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 predicaption 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 prediction 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 predicaption 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 cotton properties and 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 mathematic 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 and analysing 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 $N_d$ in dtex, the yarn specific density $\rho_y$ in g/cm$^3$, the fibre specific density $\rho_f$ in g/cm$^3$, fibre numbers in yarn cross-section $n$, the following equations are established.

$$ N_y = \rho_y \cdot S_y \cdot 1000 $$

$$ N_d = \rho_f \cdot S_f \cdot 10000 $$

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

$$ n = \frac{S_y}{S_f} = 10 \cdot \frac{N_y}{N_d} \cdot \frac{\rho_f}{\rho_y} $$

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.

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

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

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

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.

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

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

$$ n_y = 10 \cdot \frac{N_y}{N_d} \cdot \frac{1}{0.7 \cdot (1 - 0.78 \cdot e^{-0.195T_e})} $$
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 \( n_y \) with Equation 6, the results of which are also listed in Table 1. The practically tested fibre numbers in the yarn cross section \( n_r \) for the 20 yarns are also shown in Table 1 for comparison.

There are large discrepancy between the practically tested fibre number \( n_r \) 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.

\[
n_r = \frac{n_y}{\left(1 - 0.78 \cdot e^{-0.0057y}\right)} \tag{7}
\]

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

\[
n_r = 1.0618 - n_y - 0.2708 \quad R^2 = 0.9877 \tag{8}
\]

Equation 8 reveals that \( n_r \) and \( n_y \) 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 \( n_r \), and then multiply it by the correction function 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 \( F_y \) 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 \( F_{12} \) is obtained through nonlinear regression and value approaching methods as follows:

\[
F_{12} = 0.00093 \cdot T_t^{0.8654} \tag{9}
\]

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 \( F_y \) and yarn twist \( T_t \), there is an inverse trend between the two parameters, and another correction function of \( F_{12} \) is obtained with the same method i.e. Equation 9.

\[
F_{12} = 11825 \cdot T_t^{-0.8641} \tag{10}
\]

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.

\[
F_{N_y} = 0.138352 \cdot N_y^{-0.1526} \tag{11}
\]

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 combed, 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.

\[
F_y = n_r \cdot F_r \cdot F_{12} \cdot F_{N_y} = 16.1988 \cdot F_r \cdot T_t^{0.0287} \cdot N_y^{0.864} \tag{12}
\]

Where \( F_r \) is the cotton fibre strength. Text book [15] gives the ranges of cotton fibre strength as 3 ~ 4.5 cN and cotton decitex \( N_d \) in dtex as 1.67 ~ 2 dtex. Substituting \( F_r \) in the model with the mean value (3.75 cN), \( N_d \) with the mean value (1.835 dtex), and \( N_y \) and \( T_t \) in Equation 12 with data in Table 1.

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**Table 1. Experimental data and results.**

<table>
<thead>
<tr>
<th>Yarn number</th>
<th>( N_y ) tex</th>
<th>( T_t ) twists/(10 cm)(^{-1} )</th>
<th>( n_y )</th>
<th>( n_r )</th>
<th>( F_y ) cN</th>
<th>( F_r ) cN/tex(^{-1} )</th>
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ble 1, the yarn strength $F_s$ in cN predicted was calculated and is listed in Table 1. Taking the yarn strength $F_s$ predicted as an independent variable, the strength tested $F_y$ as a dependent variable, we obtained the following linear regression equation.

$$F_s = 0.8973F_y - 12.866$$

$$R^2 = 0.9672$$

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**


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