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Effect of Woven Fabric Anisotropy on Drape Behaviour

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Woven fabrics are well known for their property – direction dependence or property anisotropy, which presents a problem of irregularities in the drape profile depending on the different stiffness of fabrics in different directions. The aim of our work is to evaluate and to predict bending rigidity in different directions of tested samples. Shear rigidity was not considered. Bending length was measured and bending rigidity was calculated in twelve different directions in order to get polar diagrams that represent anisotropy level of woven fabrics due to bending rigidity. Measured values have been compared with the Cooper's theoretical model. According to this method three measurements, i. e. in warp, weft and in bias direction are sufficient to define the value of bending rigidity of specimen cut at any angle α to the warp direction. Draped circular specimens were captured with digital photo camera in order to obtain the drape profiles. Distances to the edge of draped fabric profile in twenty-four different directions were measured in order to get polar diagrams comparable with polar diagrams of bending rigidity. It was found that experimental results of bending rigidity in different directions are close to the values calculated from Cooper's model and this model is reliable to predict drape profile of lightweight woven fabrics.

Keywords: apparel, fabric, anisotropy, drape, bending, mechanical properties.

INTRODUCTION

There are two basic methods for the fabric drape objective evaluation in apparel industry: the cantilever bending tester [1] and the drape meter [2, 3]. Cantilever bending has been used for indirect drape assessment when the behaviour of the fabric specimen is evaluated by a measurable quantity called 'bending length'. This method is widely used by many researchers for theoretical and experimental drape study [4 – 6]. However two-dimensional drape cannot reflect the nature of drape because it involves three-dimensional double curvature deformations. A quantity called 'drape coefficient' is used to describe the degree of 3D deformation when fabric specimen is draped over the drapemeter [3, 4].

Most researchers have studied the relationship between the fabric drape coefficient and bending rigidity measured in two directions (warp and weft) [7, 8]. Still little attention has been paid to the relationship between the fabric drape profile and bending rigidity in various directions. The drape profile [9] of a fabric is a 2D projection captured from the Cusick drapemeter with a digital photo camera. From this image node (picks) numbers, their location and the detailed shape of the drape profile can be observed and the drape coefficient can be accurately calculated with special software.

The aim of this study is experimental and theoretical evaluation of bending rigidity in different directions and the determination of its relationship with the measurements of drape profile.

MATERIALS AND METHODS

The investigations were performed with seven lightweight fabrics samples different in fibre content. All of them were of plain weave except fabrics C and D, which were of combined rep weave and combined rep weave with plain weave respectively. The characteristics of investigated fabrics are presented in Table 1. It must be noted that fabrics chosen for the investigation had different bending rigidity in the range of 1.13 ÷ 12.08 μNm.

Table 1. The characteristics of investigated fabrics

Fabric	Fibre content	Set, dm^{-1}		Surface density, g/m^2	Thickness*, mm
		Warp	Weft		
A	polyester 35%, viscose 65%	480	270	133	0.33
B	polyester 36%, viscose 64%	460	320	114	0.32
C	polyester 38%, viscose 62%	410	240	116	0.51
D	polyester 44%, silk 56%	460	370	70	0.37
E	viscose 100%	390	270	119	0.31
F	viscose 100%	470	200	113	0.31
G	cotton 100%	390	310	83	0.26

*thickness at pressure of 2 g/cm^2

The FAST - 2 bending meter was used to measure bending length and calculate bending rigidity [10 – 12]. The specimens for this experiment were cut in twelve different directions α, as illustrated in Figure 1, where 0° and 90° indicate warp and weft directions, respectively. Measurements were performed in I and II quarters of fabric sample because not all tested fabrics were of plain weave. It is known that due to the nonsymmetrical fabric structure bending in 45° to the warp direction can be different than that in 135° to the warp. Three rectangular specimens (5 × 15 cm) were prepared in order to measure the bending length in each direction. The specimens were measured two times face side up and two times face side down.

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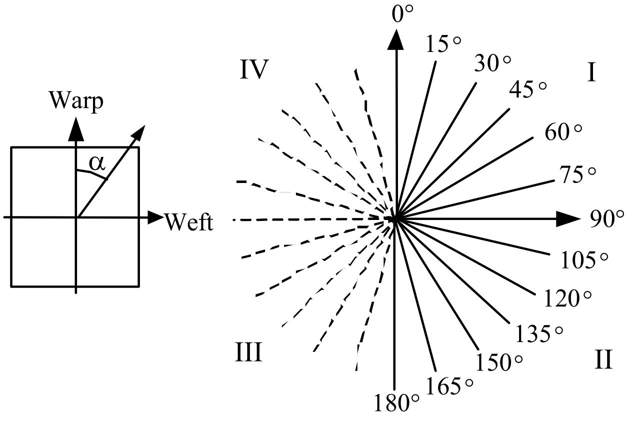
Totally four values of the bending length were determined for each specimen. The average bending length and the average bending rigidity B_A was calculated from twelve measurements for each fabric.



a b

Fig. 1. Specimen preparation: a – angle of cutting direction, b – twelve testing directions

Theoretical model introduced by Cooper [13] has been chosen for the theoretical evaluation of the fabric bending rigidity. He pointed out that in order to bend an element, which is cut at an angle α to the warp direction, about an axis perpendicular to its length, it would be necessary to apply both a bending couple and a couple preventing twisting. According to that, equation (1) has been derived:

$$B_\alpha = B_1 \cos^4 \alpha + B_2 \sin^4 \alpha + (J_1 + J_2) \cos^2 \alpha \sin^2 \alpha , \quad (1)$$

where B_1, B_2 and B_α are bending rigidities in warp, weft and α directions, respectively; J_1, J_2 are constants due to the torsion moment.

Parameters B_1, B_2 can be obtained experimentally but not J_1 and J_2. Nevertheless, the sum $(J_1 + J_2)$ can be calculated from the measurements in three different directions - warp, weft and 45°. Then the final equation to calculate bending rigidities in all possible directions looks like follows:

$$\begin{aligned} B_\alpha &= B_1 \cos^4 \alpha + B_2 \sin^4 \alpha + \\ &+ [4B_3 - (B_1 + B_2)] \cos^2 \alpha \sin^2 \alpha \end{aligned} , \quad (2)$$

where B_3 is the bending rigidity in the direction of 45° to the warp (B_{45}) or 45° to the weft (B_{135}) direction. The value B_{45} was used for the calculations at the first (I) and at the third (III) quarters of fabric sample and the value B_{135} was used for the calculations at the second (II) and at the fourth (IV) quarters (Fig. 1b).

Cooper has introduced the ratio $V = (J_1 + J_2) / (B_1 + B_2)$ to predict the trends of polar diagrams [13, 14]. When the term $(J_1 + J_2)$ is replaced by the bending rigidity values in warp, weft and 45° directions, the equation for the ratio V changes as follows:

$$V = \frac{4B_3 - (B_1 + B_2)}{B_1 + B_2} . \quad (3)$$

In this study fabric drapeability was evaluated by drapemeter [3]. For the investigation two circular specimens of 15 cm radius were prepared of each fabric.

A digital photo camera TOSHIBA PDRM70 was used to capture the projected two-dimensional draped images directly from the drapemeter (Fig. 2).

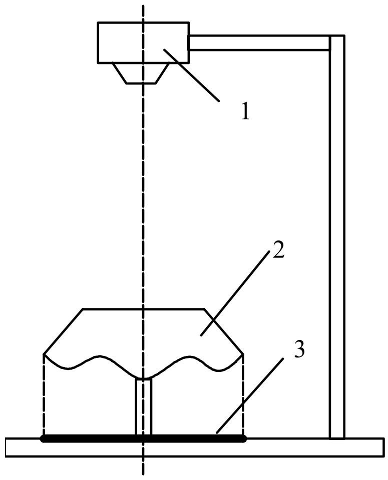


Fig. 2. Drape profile image capturing: 1 – photo camera, 2 – draped specimen on the drapemeter, 3 – drape profile projection

Captured drape profile images were processed by the AutoCAD 2000 software to measure the area of drape profile A_2 (Fig. 3). On the basis of obtained measurement results drape coefficient K_i was calculated according to the following equation:

$$K_i = \frac{\textit{projected area } A_2}{\textit{original nondraped area } A_1} 100 \cdot \quad (4)$$

The distances D_i from the centre to the edge of the drape profile projection were measured at every 15° (Fig. 3). For each specimen the average distance D_{Ai} was obtained from twenty-four measurements D_i.

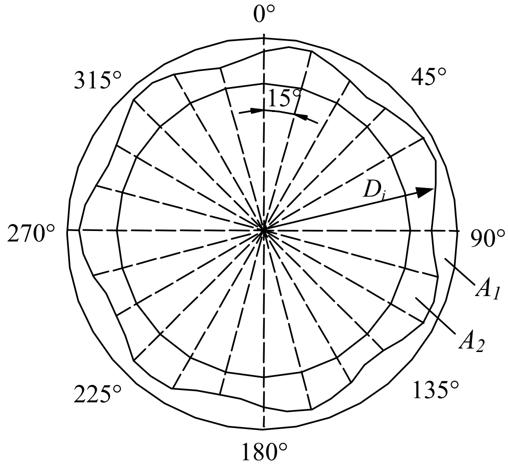


Fig. 3. The scheme of fabric drape profile measuring

Each fabric specimen was measured three times face side up and three times face side down. The average drape coefficient K_A and the average distance D_A were calculated from six values for each side of fabric.

The average drape profile of the drape coefficient K_i, which has the nearest value to the average drape coefficient K_A, was chosen for each side of the fabric.

RESULTS AND DISCUSION

The experimental results of fabric average bending rigidity B_{A1}, B_{A2}, B_{A3} in warp, weft and 45° directions, respectively, are given in Table 2. As it was mentioned in previous chapter, bending rigidity in two different bias directions B_{45} and B_{135} can differ, so the average bending rigidity in bias direction B_{A3} has been calculated according to the equation $B_{A3} = (B_{A45} + B_{A135}) / 2$. The experimental and theoretical results of average bending rigidity in different directions $B_{A\alpha}$ are given in polar diagrams (Fig. 4). The variation of all experimental results does not exceed 7 %.

Table 2. Experimental results of bending rigidity

Fabric	Average bending rigidity, μNm			B_{A1} / B_{A2}	V
	B_{A1}	B_{A2}	B_{A3}		
A	1.60	3.78	1.78	0.4	0.3
B	1.88	3.19	1.76	0.6	0.4
C	3.22	3.92	1.79	0.8	0.0
D	3.08	1.13	2.06	2.7	1.0
E	6.97	1.47	2.67	4.7	0.3
F	11.05	2.30	4.04	4.8	0.2
G	12.08	3.60	5.92	3.4	0.5

Polar diagrams of fabrics with different values of bending rigidity in warp, weft and other directions (Fig. 4) have different shapes. This difference demonstrates the anisotropy of woven fabric bending behaviour. The anisotropy of bending in two principal directions can be expressed by the ratio B_{A1} / B_{A2} (Table 2). Figure 4 shows three possible shapes of polar diagrams with a different ratio B_{A1} / B_{A2}. The first shape of polar diagram when the value of ratio $B_{A1} / B_{A2} < 1$ is horizontally orientated and is characteristic to the fabrics A ($B_{A1} / B_{A2} = 0.4$) and B ($B_{A1} / B_{A2} = 0.6$). The second shape of polar diagram when $B_{\mathrm{A1}} / B_{\mathrm{A2}} = 1$ indicate the minimal level of anisotropy in two principal directions and is characteristic to the fabric C ($B_{A1} / B_{A2} = 0.8$). The third shape of polar diagram when $B_{A1} / B_{A2} > 1$ is orientated vertically and is characteristic to the fabrics D – G (B_{A1} / B_{A2} ranges from 2.7 to 4.8).

In addition, fabrics with similar ratio B_{A1} / B_{A2} can differ in average stiffness. For example, fabric F ($B_{A1} = 11.05$ μNm, $B_{A2} = 2.30$ μNm) is stiffer than fabric E ($B_{A1} = 6.97$ μNm, $B_{A2} = 1.47$ μNm) because both values of bending rigidity B_{A1} and B_{A2} of fabric F exceed the values of fabric E (Table 2).

Table 3. The characteristics of investigated drape profiles

Fabric	Drape coefficient, %		Distance to the edge, mm	
	K_{A1}	K_{A2}	D_{A1}	D_{A2}
A	46.8	49.9	105.0	105.9
B	48.9	53.4	105.6	107.0
C	54.4	54.4	107.3	107.3
D	50.9	57.0	106.2	108.0
E	50.9	60.2	106.2	109.0
F	57.6	81.6	108.2	115.1
G	85.9	86.3	116.2	116.4

Cooper [13] pointed out that fabrics can differ by the relationship between the bending rigidity in a bias direction and that in the two principal directions. This depends on ratio V (Eq. 3, Table 2). For example, when $V = 0$ (fabric C) there are distinct minimums in polar diagram between warp and weft directions (Fig. 4b) but when $V = 1$ (fabric D) these minimums are absent.

It was interesting, whether mentioned above differences between fabrics that depend on bending rigidity measured in three principal directions, will remain for the drape profiles. In this investigation the average drape coefficients K_{A1}, K_{A2} and the average distances to the edge D_{A1}, D_{A2} for the specimens lying face side up and face side down, respectively, were calculated (Eq. 4, Table 3) and averaged drape profiles were chosen.

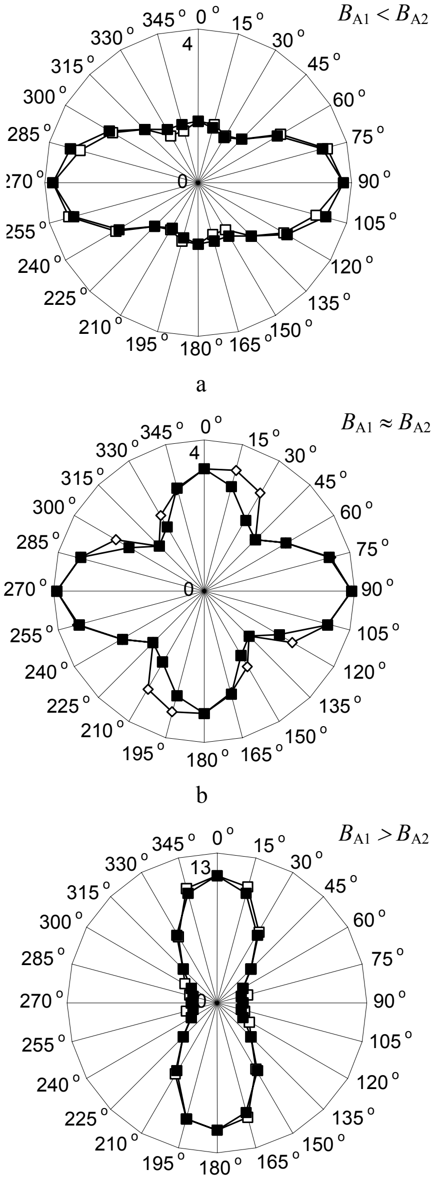


Fig. 4. Polar diagrams of average bending rigidity $B_{A\alpha}$ (μNm) in different directions (□ – experimental results, ■ – theoretical results): a – fabric A, b – fabric C, c – fabric F

Figure 4 shows the excellent fit (correlation coefficients $r = 0.907 \div 0.993$) between theoretical and experimental results of average bending rigidity $B_{A\alpha}$ in different directions. Slight differences are observed between certain quadrants of polar diagrams (Fig. 4b) but as pointed Cooper [13] it can be explained by the effect of yarn twist or peculiarities of fabric structure. Hence in further investigations we have used polar diagrams obtained from the theoretical results according to the Equation 2.

According to the analysis of bending rigidity in different directions it can be seen that the shape of polar diagram depends on ratio B_{A1} / B_{A2}. The same conclusion can be made for the fabric drape profiles. As it is shown in Figure 5a, the shape of drape profile of fabric A ($B_{A1} / B_{A2} < 1$) is slightly orientated horizontally the same as the shape of polar diagram of bending rigidity shown in Figure 4a. While the drape profile of fabric F ($B_{A1} / B_{A2} > 1$) has a distinct vertical orientation (Figure 5b) the same as in polar diagram of bending rigidity (Figure 4c).

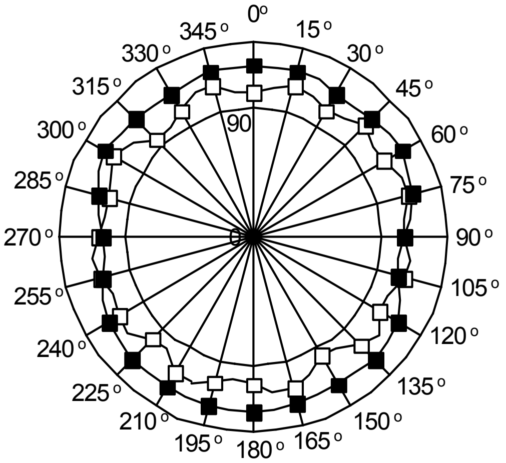


Fig. 5. Drape profiles of fabrics with different ratio B_{A1} / B_{A2} (□ – fabric A, ■ – fabric F)

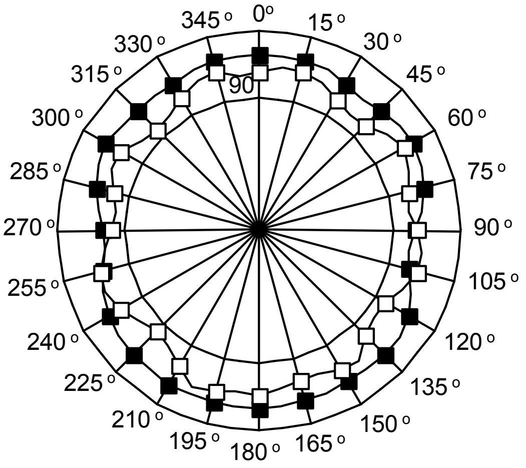


Fig. 6. Drape profiles of fabrics with different averaged bending rigidity B_A (□ – fabric E, ■ – fabric F)

As it was mentioned in the analysis of bending rigidity, fabrics with similar ratio B_{A1} / B_{A2} can have different average bending rigidity B_A. The same phenomenon was observed during the analysis of drape profiles. For example, fabric F is stiffer than fabric E because the distances D_i to the edge of drape profile of fabric F almost in all directions exceed the distances of fabric E (Fig. 6). Besides, the average distances to the edge of drape profile of fabric F (D_{A1} = 108.2 mm, D_{A2} = 115.1 mm) exceed the values of fabric E (D_{A1} = 106.2 mm, D_{A2} = 109.0 mm).

The comparison of ratio V with drape profile showed that ratio V is not available to predict the shape of drape profile. This can be explained by the radius of circular specimen, because the hanging part of the specimen was too short to get distinct differences between fabrics.

In order to get the relationship between theoretical values of bending rigidity and drape profile a correlation analysis was made. Trend lines were plotted and correlation coefficients were calculated between the average distance D_A and the average bending rigidity B_A (Fig. 7). It was found that average distance D_A is well correlated with value B_A obtained from measurements in twelve directions (r = 0.949) and with value B_A obtained from measurements in two principal directions (r = 0.931) (Fig. 7).

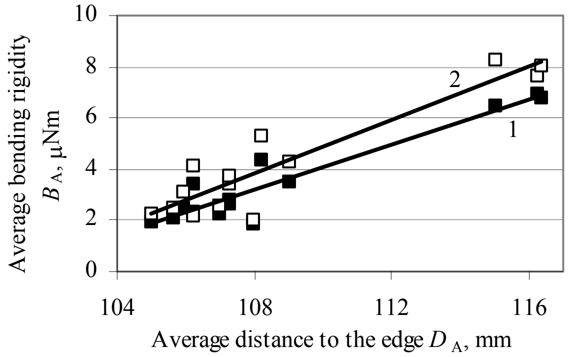


Fig. 7. The relationship between average distances D_A, mm to the edge of drape profile and average bending rigidities B_A, µNm in twelve directions (1) and in two principal directions (2)

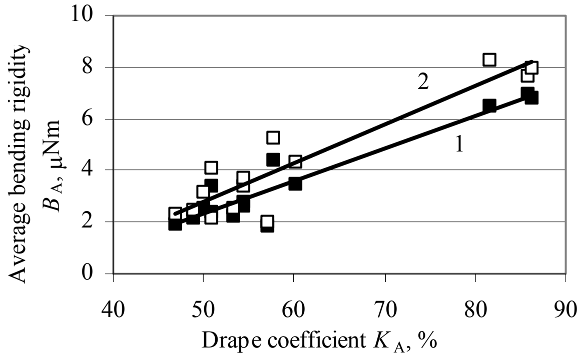


Fig. 8. The relationship between average drape coefficients K_A, % and average bending rigidities B_A, µNm in twelve directions (1) and in two principal directions (2)

The same tendency was observed with the correlation between average drape coefficient K_A and average bending rigidity B_A. The correlation coefficient between average drape coefficient K_A and average bending rigidity B_A obtained from measurements in twelve different directions was r = 0.949 and the correlation coefficient between average drape coefficient K_A and the average bending rigidity B_A obtained from measurements in two principal directions was $r = 0.930$ (Fig. 8). So, the differences between correlation coefficients are not distinct and both, B_A from measurements in twelve directions and B_A from measurements in two principal directions, are good predictors of fabric drape profile and drape coefficient. In order to define whether value of average bending rigidity in more than two directions is better to use for anisotropic fabrics drape prediction, there must be done a deeper research.

CONCLUSIONS

The results of analysis of bending rigidity in different directions and drape profile polar diagrams have shown that theoretical model of Cooper which is derived to calculate the bending rigidity in all possible directions can be used to predict the drape profiles of fabrics.

It was found that the anisotropy level of the drape profile shape depends on ratio B_{A1} / B_{A2}, which represent the anisotropy level of bending rigidity in two principal directions.

However ratio V, which depends on the difference between the bending rigidity in bias direction and that in two principal directions, is not available to predict the shape of drape profile.

Correlation analysis showed that average bending rigidity obtained from measurements in two principal directions and bending rigidity obtained from measurements in twelve different directions are well correlated with average drape coefficients and average distances to the edge of drape profile. So, both, bending rigidity in twelve directions and bending rigidity in two principal directions, are good predictors of fabric drape profile and drape coefficient.

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