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Comprehensive quality evaluation of jutecell/cotton blended yarn based on principal component analysis

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In order to evaluate the comprehensive quality of jutecell/cotton (J/C) blended yarn more accurately and conveniently, six kinds of jutecell/cotton blended yarn with different blending ratios have been designed with linear density 20tex. The comprehensive quality indices of these six yarns have been assessed with principal component analysis including hairiness indices (1mm) and (2mm), yarn evenness, snick(-50%), slub(+50%), nep (+200%), breaking strength and breaking elongation. The rank, in terms of quality, of J/C yarns with different blending ratio is 80/20 > 100/0 > 40/60 > 60/40 > 20/80 > 0/100 whose syntheses scores are -1.67, -0.98, -0.77, -0.02, 0.76, 2.68 respectively. The blending ratio of 80/20 J/C yarns gets the highest rank in terms of quality which is due to the excellent characteristics of two kinds of fibre. The findings provide practical guidance for designing the blending ratio of jutecell/cotton blended yarn correctly.

Keywords: Blending yarn, Blending ratio, Cotton, Jutecell fibre, Principal component analysis, Yarn quality

Jutecell fibre is a new type of regenerated cellulose fibre, which is produced from jute and kenaf through a special process, as developed by Shandong Hailong Co.Ltd[1]. Jutecell fibre is biocompatible, designer, environment-friendly, having the application in healthcare sector, fashionable garment sector, etc. During spinning, controlling of yarn quality is a vital issue. Currently, the research on jutecell fibre is mainly focused on its blending with other commonly used fibre, especially in the development of yarn spinning process but the research on blended yarn quality is found scanty. In this study the quality of different J/C blended yarns has been evaluated in terms of hairiness index, evenness, snick (-50%), slub (+50%), nep (+200%), breaking strength and breaking elongation using the principal component analysis method. The traditional way of evaluation of yarn quality isolates each index, so that the interaction between these indices is neglected [2]. In addition, as the evaluation indices increase, the yarn quality evaluation becomes tedious and less accurate. The application of principal component analysis solves the above disadvantage appropriately. The method includes the existing quality index, finding out the correlation among the indices and the main factor, and defining it as a main index to evaluate the quality of the yarn in order to evaluate the yarn quality easily and accurately.

Experimental

The digital spinning machines (including combing machine, drawing frame, roving frame) developed by Tianjin Polytechnic University were used to spin six kinds of J/C blended yarns (20 tex) such as 0/100, 20/80, 40/60, 60/40, 80/20, 100/0. Then the hairiness index, evenness, snick, slub, nep, breaking strength and breaking elongation of the blended yarns were tested on Type YG172 hairiness tester, USTER evenness tester ME100, YG061F type electronic single yarn strength tester.

The principal component analysis is a multivariate statistical method of dimensionality reduction which converts multiple indices to a handful of comprehensive indices with the loss of few sample information[3]. In this study, some influential indices are selected from the multitudinous indices correlating to the quality of the blended yarn, and regularity in the internal variables of the blended yarn. Hence, the evaluation was simplified and the analysis efficiency was improved. Finally, the blend ratio giving the optimum result was determined.

Results and Discussion

The collected indicators for quality assessment are hairiness index (1mm) (X_1) and hairiness index (2mm) (X_2), reflecting the hairiness distribution on yarn body which directly affect the smooth processing of yarn. Evenness (X_3) includes the yarn strength unevenness and twist unevenness which affect the breakage rate, thus reflecting the yarn actual inner quality[4]. The

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Table 1—Comprehensive evaluation indices of blended yarns

Blend ratio (J/C)	Hairiness index (1mm) (X_1)	Hairiness index (2mm) (X_2)	Evenness CV(%) (X_3)	Snick (-50%) (X_4)	Slub (+50%) (X_5)	Nep (+200%) (X_6)	Breaking strength CV(%) (X_7)	Breaking elongation CV(%) (X_8)
0/100	128.34	22.66	18.00	64.0	379.0	322.0	9.6	10.05
20/80	117.08	19.90	16.42	13.3	250.7	210.7	8.34	11.74
40/60	97.14	13.62	15.96	36.0	122.0	232.0	9.47	13.03
60/40	105.44	18.02	16.00	16.0	230.0	204.0	11.88	11.93
80/20	97.98	17.76	15.06	16.0	97.3	120.0	12.53	18.39
100/0	101.76	15.48	14.38	90.0	130.0	140.0	13.62	12.86

snick(-50%) is defined as (X_4) and slub (+50%) defined as (X_5), mainly reflecting the yarn appearance quality which has a great influence on the fabric dyeing and appearance quality in subsequence. The nep (+200%) is defined as (X_6), breaking strength CV defined as (X_7), and breaking elongation CV defined as (X_8). Table 1 shows the specific test results.

The above indicators have different dimensions which lead to a great influence on the analysis results. Firstly, mathematical statistics method is applied to make the above test data standard and to eliminate the influence of the dimension. Standardized formula[5] is shown below:

$$Yij = \frac{(Xij - \mu)}{\sigma} \quad \ldots (1)$$

where Yij is the standardized values; i, the index number (i=1,2,3,4,5,6,7,8); j, the yarn sample number (j=1,2,3,4,5,6); μ, the average of six sample indicators; andσ, the standard deviation of six samples. Standardized values of quality indicators are expressed by the standardized matrix S, as shown below:

$$S=\begin{bmatrix} 1.653 & 1.490 & 1.638 & 0.787 & 1.662 & 1.629 & -0.633 & -1.036 \\ 0.740 & 0.625 & 0.363 & -0.823 & 0.461 & 0.082 & -1.243 & -0.443 \\ -0.877 & -1.344 & -0.008 & -0.102 & -0.744 & 0.378 & -0.696 & 0.011 \\ -0.204 & 0.036 & 0.024 & -0.738 & 0.267 & -0.011 & 0.472 & -0.376 \\ -0.809 & -0.046 & -0.734 & -0.738 & -0.976 & -1.178 & 0.786 & 1.894 \\ -0.503 & -0.761 & -1.283 & 1.613 & -0.669 & -0.900 & 1.314 & -0.049 \end{bmatrix}$$

The data of Table 1, writen as matrix X, are used to calculate the correlation matrix R among the quality index[6] aplying the following formula:

$$R = \frac{X_T X}{n} \quad \ldots (2)$$

where X_T is the transposed matrix of matrix X; and n = 8. Then correlation coefficient matrix R is calculated as shown below:

Table 2—Matrix eigenvalue and its contribution rate

Principal component number	Eigen value	Contribution %	Cumulative contribution rate, %
1	5.333	66.667	66.667
2	1.365	17.060	83.728
3	0.851	10.638	94.365
4	0.253	3.166	97.531
5	0.197	2.469	100.00
6	0.000	0.000	100.00
7	0.000	0.000	100.00
8	0.000	0.000	100.00

$$R = \begin{bmatrix} 1.000 & 0.904 & 0.844 & 0.144 & 0.963 & 0.766 & -0.550 & -0.696 \\ 0.904 & 1.000 & 0.738 & -0.085 & 0.866 & 0.542 & -0.361 & -0.380 \\ 0.844 & 0.738 & 1.000 & -0.111 & 0.895 & 0.943 & -0.747 & -0.639 \\ 0.144 & -0.085 & -0.111 & 1.000 & 0.090 & 0.120 & 0.358 & -0.330 \\ 0.963 & 0.866 & 0.895 & 0.090 & 1.000 & 0.842 & -0.526 & -0.770 \\ 0.766 & 0.542 & 0.943 & 0.120 & 0.842 & 1.000 & -0.702 & -0.781 \\ -0.550 & -0.361 & -0.747 & 0.358 & -0.526 & -0.702 & 1.000 & 0.489 \\ -0.696 & -0.380 & -0.639 & -0.330 & -0.770 & -0.781 & 0.489 & 1.000 \end{bmatrix}$$

The correlation coefficient of >0.7 between two variables indicates a good correlation. On the contrary, variables can be thought independent from each other when correlation coefficient is less than 0.3. However, the correlation coefficient matrix (R) does not indicate certain correlation of each variable with others. This will undoubtedly make comprehensive quality evaluation work of the blended yarn more trivial, and show the necessity of principal component analysis to judge comprehensive quality of yarn.

The eigenvalues of the matrix (R) has been worked out by correlation coefficient matrix (R), and then, contribution rate of each principal component is resolved using the following formula:

$$\text{Variance contribution} = \frac{\lambda_i}{\sum_{i=1}^{8} \lambda_i} \quad \ldots (3)$$

The calculation results are shown in Table 2. The main components are usually extracted until the cumulative contribution rate reaches to more than 85%, and the first three principal components of the cumulative contribution value is 94.365% (Table 2).

Hence, it can be thought that the first three principal components can reflect the performance of the yarn relatively more accurately. The characteristic value of the first three principal components is extracted to calculate the corresponding eigenvectors (e) respectively, as shown below:

e1=(0.410, 0.344, 0.414, 0.017, 0.420, 0.398, -0.304, -0.339)
e2=(0.095, -0.073, -0.150, 0.827, 0.085, 0.046, 0.414, -0.314)
e3=(0.274, 0.648, -0.052, -0.075, 0.196, -0.316, 0.464, 0.378)

The expressions of the first three principal components are displayed below:

$$Y_1=0.410X_1+0.344X_2+0.414X_3+0.016X_4+0.420X_5+0.398X_6-0.304X_7-0.339X_8 \quad \ldots (4)$$

$$Y_2=0.095X_1-0.073X_2-0.150X_3+0.827X_4+0.085X_5+0.046X_6+0.414X_7-0.314X_8 \quad \ldots (5)$$

$$Y_3=0.274X_1+0.648X_2-0.052X_3-0.075X_4+.0.196X_5-0.316X_6+0.464X_7+0.378X_8 \quad \ldots (6)$$

Comprehensive expression of the first three principal component score is summarized through Y_1, Y_2, Y_3 as shown below:

$$Y=0.667Y_1+0.171Y_2+0.106Y_3 \quad \ldots (7)$$

Standardized matrix S is substituted in Y_1, Y_2, Y_3 to get the score matrix C, as shown below:

$$C=\begin{bmatrix} 3.77 & 0.73 & 0.40 \\ 1.41 & -1.04 & -0.03 \\ -0.78 & -0.41 & -1.69 \\ 0.02 & -0.30 & -0.15 \\ -2.42 & -0.98 & 1.10 \\ -2.00 & 2.00 & 0.06 \end{bmatrix}$$

Then matrix C is substituted in composite scores expressions to get the integrated situation of the first three principal components (Table 3).

Whether the scores in Table 3 are plus or minus, they only represent position relations between the quality of each blended yarn and the average quality of them. The average level of six kinds of blended yarn is defined as zero, which is the result of data standardization. It can clearly reflect the comprehensive situation of the quality index of these six kinds of blended yarn (Table 3). When the values are positive, it indicates that the comprehensive index is higher than the average level, on the other hand, when the values are negative, it is lower than the average level. It is obvious that the lower the indices values, the better is yarn quality.

Table 3 —Statistics of principal component scores

Blending ratio, % (J/C)	First principal component score	Second principal component score	Third principal component score	Composite scores
0/100	3.77	0.73	0.40	2.68
20/80	1.41	-1.04	-0.03	0.76
40/60	-0.78	-0.41	-1.69	-0.77
60/40	0.02	-0.30	0.15	-0.02
80/20	-2.42	-0.98	1.10	-1.67
100/0	-2.00	2.00	0.06	-0.98

It can be observed from the composite scores that when the content of jutecell fibre in the blended yarn is lower than 20%, the overall quality of blended yarn deviates from the average level towards higher. When jutecell fibre content is further increased to 60%, the yarn quality is close to the average level, and 80% jutecell content achieves the best quality.

The inferences drawn by the study are given below:

(i) The addition of jutecell fibre reduces the blended yarn hairiness. When the jutecell fibre content is 40-50%, the yarn hairiness in every length is lower than that in other blend ratio .

(ii) There is linear relationship between the CV of evenness variation coefficient and the blended ratio. The higher the jutecell content, the better is the yarn evenness. The increase in jutecell content reduces snick, slug and nep indices, and hence improves the quality of yarn.

(iii) Jutecell/cotton blended yarn shows the best comprehensive quality when the blend ratio is 80/20. The quality order of six kinds of J/C blended yarn is 80 /20>100/0>40/60>60/40>20/80>0/100.

(iv) The results provide much practical guidance for designing the blending ratio of J/C blended yarn correctly.

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