}$$

Converting T_e in twists/inch into T_t in twists/10 cm, the above equation becomes ***Equation 4***.

$$V_f = 0.7\cdot(1 - 0.78\cdot e^{-0.195T_t}) \tag{4}$$

Assuming the yarn mass is G in g, that is the fibre mass in the yarn. the whole volume of yarn is denoted as V_y in cm^3 and the constituting fibre volume as V_{fb} in cm^3, therefore the fibre volume fraction factor V_f is revealed as ***Equation 5***.

$$V_f = \frac{V_{fb}}{V_y} = \frac{G/\rho_f}{G/\rho_y} = \frac{\rho_y}{\rho_f} \tag{5}$$

The fibre numbers in the yarn cross section n_6 is educed with the combination of ***Equations 2, 4 and 5*** as follows.

$$n_6 = 10 \cdot \frac{N_y}{N_{df}} \cdot \frac{1}{0.7\cdot(1 - 0.78\cdot e^{-0.0495T_t})} \tag{6}$$

Table 1. Experimental data and results.

Yarn number	N_y, tex	T_t, twists·(10 cm)$^{-1}$	n_6	n_7	n_s	F_s, cN	F_r, cN.tex^{-1}	F_y, cN
1	5.80	132.4	45	43	41	123	21.2	129
2	7.20	128.2	56	42	46	154	21.4	155
3	7.30	128.7	57	43	45	160	21.9	157
4	9.70	127.6	76	57	48	173	17.8	200
5	10.8	121.8	84	64	58	162	15.0	219
6	11.7	111.1	91	69	80	205	17.5	236
7	12.8	98.80	100	76	77	211	16.5	256
8	14.5	100.4	113	86	93	236	16.3	285
9	14.6	102.0	114	86	91	238	16.3	286
10	18.2	82.1	143	108	125	291	16.0	350
11	19.5	79.7	154	116	105	324	16.6	372
12	24.2	77.5	191	144	146	396	16.4	447
13	24.3	76.8	192	145	159	400	16.5	449
14	27.8	76.2	220	166	185	419	15.1	504
15	29.2	69.5	233	176	208	432	14.8	531
16	34.3	67.6	274	207	210	497	14.5	610
17	36.4	63.8	293	221	258	578	15.9	647
18	48.6	55.0	398	300	326	622	12.8	845
19	53.0	54.0	436	328	345	832	15.7	913
20	58.3	52.0	482	363	364	996	17.1	997

Correction of fibre numbers in yarn cross section

Twenty kinds of pure cotton ring-spun yarns of different yarn count N_y and twist T_t were collected from Jiangsu Xinguang Textile Co. Ltd., the yarn count and twist of which are listed in ***Table 1***.

Text book [15] gives the cotton fibre decitex ranges within 1.67 ~ 2 dtex, and we take the mean value of 1.835 dtex, the yarn count and twist in ***Table 1*** to calculate fibre numbers in the yarn cross section n_6 with ***Equation 6***, the results of which are also listed in ***Table 1***. The practically tested fibre numbers in the yarn cross section n_s for the 20 yarns are also shown in ***Table 1*** for comparison.

There are large discrepancy between the practically tested fibre number n_s and that calculated with ***Equation 6***, attributing to the cotton fibre cross section is ellipse with lumen, far different from our assumption of it being normal circular. A correction factor for pure cotton ring-spun yarn (amount to 0.7543) was obtained based on analyses of the practically tested number and data provided by more literature [16, 17]. The ***Equation 6*** corrected is converted into ***Equation 7*** as below.

$$n_7 = \frac{N_y}{N_{df}} \cdot \frac{10.7757}{(1 - 0.78 \cdot e^{-0.0495 T_t})} \qquad (7)$$

Fibre numbers in the yarn cross section n_7 were calculated with ***Equation 7***, the results of which are also listed in ***Table 1***. Taking the calculated number n_7 as an independent variable and the tested number n_s as a dependent variable, we obtained the following linear regression ***Equation***.

$$n_s = 1.0618 \cdot n_7 - 0.2708 \qquad (8)$$
$$R^2 = 0.9877$$

Equation 8 reveals that n_s and n_7 have a high correlation coefficient with the determination ratio - as high as 0.9877. Therefore ***Equation 7*** can predict fibre numbers in the yarn cross section with high precision.

Establishment of strength prediction model for ring-spun yarn

The method of establishing a Strength Prediction Model for Ring-spun Yarn is to multiply the fibre strength by fibre numbers in the yarn cross section *n*, and then multiply it by the correction functions of the yarn count and twist to the yarn strength.

Experimental correction function of yarn twist to yarn strength

Table 1 lists the practically tested yarn strength F_s in cN and relative strength F_r in cN/tex. Using the relative strength F_r and yarn twist T_t, the correction function of F_{t1} is obtained through nonlinear regression and value approaching methods as follows:

$$F_{t1} = 0.00093 \cdot T_t^{0.8654} \qquad (9)$$

It is well known that within the range of critical twist, the yarn strength increases with the twist accretion. Thus ***Equation 9*** is reasonable. Meanwhile observing the practically tested yarn strength F_s and yarn twist T_t, there is an inverse trend between the two parameters, and another correction function of F_{t2} is obtained with the same method i.e. ***Equation 9***.

$$F_{t2} = 11825 \cdot T_t^{-0.8941} \qquad (10)$$

Equation 10 reveals that the yarn strength decreases with an increases in T_t , the reason for which is that when T_t increases gradually, the yarn surface helix angle increases, and the interior stress in the yarn also improves, subsequently inducing a decrease in the stretch bearing ability of fibres in the yarn.

Experimental correction function of yarn count to yarn strength

Using the yarn relative strength F_r and yarn count N_y in ***Table 1***, another correction function, ***Equation 11***, is obtained with the same method as for ***Equations 9 and 10***.

$$F_{N_y} = 0.138352 \cdot N_y^{-0.1526} \qquad (11)$$

Equation 11 revealed that the yarn relative strength decreases with an increase in N_y as low N_y yarns are generally made of a fraction of long-staple cotton or high quality cotton, most of which are comed, whereas high N_y yarn is generally made of poor quality cotton or sometimes blended with a fraction of reusable cotton waste, most of which is carded.

Yarn strength prediction model

Combining ***Equations 7***, ***9***, ***10*** and ***11***, the final yarn strength prediction model is deduced as follows.

$$F_y = n_7 \cdot F_f \cdot F_{t1} \cdot F_{t2} \cdot F_{N_y} =$$
$$= 16.1988 \cdot \frac{F_f}{N_{df}} \cdot \frac{T_t^{-0.0287} \cdot N_y^{0.8474}}{(1 - 0.78 \cdot e^{-0.0495 T_t})} \qquad (12)$$

Where F_f in cN is the cotton fibre strength. Text book [15] gives the ranges of cotton fibre strength as 3 ~ 4.5 cN and cotton decitex N_{df} in dtex as 1.67 ~ 2 dtex. Substituting F_f in the model with the mean value (3.75 cN), N_{df} with the mean value (1.835 dtex), and N_y and T_t in ***Equation 12*** with data in ***Ta-***

ble 1, the yarn strength F_y in cN predicted was calculated and is listed in ***Table 1***.

Taking the yarn strength F_y predicted as an independent variable, the strength tested F_s as an dependent variable, we obtained the following linear regression equation.

$$F_s = 0.8973 \cdot F_y - 12.866 \qquad (13)$$
$$R^2 = 0.9672$$

Regression ***Equation 13*** reveals that the prediction precision of the pure cotton ring-spun yarn strength prediction model is very high, with a determination ratio as high as 0.9672.

Conclusions

Considering only a few of the main factors, such as the fibre decitex, yarn count and yarn twist, with the ring-spun yarn cross section fibre number calculation equation obtained (7), the fibre number in the yarn cross section can be calculation precisely.

The fibre strength multiplied by the yarn cross section fibre number and combined with the correction function of the yarn count and twist to the yarn strength, a ring-spun yarn strength prediction model is deduced. As for application of the model, by only putting the fibre decitex, fibre strength, yarn count and yarn twist into the model using simple software, a predicted yarn strength value can be obtained. The pure cotton ring-spun yarn strength prediction model shows high precision for the determination ratio of regression Equation as high as 0.9672 and is easy to use. This model may provide some reference for cotton blending and yarn quality control in textile mills.

The yarn cross section fibre number calculation equation and yarn strength prediction model have to undergo further testing, verification and analysis for other fibre yarns.

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References

1. El Sourady AS, Worley Jr. S, Stith LS. The Relative Contribution of Fiber Properties to Variations in Yarn Strength in Upland Cotton, Groddypium hidrsutum. *Textile Research Journal* 1974; 44, 4: 301-305.
2. Fiori LA, Brown JJ, Sands JE. Effect of Cotton Fiber Strength on Single Yarn Properties and on Processing Behavior. *Textile Research Journal* 1954; 24, 6: 503-507.
3. Luis GL, Fiori LA, Sands JE. Blending Cotton Differing in Fiber Bundle Break Elongation. Part 1. Effect on the Properties of Combed Single Yarns. *Textile Research Journal* 1961; 31, 1: 43-51.
4. Luis GL, Fiori LA. Relationships Among Fiber Properties, Yarn Properties and End Breakage: A Progress Report on Medium Staple Cottons. *Textile Bulletin* 1966; 92, 5: 45-54.
5. Tan Hongluo. Calculate Lea Breaking Strength with Nerve-net System. *Sandong Textile Science & Technology* 2004; 2: 51-53.
6. Zhang Lijuan, Meng Yali, Chen Binglin. Model of spinning yarn quality. *Journal of Textile Research* 2005; 5: 122-124.
7. Daiping L, Jianhua Y. Research of Forecasting Fabric Strength by Multi-factors Relative Index Method. *Cotton Textile Technology* 2006; 10: 19-21.
8. Haitao H, Chunping X. Predication of yarn tenacity by use of AFIS and artificial neural networks. *Shanghai Textile Science & Technology* 2003; 4: 61-63.
9. Xiaofeng L, Jianjun W, Jie M, Yi Z. Gray Analysis for Correlation between Yarn Strength and of Cotton Fiber Quality. *Journal of Applied Sciences* 2007; 1: 100-102.
10. El Mogahzy YE, Broughton Jr. RM. Diagnostic Procedures for Multicollinearity Between HVI Cotton Fiber Properties. *Textile Research Journal* 1989; 59, 8: 440-447.
11. Yehia E. El Mogahzy, Roy M. Broughton Jr. and W.K.Lynch. A Statistical Approach for Determining the Technological Value of Cotton Using HVI Fiber Properties. *Textile Research Journal* 1990; 60, 9: 495-500.
12. Chaohui Z, Mei L. Relationship between raw cotton property and yarn strength. *Journal of Textile Research* 2005; 1: 52-53.
13. Subramanian TA. A Solution for Estimating Cotton Yarn Tenacity. *International Textile Bulletin* 2004; 4: 36-38.
14. Pan N. Development of A Constitutive Theory for Short Fiber Yarns: Mechanics of Staple Yarn Without Slippage Effect. *Textile Res. J.* 1992; 62: 749-765.
15. Yixin Z, Jinzhong Z, Chuangang Y. *Textile Material*. Ed. China Textile Press, 2005: 11.
16. Rongqing L. Discussion and Application of the Fiber Root Number Calculation Formula in Fine Yarn Section. *Research Journal of Zejiang Textile Garment Institute* 2008; 12, 41: 14-18.
17. Guangsong Y, Jinzhong Z, Chongwen Y. Unevenness prediction for yarns by fiber array parameter. *Journal of Textile Research* 2008; 12: 25-29.

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