Original Paper

Changes of Static- and Dynamic- Drape Coefficients of Polyester-fiber Woven Fabrics by Weight Reduction in Sodium Hydroxide Solution

Mitsuo Matsudaira and Minzhang Yang

Kanazawa University, Kakuma-machi, Kanazawa City, 920-1192, Japan

Received 1 September 2002, accepted for publication 15 February 2003

ABSTRACT

The effect of weight reduction on static- and dynamic- drape coefficients of polyester-fiber fabrics was studied precisely using 2 sets of fabric samples, one of which had various weave densities of weft yarns. Following conclusions were obtained: (1) Node number; n, the revolving drape increase coefficient; D_r, and the dynamic drape coefficient at swinging motion; D_d, increase with the increase of weight reduction ratio, and saturate around the ratio of 23%. (2) Static drape coefficient; D_s, and the revolving drape coefficient at 200 rpm; D_{200}, decrease with the increase of ratio, however, the former also saturates around 20 %. (3) The effect of yarn weave density at the same weight reduction appears clearly on D_d, D_{200}, and D_r, and these drape parameters increase with the increase in yarn weave density.

Key Words: Drape coefficient; Dynamic drape coefficient; Polyester-fiber fabrics; Weight reduction

1. INTRODUCTION

Fabric handle of silk woven fabrics is the most desirable to human being and it is no exaggeration to say that many artificial fibers have been developed to aim at silk handle[1].

In order to obtain silk handle from polyester-fiber fabrics, the method of weight reduction of polyester fabrics in sodium hydroxide solution is known[2], and it is well known that polyester-fiber fabrics become softer by the weight reduction[3,4]. The reason of that softening is considered to be inter-yarn and/or inter-fiber gap occurred in fabrics by the weight reduction, and the gap has been defined as "effective gap" and evaluated quantitatively by Matsudaira and Kawabata[5,6]. It is shown that polyester-fiber woven fabrics become very soft in bending and shearing properties[6-8], and also in tensile and compressional properties[9] with existence of the effective gap. However, the effect of the weight reduction on drape behaviors is reported quite few[10], hence the present investigation is carried out.

Studies of drape behaviors of fabrics have been reported by the authors recently and a lot of progress has been achieved[11-16]. At first, it was found that there existed an inherent node number for any fabric, and conventional static drape coefficient; D_s, of fabrics could be measured by image processing system with high accuracy and reproducibility[11]. Then, the regression equation for the coefficient was derived not only for isotropic fabrics, but also for anisotropic fabrics[12], and the effect of basic mechanical parameters of fabrics on those static drape shapes was analyzed quantitatively by computer simulation[13]. Further, dynamic drape behaviors of fabrics were studied precisely and revolving drape increase coefficient; D_r, which means the degree of spreading of overhanging fabrics with revolution, and revolving drape coefficient at 200 rpm; D_{200}, which means the saturated spreading at rapid revolution, were defined and their regression equations were also derived[14,15]. Then, dynamic drape coefficient at swinging motion; D_d, which is considered to be more similar to the motion of human body at walking, was defined and the regression equation was also derived from basic mechanical parameters of fabrics quite recently[16].

In this paper, the characterization techniques mentioned above are applied to polyester-fiber woven fabrics and the effect of weight reduction on the static and dynamic drape behaviors is studied precisely.

2. SAMPLES

Two sets of fabric samples were obtained from Kuraray Co. and Teijin Co. in Japan. One set from Kuraray is called Dechine fabrics used for women's fine wears, such as blouses and one-piece dresses. Warp and weft weave densities are constant and the ratio of weight reduction is changed from 0 % to 43 %. Warp yarns are composed of

Mitsuo Matsudaira: E-mail:matsudai@ed.kanazawa-u.ac.jp

Table 1 Outlines of Polyester Dechine Fabrics from Kuraray Co.

Sample	Weight Reduction (%)	Weave Density Ends/cm	Weave Density Picks/cm	Thickness* (mm)	Mass (g/m^2)	Twist (/m) Warp	Twist (/m) Weft
A	0.0	64.6	45.3	0.233	130	0	1800
B	12.3	64.6	45.3	0.218	114	0	1800
C	23.1	64.6	45.3	0.207	100	0	1800
D	36.9	64.6	45.3	0.191	82	0	1800
E	42.9	64.6	45.3	0.180	75	0	1800

* Thickness is measured at the pressure 49 Pa.

Table 2 Outlines of Polyester Dechine Fabrics from Teijin Co.

Sample	Weight Reduction (%)	Weave Density Ends/cm	Weave Density Picks/cm	Linear Density Warp(D,F)	Linear Density Weft(D,F)	Thickness* (mm)	Mass (g/m^2)
A-a	16.1	80.8	36.0	53.5(35)	85.3(35)	0.295	90.7
A-b	19.2	80.6	35.8	50.7(35)	81.6(35)	0.285	88.1
A-c	27.1	80.2	35.5	44.5(35)	72.6(35)	0.282	79.9
B-a	16.1	80.8	37.9	51.5(35)	85.7(35)	0.292	95.0
B-b	19.2	80.2	37.6	51.6(35)	81.4(35)	0.287	91.3
B-c	27.1	80.0	37.6	46.6(35)	73.5(35)	0.283	82.9
C-a	16.1	80.6	40.7	53.8(35)	88.4(35)	0.289	100.1
C-b	19.2	81.5	40.6	51.0(35)	82.6(35)	0.290	96.4
C-c	27.1	79.9	40.1	47.0(35)	75.6(35)	0.285	87.0
D-a	16.1	80.9	42.9	53.4(35)	89.6(35)	0.293	105.0
D-b	19.2	80.6	42.2	51.0(35)	84.0(35)	0.291	100.0
D-c	27.1	80.1	42.2	47.9(35)	76.4(35)	0.288	91.0

* Thickness is measured at the pressure 49 Pa.

twistless filament yarns and weft yarns are filament yarns with high twist. Details are shown in Table 1. The other set from Teijin is also Dechine fabrics so-called "Shingosen" fabrics having high FUKURAMI (softness and fullness) produced for the practical market. Warp yarns are composed of twistless (<100 t/m) filament yarns and weft yarns are filament yarns with high twist (3000 t/m). Warp yarn weave density is constant (61.8 ends/cm on the loom) and weft yarn weave density is changed in four steps such as 31.4, 33.3, 35.1, 40.0 picks/cm on the loom. Those fabrics were treated in sodium hydroxide solution (concentration of NaOH; 110, 140, 170 g/l) and the ratio of weight reduction was 16.1, 19.2, 27.1 %, respectively. Details of these fabrics are shown in Table 2.

3. CALCULATION OF VARIOUS DRAPE COEFFICIENTS OF FABRICS

Static drape coefficient of fabrics; D_s, and node number; n, are calculated using following equations[12]:

$$D_s = \frac{4a^2 + 2b^2 + 2a_m^2 + b_m^2 - 4R_0^2}{12R_0^2} \tag{1}$$

$$n=12.797-269.9\sqrt[3]{\frac{B}{W}}+38060\frac{B}{W}-2.67\frac{G}{W}+13.03\sqrt{\frac{2HG}{W}} \tag{2}$$

Where, R_0 ; the radius of circular supporting stand (=63.5 mm),

a ; a constant showing total size of two-dimensionally projected area (mm),

b ; a constant showing height of sine wave of two-dimensionally projected shape (mm), and

a_m, b_m ; constants showing anisotropy of fabrics.

These constants are obtained from the basic mechanical parameters for fabric handle [17], measured by KES system[18], by using following equations[12]:

$$a=35.981+1519\sqrt[3]{\frac{B}{W}}-204300\frac{B}{W}+23.27\sqrt[3]{\frac{G}{W}}$$

$$+0.0178\,G \qquad (3)$$

$$b = 29.834 - 1.945n - 0.0188G - 91.84\frac{2HG}{W} \qquad (4)$$

$$a_m = 9063\left(\frac{B_1 - B_2}{W}\right)^{2/3},\quad b_m = 6224\left(\frac{B_1 - B_2}{W}\right)^{2/3} \qquad (5)$$

Where, B; bending rigidity (mN·m^2/m),
G; shearing rigidity (N/m/rad),
2HG; hysteresis in shearing force at 0.0087 radian (N/m),
W; fabric weight (g/m^2), and
B_1, B_2; bending rigidity in warp and weft direction, respectively.

Revolving drape increase coefficient; D_r, which means the degree of spreading of overhanging fabrics with revolution and revolving drape coefficient at 200 rpm; D_{200}, which means the saturated value of spreading out of the fabric at rapid revolution (200rpm) are obtained from following equations[15]:

$$D_r = 0.792 + 2.374\sqrt{\frac{2HG}{W}} - 0.6305\sqrt[3]{\frac{G}{W}} - 6.762\sqrt[3]{\frac{B}{W}} - 2.673\frac{2HG}{W} + 0.0005W \qquad (6)$$

$$D_{200} = 61.475 - 37.02\frac{G}{W} + 0.1411G + 40.88\sqrt[3]{\frac{G}{W}} + 0.049W + 436.8\frac{2HB}{W} \qquad (7)$$

Where, 2HB is hysteresis in bending moment at 0.5 cm^{-1} (mN·m/m).

Dynamic drape coefficient of fabrics in swinging motion is defined as the change of projected area at turn-round angle as follows[16]:

$$D_d = \frac{(S_{Max} - S_{Min})}{\pi R_1^2 - \pi R_0^2} x\,100(\%) \qquad (8)$$

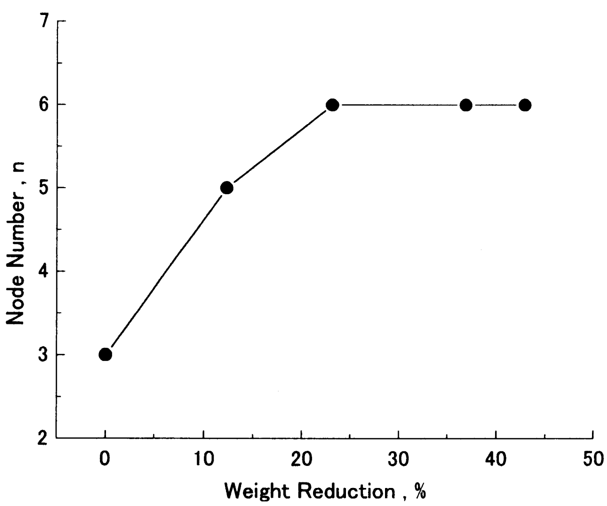

Fig.1 Changes of node number with the weight reduction ratio for Kuraray fabrics.

Where, D_d; dynamic drape coefficient at swinging motion,
S_{Max}; maximum projected area at the turn-round angle, (4)
S_{Min}; minimum projected area at the turn-round angle,
R_0; radius of the circular supporting stand (=63.5 mm),
R_1; radius of the fabric sample (=$2R_0$=127 mm).

Dynamic drape coefficient at swinging motion; D_d, is obtained from following equation[16]:

$$D_d = 90.217 + 0.1183W - 720.7\sqrt[3]{\frac{B}{W}} - 41.1\sqrt[3]{\frac{G}{W}} \qquad (9)$$

4. RESULTS

Values of node number; n, at respective weight reduction are shown in Figure 1 for Kuraray fabrics. Node number increased with the ratio of weight reduction, however, saturated at higher ratio. The effect is especially large at small ratio region.

Results of conventional static drape coefficient; D_s, are shown in Figure 2. The coefficient decreased with the weight reduction ratio, however, saturated at higher ratio. The effect of weight reduction is especially large at small ratio.

Simulated model of the static drape shapes which are estimated by image processing system[13] are shown in Figure 3. It is clear that the shape changes largely by a small ratio of weight reduction less than 12.3%.

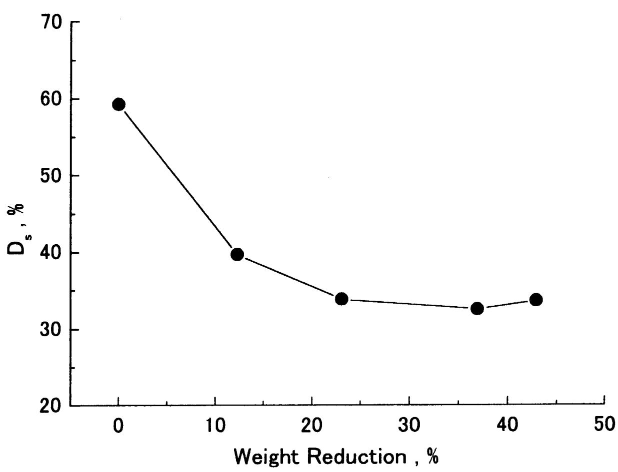

Fig.2 Changes of conventional static drape coefficient with the weight reduction ratio for Kuraray fabrics.

Results of node number for Teijin fabrics are shown in Figure 4. As the weight reduction ratio of Teijin fabrics are relatively higher (16-27%), there was no change in node number as shown in this figure. The difference of weft yarn weave density had no effect on the node number as shown in this Figure.

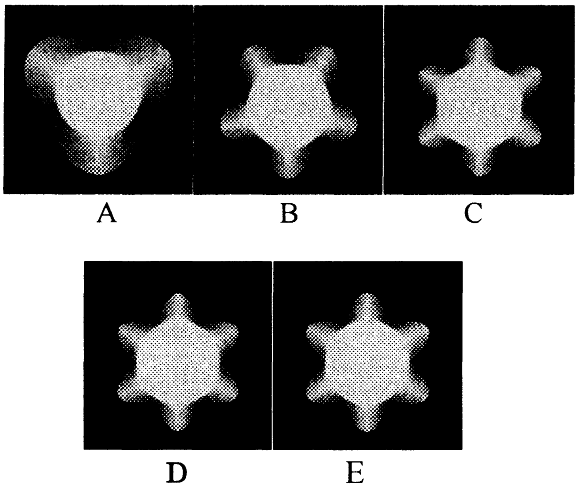

Fig. 3 Simulated models of fabric drape shapes for Kuraray fabrics with the weight reduction ratios: A;0%, B:12.3%, C;23.1%, D;36.9%, E;42.9%.

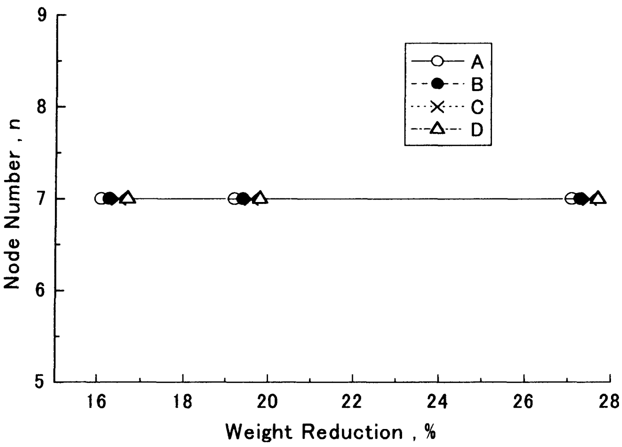

Fig.4 Changes of node number with the weight reduction ratio for Teijin fabrics.

Results of conventional static drape coefficient for Teijin fabrics are shown in Figure 5. The coefficient decreased a little with the weight reduction raio, however, the effect of weft yarn weave density is not shown in this figure.

Simulated model of the static drape shapes are shown in Figure 6 for the sample A. It is very difficult to distinguish the differencce between these three fabrics.

Results of revolving drape increase coefficient; D_r, are shown in Figure 7 for Kuraray fabrics. The coefficient increased with the ratio of weight reduction, however, saturated at higher ratio. This means that the degree of spreading of overhanging fabrics with revolution increases by the weight reduction ratio, however, it does not change at higher ratio.

Results of revolving drape coefficient for Teijin fabrics are shown in Figure 8. The effect of yarn density on the coefficient is clear and the coefficient increases with the yarn density as shown in this figure. This means that fabrics with higher weave density are easy to change the degree of overhanging with revolution speed of fabrics.

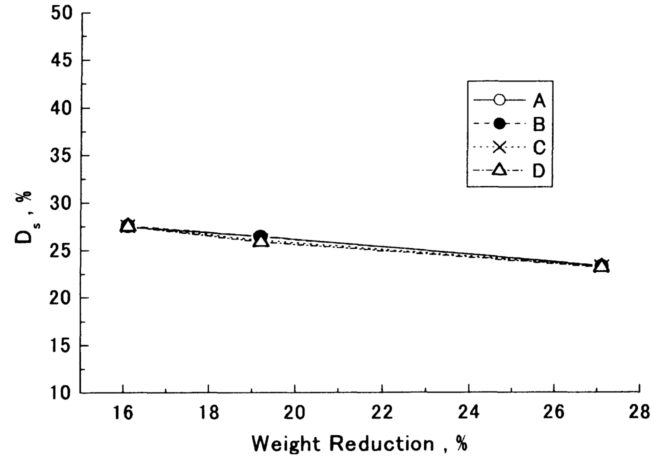

Fig.5 Changes of conventional static drape coefficient with the weight reduction ratio for Teijin fabrics.

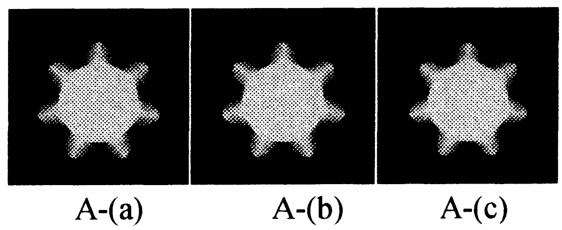

Fig.6 Simulated model of fabric drape shapes for Teijin fabrics with the weight reduction ratios: (a); 16.1%, (b); 19.2%, (c); 27.1%

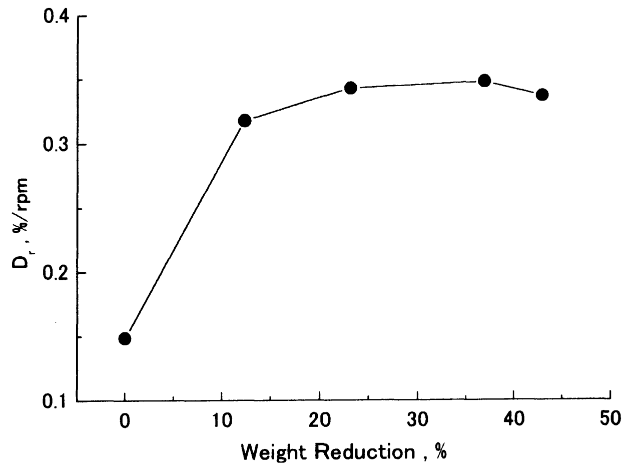

Fig. 7 Changes of revolving drape increase coefficient with the weight reduction ratio for Kuraray fabrics.

Results of revolving drape coefficient at 200 rpm; D_{200}, are shown in Figures 9 and 10 for Kuraray and Teijin fabrics, respectively. The coefficients decreased with the increase of weight reduction ratio. This means that saturated spreading of the fabric at rapid revolution (200 rpm) becomes smaller with the ratio. The effect of yarn weave density on the coefficient is clearly shown and the coefficient becomes larger with higher yarn density.

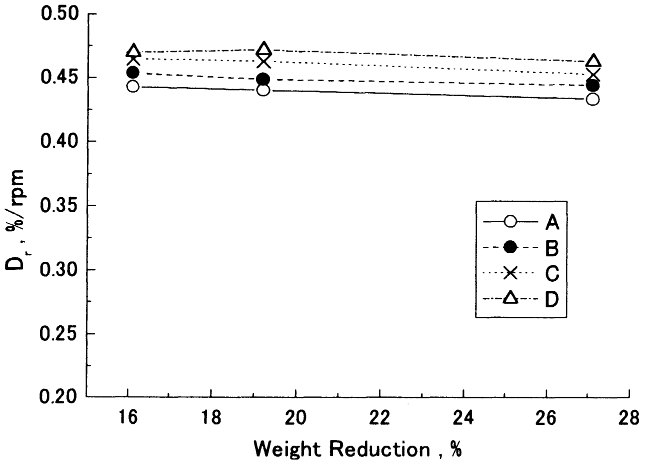

Fig. 8 Changes of revolving drape increase coefficient with the weight reduction ratio for Teijin fabrics.

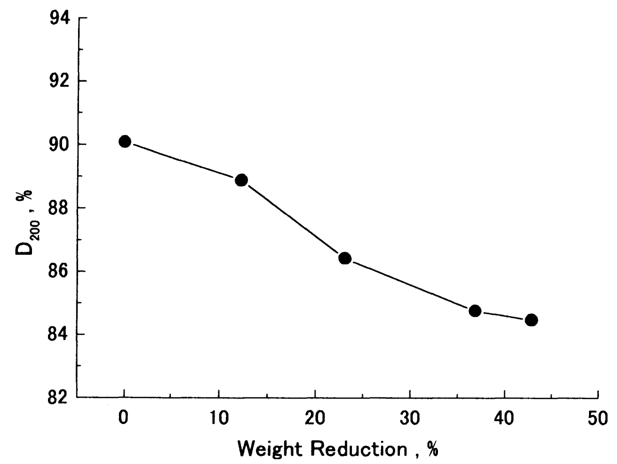

Fig. 9 Changes of revolving drape coefficient at 200 rpm with the weight reduction ratio for Kuraray fabrics.

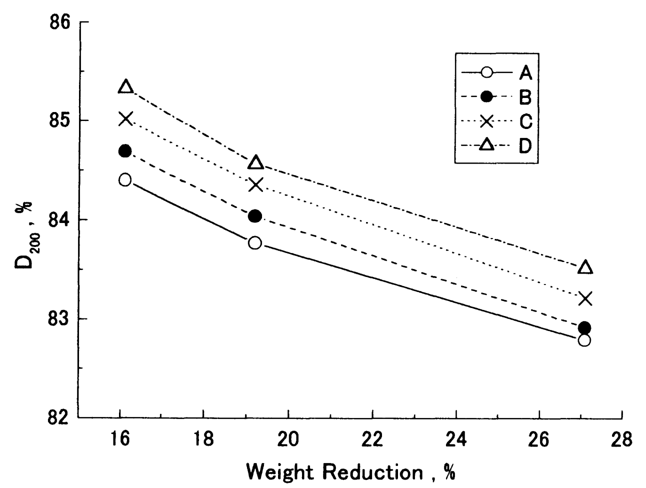

Fig. 10 Changes of revolving drape coefficient at 200 rpm with the weight reduction ratio for Teijin fabrics.

Results of dynamic drape coefficient at swinging motion; D_d, are shown in Figures 11 and 12 for Kuraray and Teijin fabrics, respectively. The coefficients increased with the ratio of weight reduction, and seem to have the maximum values at around 25%. This means that change of projected area of fabrics at turn-round angle becomes larger by the weight reduction, especially at smaller ratio. In other words, the difference of projected area of fabrics between before and after a turn round motion increases with the weight reduction. However, it decreases inversely at the higher ratio as shown in Figure 11, and the existence of optimum ratio is suggested. The effect of yarn weave density is also shown clearly and the coefficients become larger with higher yarn density as shown in Figure 12.

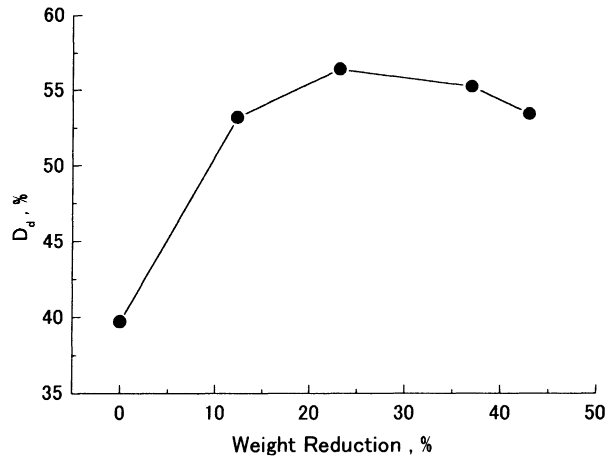

Fig. 11 Changes of dynamic drape coefficient with the weight reduction ratio for Kuraray fabrics.

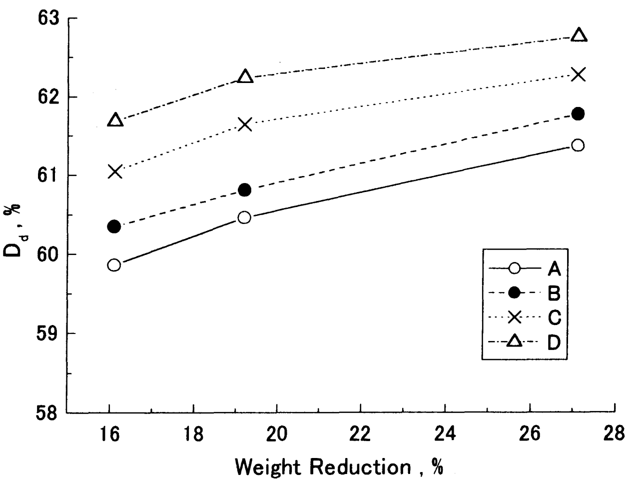

Fig. 12 Changes of dynamic drape coefficient with the weight reduction ratio for Teijin fabrics.

5. DISCUSSION

The effect of weight reduction on various drape coefficients is especially remarkable at the lower ratio of weight reduction. The reason is explained by the decrease of shear stiffness and bending stiffness by the effective gap between fibers and/or yarn occurred by weight reduction[6]. Those parameters decrease drastically by the existence of small effective gap. Therefore, various drape coefficients changes notably at the smaller weight reduction ratio. As Teijin fabrics are commercial fabrics on the market used for women's fine wears, and range of the ratio is large enough to obtain effective gap, therefore, the effect is smaller compared with that of Kuraray fabrics.

Static drape coefficient decreased with the weight reduction, however, the effect of yarn density was little. On the contrary, revolving drape increase coefficient, revolving drape coefficient at 200 rpm, and dynamic drape coefficient at swinging motion changed clearly with the weight reduction and yarn density and those values are considered to be more sensitive and useful for evaluating dynamic drape behaviors of fabrics than conventional static drape coefficient and node number. It is considered that the effect of shearing property becomes larger for the dynamic drape coefficients.

6. CONCLUSIONS

Changes of static- and dynamic- drape coefficients of polyester-fiber woven fabrics with the weight reduction in sodium hydroxide solution were studied precisely using the fabrics having various weave densities of weft yarns. Following conclusions were obtained:

(1) Node number; n, revolving drape increase coefficient; D_r, dynamic drape coefficient; D_d, increase with the ratio of weight reduction, however, conventional static drape coefficient; D_s, and revolving drape coefficient at 200 rpm; D_{200}, decrease with the weight reduction. These parameters showed saturation with the higher ratio.

(2) The effect of yarn weave density appears clearly on D_r, D_{200}, and D_d and these drape parameters increase with yarn density.

(3) Fabric drape shapes at static state are simulated clearly by image processing system.

REFERENCES

1) I. Sakurada: Silky Artificial Fibers, Chemistry, **24**(5), 406-411 (1969).
2) Y. Kosaka: Subjects about Dyeing Treatments of Polyester-fiber Fabrics, Dying Industries, **29(4)**, 174-184 (1981).
3) O. Wada: Progress in the Modification of Polyester Fabrics, Sen-i Gakkaishi (Fibers and Its Industries), **37**(12), P429-P435 (1981).
4) Y. Kosaka: Dyeing and Finishing Process of Special High Qualities Polyester Fiber, J. Textile Mach. Soc. Japan, **37**(3), P136-P146 (1984).
5) M. Matsudaira and S. Kawabata: Structure and Mechanical Properties of Silk Weaves, Proceedings of 3rd Japan-Australia Joint Symposium, Kyoto, p.623-p.631 (1985).
6) M. Matsudaira and S. Kawabata: A Study of the Mechanical Properties of Woven Silk Fabrics, Part 2: Analysis of Shearing Property of Woven Silk Fabrics, J. Textile Inst., **79**(3), 476-489 (1988).
7) S. Tsubaki: Silk-like Fabric from Synthetic Fibers, Sen-i Gakkaishi (Fibers and Its Industries), **23**(5S), S148-S153 (1967).
8) M. Yokozawa: Studies on the Bending of Silk Fabrics, Part 1: Relation between the Structural Factors and the Shearing, Bending Properties of Silk Fabrics, J. Sericultural Science of Japan, **46**(3), 198-204 (1977).
9) M. Matsudaira: Changes of Basic Mechanical Properties and Primary Hand Values of Polyester Woven Fabrics by Weight Reduction, Bulletin of Faculty of Education, Kanazawa Univ., **47**, 1-7 (1998).
10) S. Yamaguchi: The Effect of the Deweighting by Causticizing and High Specific Gravity of Polyester Fibers on the Drape Properties of Fabrics, Japan J. Research Association of Textile End-Uses, **42**(2), 243-250 (2001).
11) M.Matsudaira and M.Yang: Measurement of Drape Coefficients of Fabrics and Description of Those Hanging Shapes, J. Textile Mach. Soc. Japan, **50**(9), T242-T250 (1977).
12) M. Yang and M. Matsudaira: Measurement of Drape Coefficients of Fabrics and Description of Those Hanging Shapes, Part 2: Description of Hanging Shapes about Anisotropic Fabrics, J. Textile Mach. Soc. Japan, **51**(4), T65-T71 (1998).
13) M. Yang and M. Matsudaira: Measurement of Drape Coefficients of Fabrics and Description of Those Hanging Shapes, Part 3: The Effect of Fabric Parameters on Drape Shapes, J. Textile Mach. Soc. Japan, **51**(9), T182-T191 (1998).
14) M. Yang and M. Matsudaira: Measurement of Drape Coefficients of Fabrics and Description of Those Hanging Shapes, Part 4: Evaluation of Dynamic Drape Behavior of Fabrics Using a Testing Device, J. Textile Mach. Soc. Japan, **52**(9), T167-T175 (1999).
15) M. Yang and M. Matsudaira: Measurement of Drape Coefficients of Fabrics and Description of Those Hanging Shapes, Part 5: Relationship between Dynamic Drape Behavior of Fabrics and Mechanical Properties, J. Textile Mach. Soc. Japan, **53**(5), T115-T120 (2000).
16) M. Yang and M. Matsudaira: Measurement of Drape Coefficients of Fabrics and Description of Those Hanging Shapes, Part 6: Evaluation of Dynamic Drape Behavior of Fabrics in Swinging Motion, J. Textile Mach. Soc. Japan, **54**(3), T57-T64 (2001).
17) S. Kawabata: "The Standardization and Analysis of Hand Evaluation, 2nd Edition", Textile Mach. Soc. Japan, Osaka, Japan (1980).
18) S. Kawabata: Characterization Method of the Physical Property of Fabrics and the Measuring System for Hand-feeling Evaluation, J. Textile Mach. Soc. Japan, **26**(10), P721-P728 (1973).

Most part of this paper was presented at 31st Textile Research Symposium at Mt. Fuji (2002).