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Complex estimation of woven fabrics bending ability

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The bending ability of cotton, wool and viscose woven fabrics under the action of their own weight has been examined using the direct indicators by cantilever method, and indirect indicators by disc method. The results obtained by the usage of direct and indirect indicators are found to be sensitive to raw material as well as constructional characteristics of woven fabrics. Values of direct as well as indirect indicators can be used for establishing the complex estimation of fabrics bending ability. It is found that the viscose fabric has the best bending ability and cotton (1) the poorest.

Keywords: Bending ability, Cantilever method, Cotton, Disc method, Viscose, Wool, Woven fabrics
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1 Introduction

Functional design of fabrics, especially those intended for wearing purposes, represents one of the basic demands of quality. Today, it is not enough for fabrics to have only a good painting and colourful solution, but should also possess good properties during usage and maintenance, e.g. some physico-mechanical characteristics belong to the aesthetic properties, specially those which provide stability of form, dimensions and surface of the fabrics. For clothing fabrics, dimensional stability as well as durability play important roles. Both these characteristics, in essence, depend on elastic properties of fabric. Hence, the study on elasticity of fabrics is important both from the theoretical and the practical aspects.

Attempts have been made to find out the method for determining index of elasticity under action of various forces, like tensile[1,2], pressure[3-6], shear[7,8] and bending[9-11], that might provoke the deformation of fabrics during their exploitation. For example, combined effect of bending force and pressure leads to wrinkling, creasing, even cracking of material. Axial force, whether leads to tension or compression of material, changes the original form of fabric. The phenomenon as mentioned above disturbs the total aesthetic value of fabric and represents negative indicator of its quality.

Besides tensile, bending is one of the most frequent deformations of fabrics during their everyday usage. Investigation of fabrics bending ability might be conducted in two different ways, such as by the usage of direct and indirect methods. As a result of the application of direct methods, direct indicators of bending ability (stiffness and bending modulus) are obtained. On the other hand, drape is one of the most frequently used indirect indicators of fabrics bending ability.[12] Due to the various types of fabrics that are used in the domain of clothing, there is the difficulty in establishing general conclusions of fabrics drapeability. Therefore, the study of drape characteristics is necessary for successfully designing of clothing materials with desired aesthetic properties.

The present paper was aimed at investigating the bending ability of various woven clothing fabrics as well as establishing the influence of structural parameters on direct (stiffness and bending modulus) and indirect (drape coefficient and ratio C/A) indicators of fabrics bending ability. On the basis of the values of monitored characteristics of these fabrics by the application of ranking method, the complex estimation of fabric bending ability was established.

2 Materials and Methods

Five commercially produced woven clothing fabrics of different raw materials, such as cotton, wool and viscose, made in variants of plain and twill weaves, were used for the study. The characterization of prepared samples was done through determination of the fabric properties, such as yarn fineness[13], weave density[14], warp and weft crimp[15], mass per unit area[16], and thickness[17], by standard methods. The results are given in Table 1.

Cantilever method[18] (Fig. 1) was used for the

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determination of direct indicators of fabrics bending ability (stiffness and bending modulus). The stripe of fabric, to be tested, in dimensions of 16 × 3 cm was placed on horizontal supporting platform and fixed in place by a weight. When the toggle switch was cut in the mechanism, it smoothly and uniformly lowered the movable side shelves of the platform, thus imparting flexural deformation to the test stripe. From the moment of its separation from the platform, the stripe flexed under the action of it's own mass. When the side shelves were completely lowered, the flexure indicator was displaced upwards by screw showing on scale the flexure (f) of both free ends of the stripe.

The relative deflection (f_o) was calculated by the following formula[9,18]:

$$f_o = \frac{f_{sr}}{l} \quad \text{... (1)}$$

where f_{sr} is the average deflection of both ends of the fabric stripe (cm); and l, the length of the hanging-down ends of the test stripe (cm). This length (l) was determined by the following formula[18]:

$$l = \frac{L-2}{2} \quad \text{... (2)}$$

where L is the length of the test stripe; in this case it is 16 cm.

The size of relative deflection (f_o) is not allowed to be greater than 0.65, and the size of average deflection (f_{sr}) not less than 1 cm. If at 16 cm long test stripe these conditions are not satisfied, the length of the stripe is reduced for 1 cm and relative as well as average deflection are determined again. The procedure of reducing the length of the test stripe is repeated as long as it is needed to obtain the values of (f_o) and (f_{sr}) which will satisfy the mentioned limited conditions.

Fabric stiffness (B) was calculated using the following formula[18]:

$$B = \frac{m \cdot l^3}{A} \quad \text{... (3)}$$

where m is the weight per unit length ($N \cdot m^{-1}$) of the test stripe; l, the hanging length (m) of the test stripe, which was determined according to Eq. (2); and A, the dimensionless value, in dependence of relative deflection (f_o) (Table 2).

Bending modulus (E) was monitored through the value of fabric stiffness (B)[19], as shown below:

$$E = \frac{B}{I_x} \quad \text{... (4)}$$

where B is the fabric stiffness ($N \cdot m^2$); and I_x, the principal moment of inertia (m^4) of the surface. Principal moment of inertia of the surface (I_x) is given by the following relationship[20]:

$$I_x = \frac{b \cdot \tau^3}{12} \quad \text{... (5)}$$

where b is the sample width (3 cm); and τ, the fabric thickness (m).

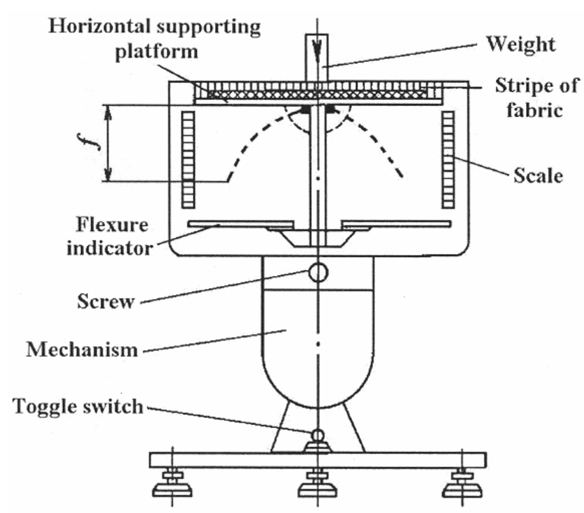

Fig. 1 Apparatus for determination of fabric stiffness and bending modulus (Cantilever method)[18]

Table 1—Structural characteristics of woven fabrics

Fabric sample	Type of weave	Fineness, tex		Density, dm^{-1}		Crimp, %		Mass, $g \cdot m^{-2}$	Thickness mm
		Warp	Weft	Warp	Weft	Warp	Weft		
Cotton (1)	Plain	35	35	269	221	7.8	8.6	180	0.364
Cotton (2)	Plain	12	12	597	311	6.5	6.5	122	0.262
Wool	Plain	27x2	23x2	170	184	4.6	8.5	193	0.522
Wool	Twill 2/2	49	23x2	171	181	5.7	5.4	180	0.560
Viscose	Plain	27	34	257	268	9.3	8.1	160	0.366

Table 2—Value (A) in dependence of relative deflection (f_o) according to Luvishis[18]

f_o	A	f_o	A	f_o	A	f_o	A	f_o	A
0.01	0.10	0.14	1.18	0.27	2.32	0.40	3.75	0.53	5.64
0.02	0.18	0.15	1.25	0.28	2.42	0.41	3.87	0.54	5.84
0.03	0.26	0.16	1.35	0.29	2.53	0.42	4.04	0.55	6.06
0.04	0.35	0.17	1.43	0.30	2.63	0.43	4.17	0.56	6.26
0.05	0.42	0.18	1.51	0.31	2.74	0.44	4.29	0.57	6.47
0.06	0.51	0.19	1.60	0.32	2.83	0.45	4.42	0.58	6.68
0.07	0.60	0.20	1.69	0.33	2.94	0.46	4.56	0.59	6.92
0.08	0.68	0.21	1.76	0.34	3.05	0.47	4.70	0.60	7.18
0.09	0.76	0.22	1.84	0.35	3.15	0.48	4.83	0.61	7.50
0.10	0.84	0.23	1.95	0.36	3.26	0.49	4.98	0.62	7.79
0.11	0.92	0.24	2.04	0.37	3.38	0.50	5.13	0.63	8.12
0.12	1.01	0.25	2.14	0.38	3.49	0.51	5.33	0.64	8.44
0.13	1.08	0.26	2.23	0.39	3.61	0.52	5.51	0.65	8.76

Disc method was used for the determination of indirect indicators of fabrics bending ability, such as drape coefficient (K_d) and ratio C/A. Drape coefficient characterizes drapeability of investigated fabric in all structural directions. Drape coefficient (%) is calculated according to the following formula[21,22]:

$$K_d = \frac{A_S - A_d}{A_D - A_d} \times 100 \qquad \dots (6)$$

where A_D is the surface of undeformed sample (m^2); A_S, the surface of sample projected shadow (m^2); A_d, the upper surface of supporting disc (support) (m^2); A_D - A_d, the ring surface of undeformed sample which is not occupied by the support (m^2); and $A_S - A_d$, the shaded surface of the freely hanging sample (m^2).

Ratio C/A of line axises C and A, where C is the maximum dimension of the projection along the fabric (warp direction) and A is the maximum dimension of the projection across the fabric (weft direction), shows the direction in which the fabric can be better draped. If the ratio C/A is greater than 1 ($C/A > 1$) it means that the fabric drapeability is better in cross direction (weft direction) and if it is less than 1 ($C/A < 1$) it indicates the better drapeability in longitudinal direction (warp direction).

Values of indirect indicators were obtained using the apparatus designed by the authors for this study by the application of disc method. The way of assembling and illuminating the sample for this method is given in Fig. 2.

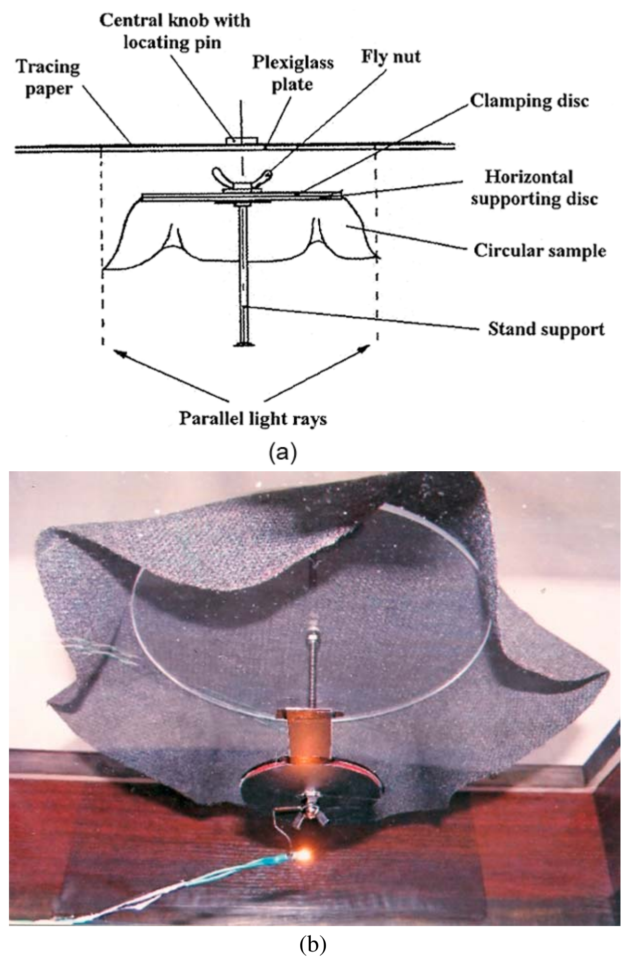

Fig. 2 Apparatus for determination of woven fabrics drapeability[21,22] [(a) schematic diagram of the apparatus and (b) illumination of sample]

Circular sample of diameter (D) was placed on horizontal supporting disc and fixed with clamping disc and fly nut. Supporting disc as well as clamping disc were of diameter (d) which is less than circular sample diameter (D). Supporting disc was placed on the stand support, which was attached for horizontal support made of transparent plexiglass. Circular textile surface (in this experiment it is woven fabric) was centered in such way to hang around the supporting disc. Sample was illuminated from the lower side by the parallel light rays coming from the light point source and reflecting from spherical mirror. Central knob with locating pin and tracing paper was centered on transparent plexiglass plate, which was placed above the sample.

3 Results and Discussion

It is well-known fact that the woven structures, according to their construction, belong to biaxial materials and because of that the methods for determination of bending ability are planned in such way that the direct and indirect indicators of fabrics are investigated in both warp and weft directions. Keeping in mind that the bending deformation depends on certain number of fabric structural elements, like binding coefficient (weave type), the direct as well as indirect indicators of bending ability of fabrics are monitored considering the influence of material structural parameters (raw material, fabric thickness and weave type). Graphic interpretation of the results of measuring stiffness and bending modulus of fabrics through histograms are shown in Fig. 3.

It is observed from Fig. 3 that considering the influence of raw material, the stiffness as well as bending modulus of cotton (1) fabric are eight times greater in warp direction and six times greater in weft direction as compared to viscose fabric. In other words, viscose fabric has better elasticity after the secession of bending force action as compared to cotton (1) fabric in warp as well as weft directions (Fig. 3a).

Stiffness of cotton (1) fabric is greater than the stiffness of cotton (2) fabric, which might be explained by the greater value of surface mass of cotton (1) fabric. Higher value of stiffness in warp direction as compared to that in weft direction of cotton (1) as well as cotton (2) fabrics is the result of fabric density which

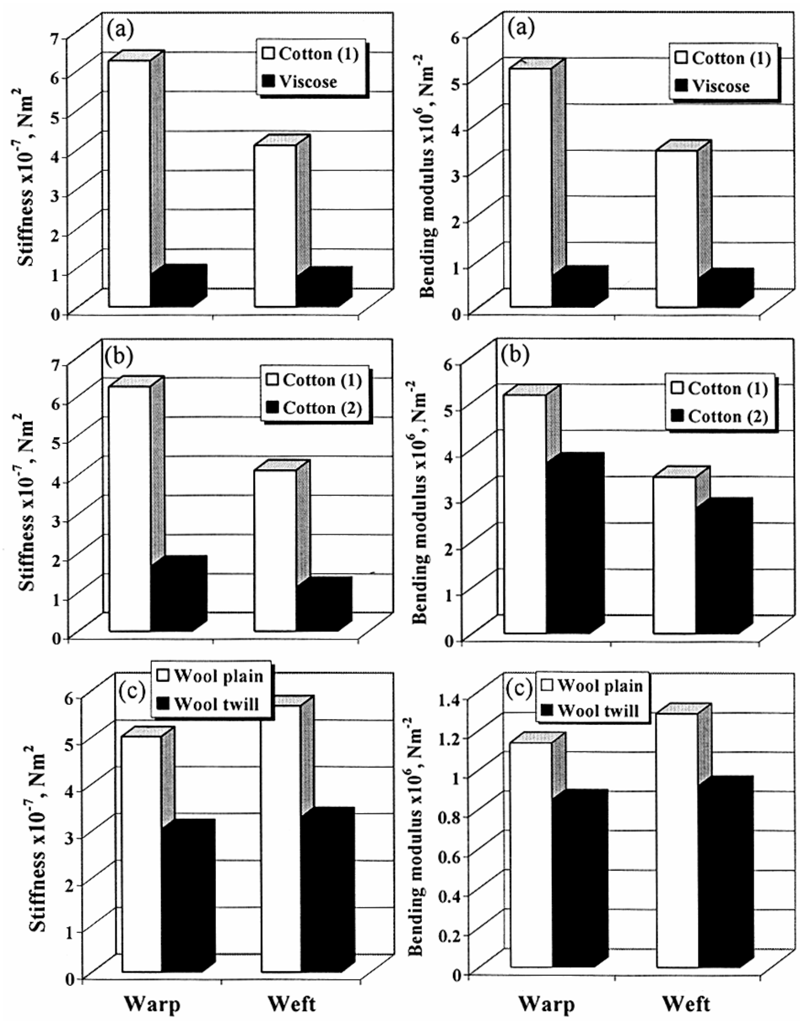

Fig. 3—Direct indicators of woven fabrics bending ability [(a) influence of raw material, (b) influence of thickness, and (c) influence of weave type]

is greater in warp direction than in weft direction. Bending modulus values show that both the fabrics have the same trend of behaviour under action of bending force as in the case of stiffness. In other words, cotton (1) fabric has less elasticity as compared to the cotton (2) fabric (Fig. 3b).

Plain weave wool fabric has greater stiffness and less elasticity (expressed through the value of bending modulus) as compared to twill weave wool fabric. Such behaviour of fabrics can be explained by the fact that plain weave fabrics, owing to the absence of free surfaces, have the exceptionally compact structure. In the crossover points of warp and weft yarns, friction forces as well as adhesive forces act, whose value is maximal exactly at the mentioned interlacing points. Greater stiffness, more exactly less bending elasticity of both wool fabrics in weft direction, is the result of greater fabric density in weft direction than in warp direction (Fig. 3c).

Results of measuring indirect indicators (drape coefficient and ratio *C/A*) are shown in Fig. 4. It is observed that the drapeability of viscose fabric is better as compared to drapeability of cotton (1) fabric (Fig. 4a). Also, the fabric of less thickness, such as cotton (2) fabric, has better drapeability as compared to the fabric of greater thickness, i.e. cotton (1) fabric (Fig. 4b). Twill weave wool fabric expresses better drapeability than the plain weave wool fabric. This phenomenon might be due to the action of adhesive forces, which are expressed in a greater extent at firm, compact weaves (plain) as compared to the less compact weaves (twill) with lower binding coefficient (Fig. 4c).

It is observed from Fig. 4 that both cotton (1) and cotton (2) fabrics have better drapeability in weft direction than in warp direction in contrast to the wool plain and twill, and viscose fabrics which have better drapeability in warp direction than in weft direction. The results of determination of fabrics bending ability through the value of drape coefficient as well as the ratio *C/A* are in accordance with the results of determination of direct indicators (stiffness and bending modulus).

Considering that these fabrics are mainly intended for clothing purposes, it is also necessary to establish if they provide suitable comfort and wearing quality. Hence, on

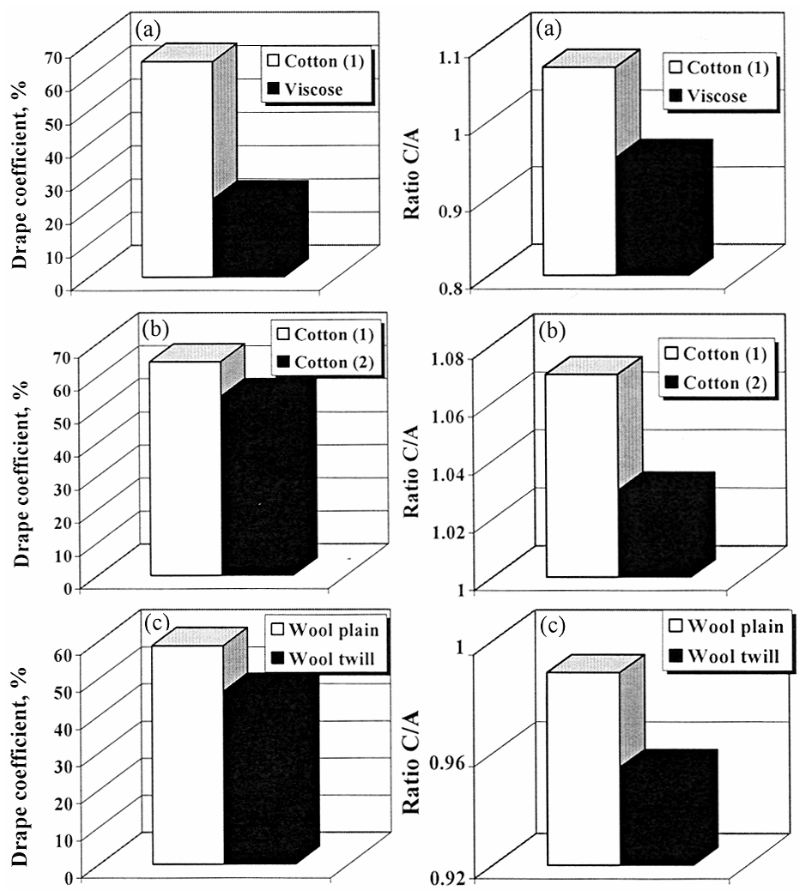

Fig. 4—Indirect indicators of woven fabrics bending ability [(a) influence of raw material, (b) influence of thickness, and (c) influence of weave type]

Table 3—Rank order of woven fabrics

Fabric sample	q_1		q_2		q_3	$q_{av.}$	Q_F
	Warp	Weft	Warp	Weft			
Cotton (1)	5	4	5	5	5	4.8	V
Cotton (2)	2	2	4	4	3	3	III
Wool plain	4	5	3	3	4	3.8	IV
Wool twill	3	3	2	2	2	2.4	II
Viscose	1	1	1	1	1	1	I

q_1 - Grade of stiffness, q_2 – Grade of bending modulus, q_3 – Grade of drape coefficient, $q_{av.}$ – Average value of grades and Q_F - Rank.

the basis of the values of stiffness, bending modulus and drape coefficient, ranking of monitored fabrics was conducted[23] (Table 3). Ranking method consists of providing the grading from '1' to '*n*', where '*n*' represents the total number of fabrics. Grade '1' points to the best quality of fabric from the aspect of monitored characteristic. In this experiment, the less value of stiffness, bending modulus and drape coefficient means the better quality of fabric.

Table 3 shows that the rank of fabrics decreases according to the following sequence:

Viscose > wool twill >cotton (2) >wool plain > cotton (1)

In other words, quality of fabrics from the aspect of their bending ability decreases as per the above sequence.

4 Conclusions

The results obtained by the usage of direct and indirect methods are found to be in complete agreement. Also, the sensitivity of the applied methods concerning the raw material as well as the constructional characteristics of woven fabrics is observed. Values of stiffness, bending modulus, drape coefficient and ratio *C/A* of woven fabrics show that the viscose fabric has the best bending ability and cotton (1) the poorest. Also, better elasticity after the secession of bending force action is found in fabrics of less thickness as well as the fabrics of lower value of binding coefficient. These conclusions point to the fact that woven fabrics structure has great influence on their behaviour under action of bending force. This finding is important for designing certain forms of clothes.

On the basis of data obtained, the complex estimation of investigated fabrics bending ability has been established. To obtain complete information about elastic behaviour of fabrics at bending, it is necessary to carry out the additional investigations on bending relaxation velocity, bending deformation components, and crease recovery angle.

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