Bending Vibrational Properties of Polyester Shingosen Fabrics

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Abstract

Bending vibrational properties of polyester Shingosen fabrics were measured and analyzed by using the new mechanical parameters of bending vibration. It was shown that bending vibration of New Silky, Rayon Touch, and Peach Face type Shingosen fabrics continued longer than New Worsted type in the conventional classification, however, shorter than natural silk filament fabrics. In the classification of production characteristics, yarn-processing type Shingosen fabrics damped sooner than fabric-finishing and fiber-production type in bending vibration. In the classification of fiber characteristics, bending vibration of contractile fibers type Shingosen fabrics continued the longest and ultra-fine fibers type the shortest. Those features of Shingosen fabrics in bending vibrational properties became more distinct by discriminant analysis using the parameters of bending vibration as variables.

Keywords: bending vibration, Shingosen, mechanical parameters, dynamic drapeability

1. Introduction

The family of new Japanese polyester-fiber-based woven fabrics, referred to as Shingosen, is characterized by particular fiber forms, yarns and fabric constructions, demanding carefully specified finishing procedures. Their handle and mechanical properties have already been investigated by the objective-evaluation method developed by Kawabata and Niwa using the KES system. The fabrics were found, in general, to have high FUKURAMI (fullness and softness) and those of bending rigidity (B) and hysteresis in bending moment (2HB) showed smaller values like those of women’s fine dress fabrics. However, there has been no investigation concerning bending vibrational properties, which is mostly related to dynamic drapeability of fabrics, hence the present investigation.

Bending vibrational properties of fabrics have been studied recently by the authors, and new mechanical parameters which represent those properties well were proposed. In this paper, those parameters of polyester-fiber Shingosen fabrics are measured and attempts are made to classify the Shingosen fabrics into types based upon the manufacturing conditions required for their production by those parameters.

2. Experimental Procedure

2.1 Samples

The polyester-fiber poly(ethylene terephthalate) Shingosen fabrics examined were produced recently (1991-1994) by Japanese manufactures such as Kanebo, Toray, Mitsubishi Rayon, Kuraray, Asahi Kasei (Chemicals), Teijin, Toyobo, and Unitika as shown in Table 1. The classification of these fabrics was decided according to the specification of the manufactures, such as, New Silky, New Worsted, Rayon (Dry) Touch, and Peach Face (Powder Touch) types. These materials are used mainly for fine women’s wear, primarily blouses, one-piece dresses, and dress shirts.

2.2 Measurements

Bending vibrational properties of fabrics were measured by KES-LABO-MODEL-F2 bending vibration tester. Schematic model of the apparatus is shown in Fig.1. A sample sized 1 cm in width and 3 cm in length is bent and held by two plates, one of which vibrates with a pendulum. Initial amplitude of the vibration was constant at 1 mm. Mechanical parameters of bending property, B and 2HB were measured by KES bending tester. All the measurements were carried out at the conditions of temperature 293 ± 1 K and 65 ± 5% relative humidity.

3. Results

3.1 Four Parameters of Bending Vibration for Conventional Classification

A representative example of bending vibrational property of fabric is shown in Fig.2 with four parameters. \( \Delta d_1 \) is amplitude decrease in the 1st step of the bending vibration and dominated mainly by inter-yarn friction and/or fabric structure. \( S_1 \) is vibration duration period of the 1st step. \( \Delta d_2 \) is amplitude decrease in the 2nd step and dominated mainly by inter-fiber friction and/or yarn structure. \( S_2 \) is vibration duration period of the total steps (1st step + 2nd step). Bending vibration of almost all the samples examined here damped approximately linearly with time within \( S_2 \), having two slopes of the amplitude decrease as shown in Fig.2. It is shown

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Table 1  Polyester-fibre Shingosen-fabric Features

| Shingosen Types | Number of Samples | Weave Density( /m) | Yarn Density(tex) | Thickness* (mm) | Mass (g/m²) |
|----------------|-------------------|-------------------|------------------|----------------|-------------|
|                 |                   | Ends/m | Picks/m | Warp | Weft |                   |              |              |
| New Silky       | 31                | 4300-1100 | 2800-5200 | 5.2-21.0 | 4.2-21.8 | 0.21-0.76 | 45-214 |
| New Worsted     | 21                | 3600-7600 | 2400-4200 | 4.3-27.0 | 8.6-25.4 | 0.29-1.12 | 91-324 |
| Rayon Touch     | 24                | 3800-9800 | 2300-4300 | 4.4-26.3 | 7.2-30.0 | 0.24-0.65 | 98-209 |
| Peach Face      | 22                | 5900-10300 | 3300-6000 | 4.3-15.4 | 4.8-18.4 | 0.32-0.65 | 98-166 |

*Thickness is measured under 0.5 gf/cm².

Results of Δd² are shown in Fig.4 for four conventional groups of Shingosen fabrics. These values are averaged values of both warp and weft bending vibration. A result of natural silk filament weave, which is a representative one, is also shown in Fig.3. The silk fabric is made of twistless filament yarns in both warp and weft and called "Habutae" used for women's blouses. New Silky, Rayon Touch and Peach Face type Shingosen fabrics showed small values and New Worsted type showed relatively large values. The significance level between each group is 5 % between New Silky and New Worsted, Rayon Touch and New Worsted, 1 % between Peach Face and New Worsted. However, almost all Shingosen fabrics showed larger values than the natural silk fabric. This means that bending vibration of Shingosen fabrics with New Silky, Rayon Touch, and Peach Face types damps smaller than New Worsted type, however, larger than natural silk fabrics. Inter-yarn friction in those fabrics may be larger than silk fabrics, even in the case of New Silky type Shingosen fabrics.

Fig.1 Schematic model of the apparatus of bending vibration of fabrics.

Fig.2 A representative example of bending vibration of fabric and four mechanical parameters.

recently that those parameters are related to dynamic movement of flared skirt evaluated subjectively in the point of beautiful appearance. \(^{10}\)

Results of Δd1 are shown in Fig.3 for four conventional groups of Shingosen fabrics. A result of silk filament weave is also shown in Fig.4. Although the difference between each group is smaller than Δd1, the similar tendency is shown. The significance level is 10 % between New Silky and New Worsted, Rayon Touch and New Worsted. Inter-fiber friction may be large in New Worsted and small in New Silky, Rayon Touch, and Peach.
Face type fabrics and extremely small in natural silk fabrics.

Results of S1 are shown in Fig. 5 for four conventional groups of Shingosen fabrics, together with a silk filament weave. New Silky, Rayon Touch, and Peach Face types showed larger values than New Worsted type. The significance level is as same as the results of $\Delta d1$. This means that bending vibration of 1st step, which damps mainly by the inter-yarn friction, continues longer for the former types and shorter for the latter type. Silk fabrics continue the longest.

Results of S2 are shown in Fig.6 for four conventional groups of Shingosen fabrics, together with a silk filament weave. Although the difference between each group is smaller than S1, the similar tendency is shown. The significance level is as same as the results of $\Delta d2$.

3.2 Four Parameters of Bending Vibration for the Other Classification

The Shingosen fabrics were produced by combining various techniques$^{[2,11]}$. Fibers were mixed which possessed different contractile and non-contractile properties, cross-section geometries, thick and thin portions, hollow and solid cores, and smooth and grooved surfaces.

The yarns similarly were textured by different processes, i.e. false-twisting and differential shrinkage, capitalizing on the distribution of fiber fineness. Fabric constructions and finishing procedures were also varied. The fabrics were classified into three types depending upon the features of the fibers, yarns or finished fabrics$^{[12]}$, namely:

(a) fabric-finishing: surface raising;
(b) yarn-processing: false-twist texturing, complex yarn-texturing; and,
(c) fiber-production: different contractile and non-contractile properties, cross-section geometries, thick and thin portions, hollow and solid cores, smooth and grooved surfaces, ultra-fine diameters.

The classification was carried out by the opinions of engineers who were working in the finishing companies of Singosen fabrics. They classified the fabrics by a principal technique if two or more techniques were included.

The numbers of samples in these types are shown in Table 2. The four parameters of bending vibration are shown in Fig.7. Fabric-finishing and fiber-production type Shingosen fabrics showed smaller values of $\Delta d1$, and larger values of S1 than yarn-processing type (significance level: 5%). This means that bending vibration of fabric-finishing and fiber-production types continues longer than yarn-processing type and that inter-yarn friction in the former fabrics is smaller. Results of $\Delta d2$ and S2 showed the similar tendency with $\Delta d1$ and S1, respectively.

Yarn-processing type Shingosen fabrics are considered to have larger inter-fiber and inter-yarn frictions in the bending vibration.

The Shingosen fabrics of the fiber-production type were further subdivided into three groups depending upon the production technique$^{[12]}$ as follows:

(d) contractile fibers: mixed fibers of contractile and non-contractile types;
(e) irregular fibers: irregular fiber-cross-section geometries, core characteristics, and surface features; and,
(f) ultra-fine fibers: extremely fine subdenier fibers.

The classification was carried out by the opinions of
engineers who were working in the finishing companies of Singosen fabrics. They classified the fabrics by a principal technique if two or more techniques were included.

The number of fabric samples for each of these groups is shown in Table 3. The four parameters of bending vibration are shown in Fig.8. Contractile fibers type Shingosen fabrics showed the smallest value of $\Delta d_1$ and the largest value of $S_1$, on the other hand, ultra-fine fibers type showed the largest value of $\Delta d_1$ and the smallest value of $S_1$. The significance level of the difference between each group is 5 % for both parameters. This means that bending vibration of contractile fibers type continues longer than the other two types of Shingosen fabrics and that inter-yarn friction in the fabrics is smaller. On the other hand, bending vibration of ultra-fine fibers type damps sooner than the other two types of Shingosen fabrics and the inter-yarn friction is the largest in the fabrics. Although the difference between each type is smaller, results of $\Delta d_2$ and $S_2$ showed the similar tendency with $\Delta d_1$ and $S_1$, respectively. Ultra-fine fibers type Shingosen fabrics are considered to have larger inter-fiber and inter-yarn frictions in the bending vibration.

### Table 2: Classification of Shingosen Fabrics by Production Characteristics

| Shingosen Types       | Number of Samples | New Silky | New Worsted | Rayon Touch | Peach Face |
|-----------------------|-------------------|-----------|-------------|-------------|------------|
| Fabric-finishing      | 11                | 2         | 0           | 0           | 9          |
| Yarn-processing       | 37                | 8         | 17          | 4           | 8          |
| Fibre-production      | 50                | 21        | 4           | 20          | 5          |

![Fig.7 Four parameters of bending vibration for fabric-finishing, yarn-processing, and fiber-production type Shingosen fabrics.](image)

4. Discussion

Although the difference between variously classified Shingosen fabrics was clear by using some parameters of bending vibration, the difference is discussed further by discriminant analysis[^14][15]. The basic principle of the discriminant analysis is as follows.

It is assumed that there exists a proper combination of the bending vibrational parameters which characterizes, for example, New Silky type Shingosen fabrics. Consider two groups of fabric, that is, New Silky and New Worsted types. Bending vibrational properties of fabrics can be expressed by the four parameters; $\Delta d_1$, $\Delta d_2$, $S_1$, and $S_2$. Then the $Z$ value, which is obtained by a linear combination of the bending vibrational parameters $X_1$ to $X_4$, is defined as follows:

$$Z = h_1 X_1 + h_2 X_2 + h_3 X_3 + h_4 X_4$$

(1)

The coefficients $h_i$ are determined so as to maximize the distance between the mean value of $Z$ of the New Silky and that of the New Worsted, and to minimize the variation of the values of $Z$ within two groups. As a measure of the separation of the two groups, it is convenient to use the square of difference between two groups as follows:
Table 3  Classification of Shingosen Fabrics by Fibre Characteristics

| Shingosen Types | Number of Samples | Conventional Shingosen Groups |
|-----------------|-------------------|------------------------------|
|                 |                   | New Silky | New Worsted | Rayon Touch | Peach Face |
| Contractile fibres | 35                | 14       | 1           | 10          | 10         |
| Irregular fibres     | 13                | 6        | 2           | 5           | 0          |
| Ultra-fine fibres    | 12                | 2        | 0           | 0           | 10         |

\[
\left( \bar{Z}_i - \bar{Z}_{II} \right)^2
\]

Here, \( \bar{Z}_i \) is the mean value of \( Z \) of the New Silky type Shingosen group; and,

\[
\bar{Z}_{II}
\]

is the mean value of the New Worsted type Shingosen group.

As a measure of the variation of the values of \( Z \) within the two groups, it is convenient to use the following equations:

\[
\frac{\sum_{i=1}^{II} \sum_{j=1}^{n_i} (Z_{ij} - \bar{Z}_i)^2}{(Z_{i} - Z_{II})^2}
\]

Here, \( Z_{ij} \) is the \( Z \) value of the \( j \)th individual in the \( i \)th group, where \( i=1 \) or \( II \);

\( \bar{Z}_i \) is the mean value of \( Z \) in the \( i \)th group, where \( i=1 \) or \( II \); and,

\( n_i \) is the number of samples in the \( i \)th group.

Then the desired equation will be that for which the \( h \)'s are determined to maximize the following function:

\[
G = \frac{\sum_{i=1}^{II} \sum_{j=1}^{n_i} (Z_{ij} - \bar{Z}_i)^2}{\sum_{i=1}^{II} \sum_{j=1}^{n_i} (Z_{ij} - \bar{Z}_i)^2}
\]

If there are three fabric groups, there exist two independent discriminant functions \([13,14]\) and the two \( Z \) values, \( Z_1 \) and \( Z_2 \), are used to discriminate the three fabric groups on the \( Z_1 - Z_2 \) pane:

\[
Z_1 = h_1 X_1 + h_2 X_2 + h_3 X_3 + h_4 X_4
\]

\[
Z_2 = k_1 X_1 + k_2 X_2 + k_3 X_3 + k_4 X_4
\]

The coefficients \( h \) and \( k \) are determined in the same manner as in the discriminant analysis between two groups.

The distribution of \( Z \) values of three groups is shown in Fig.9 for New Silky, New Worsted, and Peach Face type Shingosen fabrics. It is clearly displayed that the distribution of New Worsted type is separated very much from the other two types. This means that the bending vibrational properties of New Worsted type Shingosen fabrics are different from the other two types. The distribution of \( Z \) values for New Silky, Rayon Touch, and Peach Face type Shingosen fabrics is shown in Fig.10. The difference between these three groups was not so clear. Therefore, it is concluded that New Silky, Rayon Touch, and Peach Face type Shingosen fabrics are quite similar to one another in bending vibrational properties.

The result of three groups, fabric-finishing, yarn-processing, and fiber-production type Shingosen fabrics.
fabrics is shown in Fig. 11. The distribution of yarn-processing type is large and that of fabric-finishing type is included in fiber-production type. Yarn-processing type shows a wide variety in bending vibration and fabric-finishing type has a narrow bending vibration compared to fiber-production type.

The result of distribution curves of two discriminant functions for three groups, contractile fibers, irregular fibers, and ultra-fine fibers type Shingosen fabrics is shown in Fig. 12. It is clearly shown that contractile and ultra-fine fibers types are separated completely from each other. However, irregular fibers type is overlapped with both contractile and ultra-fine fibers types. It is concluded that bending vibrational properties of ultra-fine fibers type are different from contractile fibers type and that irregular fibers type is in the middle of the two types.

Coefficients $h$ and $k$ for the equations (4) and (5) are shown in Table 4 for four combination of three fabric groups. As the value of bending vibrational parameters is normalized with the mean and the standard deviation of all the samples examined here, those values are also shown in Table 4.

5. Conclusions

The bending vibrational properties of polyester-fiber Shingosen fabrics were measured and analyzed by using the new mechanical parameters and the following conclusions were obtained:

(i) In the conventional classification of Shingosen fabrics, bending vibration of New Silky, Rayon Touch, and Peach Face types continues longer than New Worsted type, however, shorter than natural silk filament fabrics.

(ii) In the classification of production characteristics, yarn-processing type damps sooner than fabric-finishing and fiber-production type Shingosen fabrics in bending vibration.

(iii) In the classification of fiber characteristics, bending vibration of contractile fibers type continues the longest and ultra-fine fibers type the shortest.

(iv) Features of Shingosen fabrics in bending vibrational properties become more distinct by discriminant analysis using the four parameters of bending vibration as variables.
Table 4 Coefficients of Discriminant Functions Between Three Groups of Shingosen

| Group              | Coefficients | $\Delta d_1$ | $\Delta d_2$ | $S_1$ | $S_2$ |
|--------------------|--------------|---------------|---------------|-------|-------|
| New Silky          | $h$          | 1.000         | -1.033        | -0.387| -0.072|
| New Worsted        | $k$          | 1.000         | -1.451        | -0.535| -0.341|
| Peach Face         | Mean         | 0.201         | 0.143         | 2.64  | 5.50  |
|                    | S. D.        | 0.103         | 0.055         | 0.71  | 1.51  |

| Group              | Coefficients | $\Delta d_1$ | $\Delta d_2$ | $S_1$ | $S_2$ |
|--------------------|--------------|---------------|---------------|-------|-------|
| New Silky          | $h$          | 1.000         | -1.242        | 0.484 | -0.724|
| Rayon Touch        | $k$          | 1.000         | -1.471        | -0.845| -0.400|
| Peach Face         | Mean         | 0.201         | 0.143         | 2.64  | 5.50  |
|                    | S. D.        | 0.103         | 0.055         | 0.71  | 1.51  |

| Group              | Coefficients | $\Delta d_1$ | $\Delta d_2$ | $S_1$ | $S_2$ |
|--------------------|--------------|---------------|---------------|-------|-------|
| Fabric-finishing   | $h$          | 1.000         | -1.100        | -0.216| -0.410|
| Yarn-processing    | $k$          | 1.000         | -0.369        | -0.241| -0.535|
| Fiber-production   | Mean         | 0.201         | 0.143         | 2.64  | 5.50  |
|                    | S. D.        | 0.103         | 0.055         | 0.71  | 1.51  |

| Group              | Coefficients | $\Delta d_1$ | $\Delta d_2$ | $S_1$ | $S_2$ |
|--------------------|--------------|---------------|---------------|-------|-------|
| Contractile fibers | $h$          | 1.000         | -0.612        | -0.053| -0.218|
| Irregular fibers   | $k$          | 1.000         | 0.136         | -0.104| -0.052|
| Ultra-fine fibers  | Mean         | 0.201         | 0.143         | 2.64  | 5.50  |
|                    | S. D.        | 0.103         | 0.055         | 0.71  | 1.51  |

References

[1] Y. Koyama, M. Niwa, and S. Kawabata: Proceed. 20th Text. Res. Sympo. Mt. Fuji, p.136 (1991).
[2] M. Matsudaira: J. Text. Inst., 85, 158 (1994).
[3] M. Matsudaira and Y. Kimura: Bull. Kanazawa Univ., 45, 25 (1996).
[4] S. Kawabata: “The Standardization and Analysis of Hand Evaluation”, Text. Mach. Soc. Japan, Osaka, Japan, (1980).
[5] S. Kawabata and M. Niwa: J. Text. Inst., 80, 19 (1989).
[6] S. Kawabata: J. Text. Mach. Soc. Japan, 26, P721 (1973).
[7] M. Matsudaira and R. Zhang: J. Text. Mach. Soc. Japan, 49, T324 (1996).
[8] R. Zhang and M. Matsudaira: J. Text. Mach. Soc. Japan, 50, T301 (1997).
[9] R. Zhang and M. Matsudaira: J. Text. Mach. Soc. Japan, 51, T47 (1998).
[10] R. Zhang and M. Matsudaira: J. Text. Mach. Soc. Japan, 52, T137 (1999).
[11] O. Wada: J. Text. Inst., 83, 322 (1992).
[12] M. Matsudaira, H. Qin and Y. Kimura: J. Text. Inst., 89, 117 (1998).
[13] P. G. Hoel: “Introduction to Mathematical Statistics, 3rd edition”, Wiley, New York, USA, p.179 (1962).
[14] T. Okuno H. Kume T. Haga and T. Yoshizawa: “Methods of Multivariate Analysis, Revised edition”, Japan Scientific and Technical Union Publishing Co., Tokyo, Japan, p.263 (1981).
[15] M. Matsudaira and M. Matsui: J. Text. Inst., 83, 133 (1992).