

Influence of the Structural Parameters of Woven Fabrics on their Drapeability

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Abstract

Drape is a very important utility parameter of fabrics, especially applied in clothing. It influences the aesthetic effect of clothing, in particular its fitting to the user's body. Fabric draping is the result of interaction between gravitation and various fabric characteristics. In the work presented, cotton woven fabrics of different structure were measured in the range of their drapeability. The fabrics differed from each other in the range of their weave and linear density of weft yarn. Measurement of the fabrics was made by means of a fabric drape tester. Results of the measurement were analysed in the aspect of the relationships between the drape of the fabrics and their parameters, such as the kind of weft yarn, weave, weft density and stiffness. Results confirmed that for the group of fabrics investigated, their stiffness is the most significant property influencing the drapeability of fabrics. Additionally different weaves result in different values of the drape coefficient and shape factor.

Key words: woven fabrics, drape, weave, stiffness.

Introduction

Drape is one of the parameters characterising the appearance of textile products. It is especially important for clothing goods because it influences the aesthetic effect of clothing, in particular its fitting to the user's body. Drapeability also plays a significant role in the case of decorative textile products such as curtains, tablecloths, bedspreads and so on.

Drapeability is defined as the ability of fabrics to create folds under the influence of gravity in conditions favorable for fold creation [1]. Physically drapeability is an effect of interaction between the fabric mass and its stiffness. Taking into account that the stiffness of fabrics is influenced by their different structural and physical parameters, we can state that fabric draping is the result of interaction between gravitation and various fabric characteristics.

The drapeability of textile materials can be analysed as a unidirectional or multidirectional parameter. Unidirectional drapeability is applied to characterise curtains or other textile products creating folds in one direction. Multidirectional drapeability is the most popular and is

used to characterise the majority of textile materials, especially clothing.

Measurement of fabric drape started with Pierce in 1930. He developed the "cantilever method" as an objective test for measuring fabric bending properties and then used two dimensional bending characteristics as a measure of fabric draping quality [2, 3].

Generally multidirectional drapeability measurement is based on an analysis of the shape of the draped fabric sample projection. The first "Drape coefficient" F was developed as a parameter to analyse drape test data/image. It was defined as the fraction of the area of the annular ring placed concentrically above a draped fabric covered by the projection of the draped sample [4]. The drape coefficient F was calculated according to the following equation:

$$F = \frac{S - \pi r_1^2}{\pi r^2 - \pi r_1^2} \quad (1)$$

where:

F – drape coefficient,
 S – area under the draped sample, in mm^2 ,
 r – radius of the sample, in mm ,
 r_1 – radius of the support disk, in mm .

The higher the value of the F parameter, the lower the drapeability of the fabric investigated.

There are different varieties of multidirectional drapeability measurement. In each variant a circular fabric sample is the object of investigation. The radius of the circular sample measured can be different. In multidirectional drapeability

assessment a crucial role is played by the area of draped sample projection (**Figure 1**). The area of draped fabric shape projection is compared with the initial area of the circular sample.

On a Cusick Drape Meter, the most popular drape test device, the specimen deforms with multi-directional curvature. In the test, a circular specimen is held concentrically between two smaller horizontal discs and is allowed to drape into folds under its own weight [5]. A light is shone from underneath the specimen and a fabric drape profile can be observed.

On a Cusick Drape Tester the drape coefficient is defined by the following equation:

$$DC = \frac{W_2}{W_1} \cdot 100 \quad (2)$$

where:

DC – drape coefficient, in %,
 W_1 – weight of the paper ring, in g,
 W_2 – weight of the inner part of the paper ring remaining after cutting it along the line expressing the perimeter of the folded sample shadow, in g.

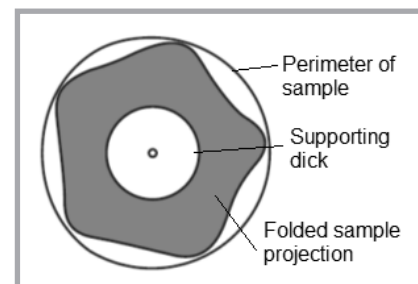


Figure 1. Projection of fabric sample during drapeability measurement.

Also in this method the higher the drape coefficient DC , the lower the drapeability of the fabric. The opposite situation occurs while measuring the drapeability of fabrics using a fabric drape tester according to the Polish Standard [6]. In this method the measure of multidirectional drapeability is the drape coefficient K , calculated from the following equation:

$$K = \frac{\pi r^2 - S}{\pi(r^2 - r_1^2)} \cdot 100 \quad (3)$$

where:

K – drape coefficient, in %,

S – area under the draped sample, mm^2 ,

r – radius of the sample, in mm ,

r_1 – radius of the support disk, in mm .

In this method a higher value of the drape coefficient means better drapeability of fabric. The method is described in details in further part of the article (in Materials and Methods chapter).

It should be emphasized here that different methods of the drape measurement provides different drape coefficients which are calculated on the basis of different **Equations (1) (2) or (3)** and interpreted in different way. Due to this fact it is justified to apply different signs to indicate the drape coefficient measured using the Causick Drape Tester – DC , drape coefficient F calculated according to the **Equation (1)** and drape coefficient K determined by Fabric Drape Tester.

In the modified Causick method a digital camera captures an image of the draped fabric sample and translates the image gathered into appropriate data.

The basic methods of fabric drape measurement mentioned above are used to analyse the drapeability of fabrics in a static state. There are also methods enabling assessment of the draping behavior of fabrics in dynamic conditions. It was stated that different fabrics would have similar static drape behavior, while differing in dynamic drape behaviour [7]. Ranganathan et al. [8] used a dynamic apparatus to measure fabric drape. The sample was clamped in the apparatus and rotated. The movement of the sample was recorded to obtain a hysteresis diagram. The maximum value at 45° rotation and the area of the hysteresis loop were used as parameters of dynamic drape behaviour [8].

Stylios and Zhu developed a 3D drape meter called “The Marilyn Monroe me-

ter” (M3) to work on the modelling of the dynamic drape of garments. They proposed an efficient parameter correlated with subjective assessment of fabric drape called the feature vector V , based on the average maximum fold length (peak) and the average minimum fold length (trough) [9].

Matsudaira et al. published a series of papers focused on dynamic drape [10]. Their tester consisted of a rotatable circular supporting disc, with the speed ranging between 0-240 r. p. m and image analysis system capturing and analysing the images of the draped samples tested in dynamic conditions.

The drapeability of textile materials is a complex phenomenon. It depends on many factors connected with the structure of fabrics. First of all it is strongly associated with fabric stiffness. Stiffer fabric means that the area of its shadow is larger compared to the unsupported area of the fabric, hence the drapeability is lower. Fabric weight is also a very important factor influencing the drape ability of fabrics. The drapeability of fabrics is a result of these two opposed features. However, the value of the drape coefficient by itself is not sufficient for the drape characteristic of fabrics [9, 11]. Therefore other factors are also analysed such as the number and shape of folds created by the draped fabric, the feature vector, consisting of the average minima and average maxima of fold lengths [11], or the evenness of folds. The application of computer aided image analysis makes it possible to analyse images of folded fabric sample projection in different ways [12-15].

Generally textile materials are anisotropic objects. Their anisotropy plays a significant role in the properties of fabrics and their behavior during usage. Many investigations have confirmed that practically all the properties of textile materials: mechanical, thermal, electrical etc. depend on the direction of measurement [15-17], also concerns the drapeability of fabrics. Due to this fact it is necessary to analyse not only the average value of the drape coefficient but also the drapeability of fabrics in different directions. Taking this into consideration, Szpajew proposed the shape factor k , calculated according to the following formula [1]:

$$k = \frac{l_o}{l_w} \quad (4)$$

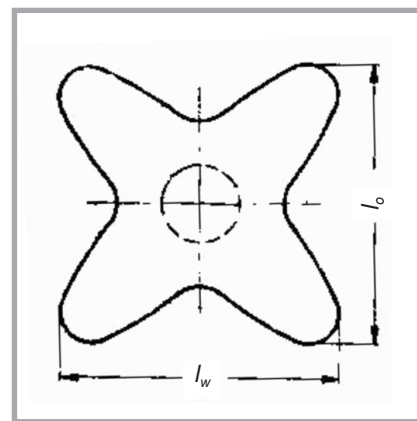


Figure 2. Maximal size of the folded fabric sample in both directions.

where:

l_o – the maximal size of the folded fabric projection in the warp direction,

l_w – the maximal size of the folded fabric projection in the weft direction (**Figure 2**).

If $k > 1$ the fabric has better drapeability in the weft direction. In the opposite situation, when $k < 1$ – the fabric shows better drapeability in the warp direction.

The drapeability of fabrics is a very important and complex phenomenon. Due to this fact it has been investigated by many researchers. The bibliography concerning the drapeability of textile materials is huge. It is difficult to mention all research works published in this topic till now. Generally the investigations of fabric drape concern the following main issues:

- development of alternative methods of drapeability measurement [7, 19-21],
- numerical simulation of fabric and clothing drape [12, 15, 22],
- dependence of drape on measurement conditions, such as time, the diameter of the sample, rotation speed (in dynamic drape assessment) etc. [23-25],
- influence of the structure and mechanical properties of fabrics and seams on the drapeability of fabrics and clothing [26-31].

In the last topic, different fabrics were the objects of investigation. Usually they were woven fabrics of different structure: weave, warp and weft count and warp and weft density, made from different fibers. Nonetheless samples of different weave were also characterised by different raw material, yarn count or fabric tightness. Due to a too big number of

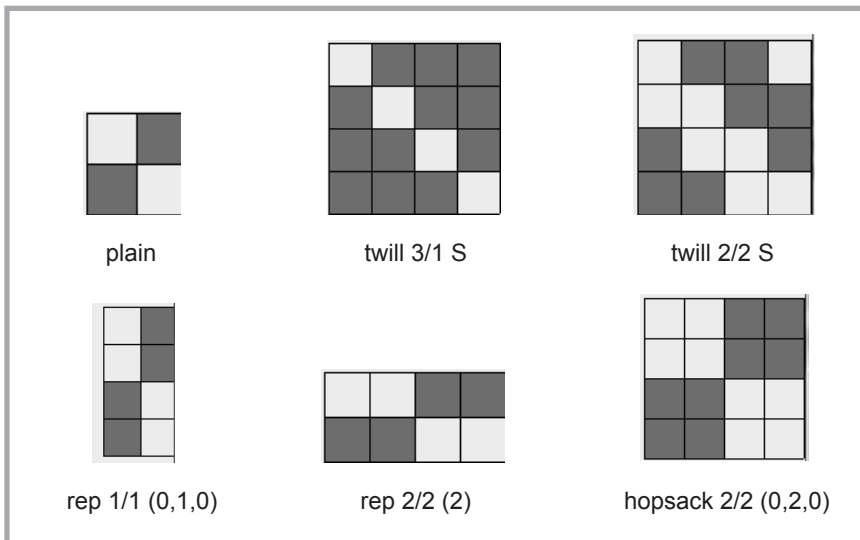


Figure 3. Weaves applied in the fabric variants manufactured

changing structural parameters and interactions between them, the investigations presented did not allow to determine the influence of the weave on the drapeability of fabrics. In none of the articles

published till now we can find no direct answer as to how the weave of fabric influences its drape behavior. Only in the article published by Özdil et al. [31] can we see a comparison of the drapeability

Table 1. Basic properties of yarns applied in the fabrics investigated

Parameter	Unit	50 tex CO OE	60 tex CO OE	100 tex CO OE
Linear density	Tt	50.8	60.4	101.4
Mass variation coefficient	%	0.4	1.51	1.84
Twist	rpm	541	499	521
Twist variation coefficient	%	6.10	3.34	5.40
Breaking force	cN	512	774	1074
Breaking force variation coefficient	%	8.10	6.40	7.60
Tenacity	cN/tex	10.1	12.8	10.6
Elongation at break	%	6.7	7.4	8.4
Elongation variation coefficient	%	6.7	5.0	7.2
CV Uster	%	14.5	12.5	11.1
Thin places/1000 m	–	7.2	0.8	5.0
Thick places/1000 m	–	12.0	2.4	16.0
Neps/100 m	–	13.6	4.0	19.0

Table 2. Set of fabric variants investigated.

No.	Weave	Linear density of warp, tex	Linear density of weft, tex	Warp density, cm ⁻¹	Weft density, cm ⁻¹
1	plain	50	100	31.2	11.5
2	plain	50	60	31.6	11.7
3	twill 3/1 S	50	100	31.7	11.6
4	twill 3/1 S	50	60	31.7	11.7
5	twill 2/2 S	50	100	31.9	11.6
6	twill 2/2 S	50	60	31.9	11.8
7	rep1/1 (0,1,0)	50	100	31.1	11.5
8	rep 1/1 (0,1,0)	50	60	31.7	11.8
9	rep 2/2 (2)	50	100	31.7	11.9
10	rep 2/2 (2)	50	60	32.0	11.8
11	hopsack 2/2 (0,2,0)	50	100	31.6	11.7
12	hopsack 2/2 (0,2,0)	50	60	31.6	11.7

of plain and sateen woven fabrics. Moreover authors did not usually investigate the anisotropy of the drapeability of woven fabrics in the function of weave.

The aim of the work presented was to analyse the influence of weave on the drapeability of woven fabrics as well as to investigate the drape behavior of fabrics of different weaves in both directions – warp and weft. On the basis of results obtained the influence of the weave of the drape anisotropy was studied based on an analysis of the shape factor k proposed by Szpajew [1]. Both an assessment of the influence of the weave on fabric drapeability and analysis of the anisotropy of fabric drape using Szpajew's shape factor k can be considered as a novelty in the area of fabric drapeability investigation.

Materials and methods

In order to analyse the influence of weave on the mechanical properties of woven fabrics, 12 variants of cotton woven fabrics were manufactured. Cotton rotor yarns of different linear density were used for manufacturing fabrics: 50 tex CO OE (open end) as the warp as well as 60 tex CO OE and 100 tex CO OE as the weft. Basic parameters of the yarns applied are presented in Table 1.

The fabrics were made of the same warp yarn and density of warp and weft. Weaves applied in the woven fabric variants prepared are presented in Figure 3.

The fabrics differ from each other in the aspect of their weave and linear density of weft yarn. The set of fabrics analysed consists of two groups of fabrics:

- fabrics made of weft yarn of 100 tex linear density,
- fabrics made of weft yarn of 60 tex linear density.

In both groups of fabrics there are 6 variants of different weaves (Figure 3). Such a set of fabrics was prepared in order to check if in both groups the same dependencies of drapeability on weave occur. All fabric variants were manufactured as a one piece of fabric from the same warp on the same loom at the same loom adjustments. All fabric variants were dyed and finished in the same way – starch finishing, typical for cotton fabrics. The finishing was performed for one piece of fabric in one process. Thus the conditions of finishing were identical for all fabric variants. However, due to the different

weaves resulting in a different way of warp and weft interlacing and a different number of interlacing points in the fabric repeat, the relaxation of fabrics after weaving and finishing processes runs in a slightly different way for each fabric variant. It caused that the final values of warp and weft density are different for particular variants. Nonetheless the differences are not substantial; they are in the range of tolerance for such kinds of fabrics. The basic characteristics of the fabrics investigated are presented in **Table 2**.

The fabrics were measured in the range of their basic structural parameters, and the following parameters were assessed:

- warp working-in,
- weft working-in,
- mass per square meter,
- thickness,
- bending stiffness.

Measurement was performed using standardised testing methods. The bending stiffness of the fabrics was measured using a cantilever stiffness tester [32] according to the Polish Standard [33].

Results of the measurement are presented in **Table 3**.

Measurement of the drapeability of fabrics was made using the fabric drape tester presented in **Figure 4**.

The light rays (10) issuing from the light source (8) placed in the focus of the concave – convex lens (7) form a parallel beam that illuminates the sample (3). The inserted plate (6) is used to place the fabric sample in the tester. The supporting disc (1) and clamping plate (2) are fixed on the pin (4). They are used to support and raise the sample (3) from the plate (6). Then the folded sample is visible on the screen (5) in its real size [6, 34].

In this method a higher value of the drape coefficient means better drapeability of the fabric.

The area of draped sample projection was measured by means of a planimeter. In the method applied the radius of the sample is 100 mm, whereas that of the supporting disk is 35 mm. The drape coefficient K is expressed in percentage and can be in the range from 0 % to 100 %. In contrast to Causic's method, the higher the value of the drape coefficient K , the better the drapeability. For very flexible products the drape coefficient K is close

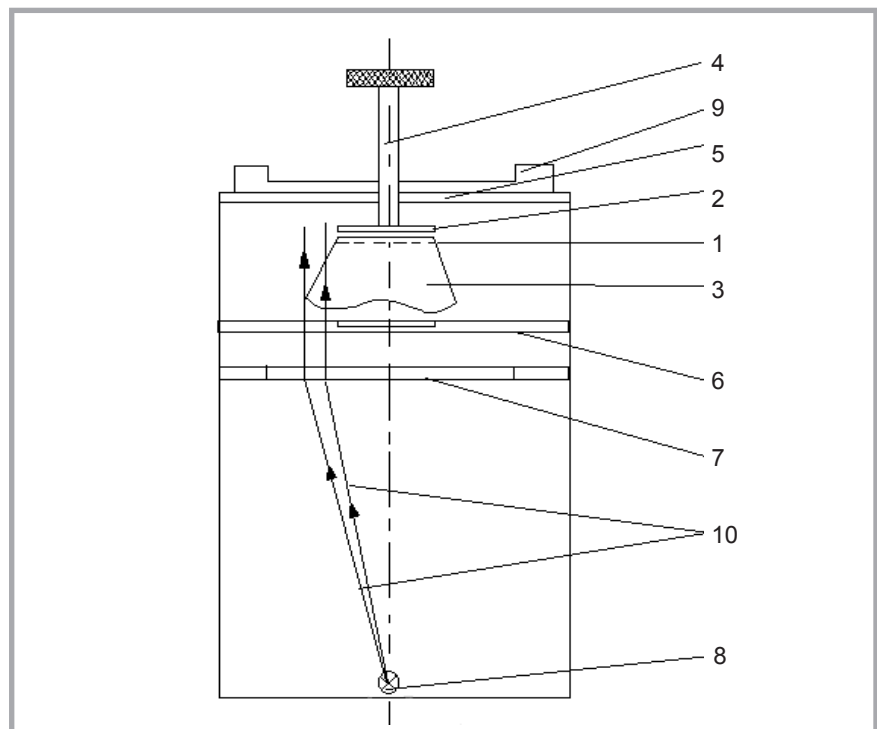


Figure 4. Fabric drape tester applied in the experiment: 1 – supporting disc, 2 – clamping plate, 3 – sample, 4 – pin, 5 – screen, 6 – sliding plate, 7 – lens; 8 – light source, 9 – frame, 10 – light rays [6, 34].

Table 3. Basic characteristics of fabrics investigated

No.	Warp working-in, %	Weft working-in, %	Mass per square meter, gm ⁻²	Thickness, mm	Stiffness in warp direction, mNm	Stiffness in weft direction, mNm	Total stiffness, mNm
1	14.2	2.9	312	115	0.10	0.09	0.09
2	8.8	3.7	316	117	0.09	0.05	0.07
3	7.9	3.3	317	116	0.11	0.11	0.11
4	5.5	3.8	317	117	0.10	0.04	0.06
5	7.0	2.7	319	116	0.12	0.10	0.11
6	5.9	3.9	319	118	0.08	0.04	0.06
7	7.3	1.2	311	115	0.09	0.19	0.13
8	6.1	2.4	317	118	0.07	0.04	0.05
9	9.8	3.9	317	119	0.14	0.14	0.14
10	6.8	5.4	320	118	0.12	0.06	0.08
11	6.4	2.3	316	117	0.10	0.11	0.10
12	5.3	3.2	316	117	0.08	0.04	0.06

Table 4. Results of drapeability measurement

No.	Weave	Drape coefficient K %		Shape factor k
		Av.	SD	
1	plain	13.02	3.47	1.03
2	plain	19.43	3.62	1.14
3	twill 3/1 S	17.69	4.96	1.20
4	twill 3/1 S	29.41	3.36	1.28
5	twill 2/2 S	9.44	6.21	1.07
6	twill 2/2 S	26.64	2.35	1.30
7	rep1/1 (0,1,0)	8.00	4.00	1.01
8	rep 1/1 (0,1,0)	25.10	3.68	1.22
9	rep 2/2 (2)	2.94	2.61	1.00
10	rep 2/2 (2)	12.10	1.04	1.11
11	hopsack 2/2 (0,2,0)	8.36	4.43	0.98
12	hopsack 2/2 (0,2,0)	24.48	3.43	1.11

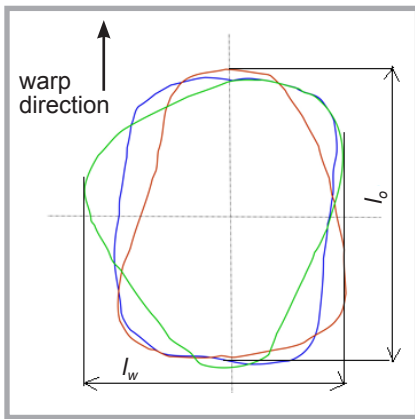


Figure 5. Examples of folded projections of sample No. 7

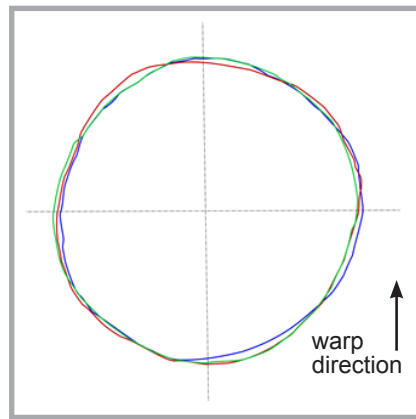


Figure 6. Projections of folded fabric No. 9 of the lowest value of drape coefficient K .

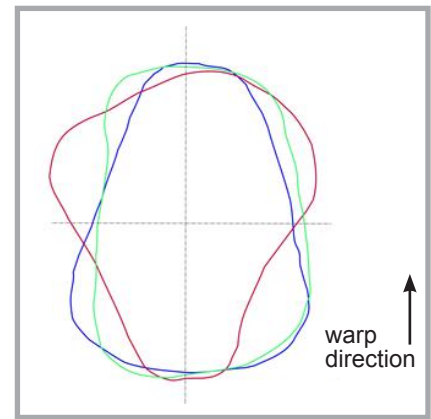


Figure 7. Projections of folded fabric No. 4 of the highest value of drape coefficient K .

to 100 %, whereas for very stiff products it is close to 0 % [34].

The picture above (**Figure 5**) presents examples of folded sample projections.

For each fabric the drape coefficient K was assessed for 3 laboratory samples. Next the average value from 3 repetitions was calculated as a final result. Additionally the shape factor k defined by **Equation (3)** was analysed. To do this it was necessary to mark the direction of warp and weft for each sample investigated (**Figure 6**).

ANOVA and the linear correlation test were applied in order to analyse the results of the experiment.

■ Results and discussion

Results of the drapeability measurement by means of a fabric drape tester are presented in **Table 4**.

The drape coefficient of the fabrics investigated is in the range from 2.94% to 29.41%. Generally the fabrics investigated are characterised by relatively low drapeability due to their starch finishing and tight structure created by the coarse yarns (50, 60 and 100 tex). The lowest value was noted for sample No. 9 of the rep 2/2 (2) weave made from 100 tex weft yarn, and the highest for sample No. 4 of twill 3/1 S weave made from 60 tex weft yarn. **Figures 6** and **7** present projections of folded fabrics characterized by the lowest and highest values of the drape coefficient K .

Analysing **Figures 6** and **7**, we can see differences in the anisotropy of the drape

behavior of the fabrics presented. Fabric No. 9 is characterised by the same maximal size of the projection in both directions – warp and weft. For this fabric the value of the shape factor k is 1.00 (**Table 4**, see page 59). In the case of fabric No. 4 there is clearly a visible difference in drapeability in the warp and weft directions. For this fabric one of the highest values of the shape factor k ($k = 1.28$) was noted (**Table 3**).

Figure 8 presents values of the drape coefficient K in the function of the weave and linear density of weft yarn. Results show an influence of the weave and weft linear density on the drape coefficient K . On the basis of the results obtained for all fabric variants, statistical analysis was performed using the ANOVA test. The statistical analysis confirmed that the stated influence of both independent variables: weave and weft density on the drapeability is statistically significant at the probability level 0.95.

It can be seen that the fabrics made of weft yarn of 100 tex linear density are characterised by significantly lower drapeability than those made of 60 tex weft yarn. It is easy to explain, because fabrics made of 100 tex weft yarn are stiffer, especially in the weft direction, than fabrics made of thinner – 60 tex weft yarn. The dependency of drapeability on fabric stiffness is indisputable. As mentioned earlier, Pierce already in 1930 suggested using two dimensional bending characteristics as a measure of fabric draping quality [2, 3]. Moreover the Drape Angle method proposed by Hes [35] is also based on the relationship between the stiffness and drapeability of fabrics.

The influence of the kind of weave on the drapeability coefficient K is clearly visible for both groups of fabrics: made of 100 tex and 60 tex weft yarn. The highest drapeability was noted for fabrics of twill 3/1 S weave, whereas the lowest – for rep 2/2 (2) weave. The highest value of drape coefficient K for the 3/1 S fabrics can be explained by the longest thread sections between interlacing points. The lowest drapeability of 2/2 (2) weave fabrics is difficult to explain. It may be an effect of the interaction of many structural factors such as the length of thread sections between interlacing points, as well as the stiffness of warp and weft yarns and their density.

The results of the experiment also confirmed a strong and statistically significant negative correlation ($R_{xy} = -0.886$) between the drape coefficient K and stiffness of fabrics (**Figure 9**). The higher the fabric stiffness, the lower the value of the drape coefficient K .

In order to analyse the relationship between the drapeability of fabrics and their structure, different structural parameters were calculated: fabric cover, filling and integrated fabric structure factor P according to Milašius [36, 37].

The fabric cover is considered as a fraction of the total fabric area covered by the component yarns. The cover factors were calculated according to the formulas:

$$Z_{warp} = S_1 \cdot d_1 \quad (5)$$

$$Z_{weft} = S_2 \cdot d_2 \quad (6)$$

$$Z_{total} = Z_{warp} + Z_{weft} - \frac{Z_{warp} \cdot Z_{weft}}{100} \quad (7)$$

were:

Z_{warp} – cover by warp,

Z_{weft} – cover by weft,

Z_{total} – cover by both warp and weft,
 S_1 – warp density in cm^{-1} ,
 S_2 – weft density in cm^{-1} ,
 d_1 – warp diameter in mm ,
 d_1 – weft diameter in mm .

Theoretical values of the yarn diameter were calculated according to Ashenhurst's equation [38].

$$d = \frac{c}{\sqrt{1000}} \cdot \sqrt{T} \quad (8)$$

where:

d – yarn diameter in mm ,
 c – constant value for given yarn, for cotton yarn $c = 1.25$,
 T – linear density of yarn in tex .

The filling factors were calculated as follows:

$$E_{warp} = \frac{d_1 \cdot R_1 + d_2 \cdot p_2}{R_1} S_1 \quad (9)$$

$$E_{weft} = \frac{d_2 \cdot R_2 + d_1 \cdot p_1}{R_2} S_2 \quad (10)$$

$$E_{ave} = \frac{E_{warp} \cdot T_1 + E_{weft} \cdot T_2}{T_1 + T_2} \quad (11)$$

where:

E_{warp} – filling by warp,
 E_{weft} – filling by weft,
 E_{ave} – filling by both warp and weft,
 R_1 – warp repeat,
 R_2 – weft repeat,
 p_1 – number of warp interlacing points in repeat,
 p_2 – number of weft interlacing points in repeat.

In order to characterise the structure of woven fabrics by means of one factor, the integrated fabric structure factor φ was also applied. Factor φ , elaborated by Milašius, is calculated according to the following formula [36, 37]:

$$\varphi = \sqrt{\frac{12}{\pi}} \frac{1}{P} \sqrt{\frac{T_{av}}{\rho}} S_2^{1+2/3\sqrt{T_1/T_2}} S_1^{2/3\sqrt{T_1/T_2}} \quad (12)$$

where:

φ – integrated fabric structure factor according to Milašius [36, 37],
 P – weave factor, called 'the weave-firmness factor' proposed by Milašius [36, 37]
 T_{av} – average linear density of yarn in tex ,
 ρ – overall density of raw materials of the threads,
 S_1 – warp density in cm^{-1} ,
 S_2 – weft density in cm^{-1} ,
 T_1 – linear density of warp yarn in tex ,
 T_2 – linear density of weft yarn in tex ,
 T_{av} – average of linear density of threads calculated as [36, 37]:

$$T_{av} = \frac{T_1 \cdot S_1 + T_2 \cdot S_2}{S_1 + S_2} \quad (13)$$

Table 5 (see page 62) presents calculated values of the correlation coefficient between the drape coefficient K and parameters characterising the structure of fabrics.

On the basis of the results presented in **Table 5**, we can see that the strongest correlation occurred between the drape coefficient K and cover by weft as well as

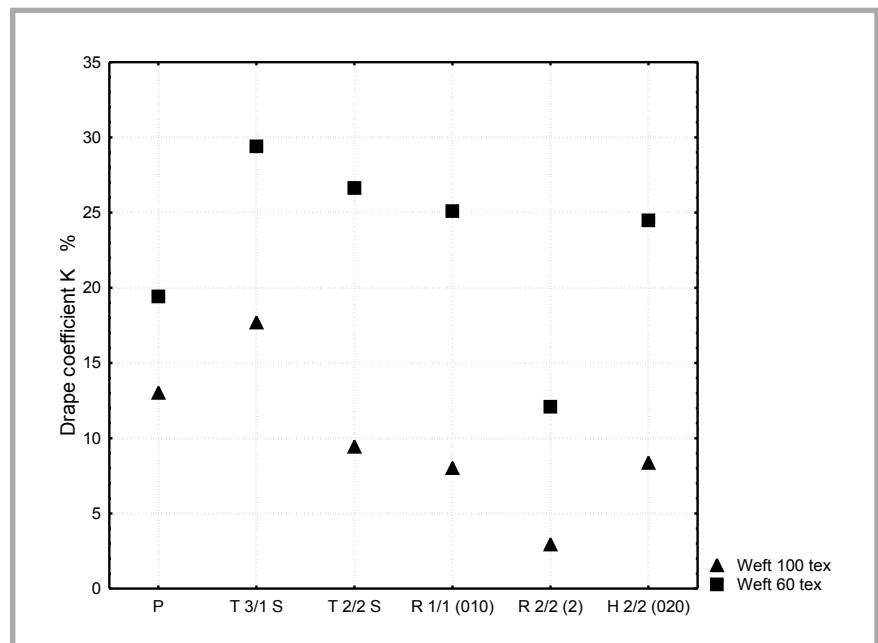


Figure 8. Drape coefficient as a function of the fabric weave and linear density of weft yarn

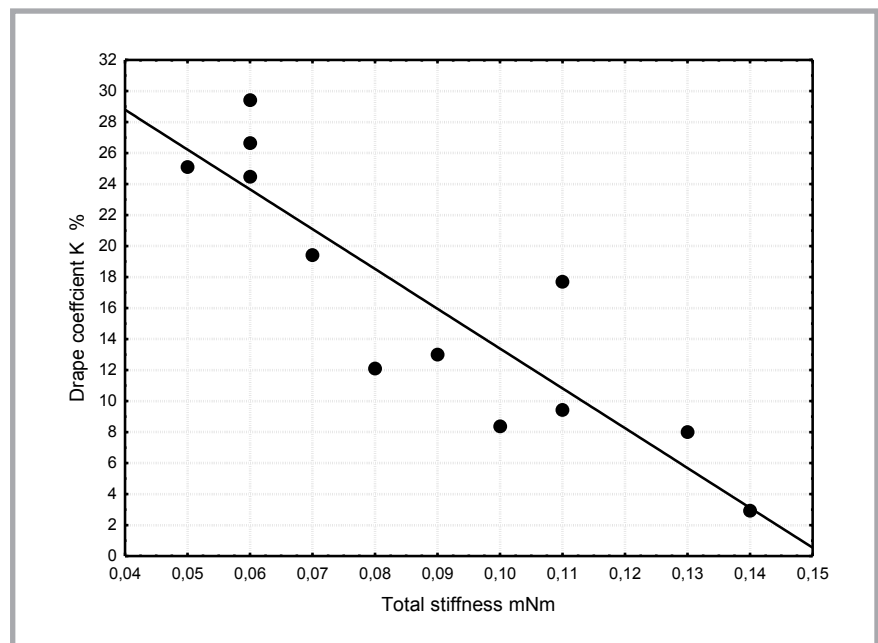


Figure 9. Drape coefficient vs. fabric stiffness

between the drape coefficient K and filling by weft. In both cases it is a negative correlation. The higher the cover by weft and filling by weft, the lower the drape coefficient K . Statistical analysis (linear correlation test) also showed that the correlation between the drape coefficient K and integrated fabric structure factor φ according to Milašius is rather weak (**Table 5**).

However, as we can see in **Figure 10** (see page 62), the fabrics investigated create a non-homogeneous group. A lack of ho-

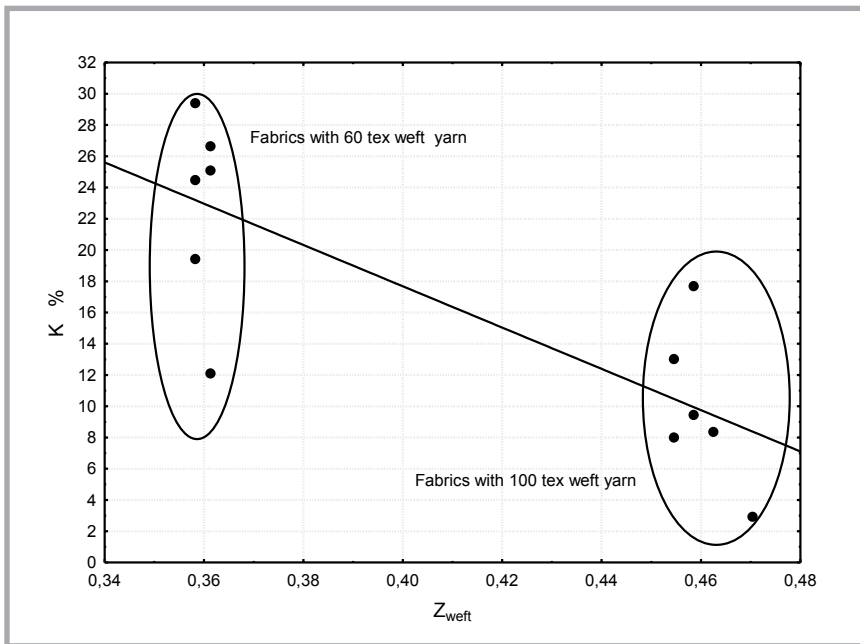


Figure 10. Relationship between the cover by the weft and drape coefficient.

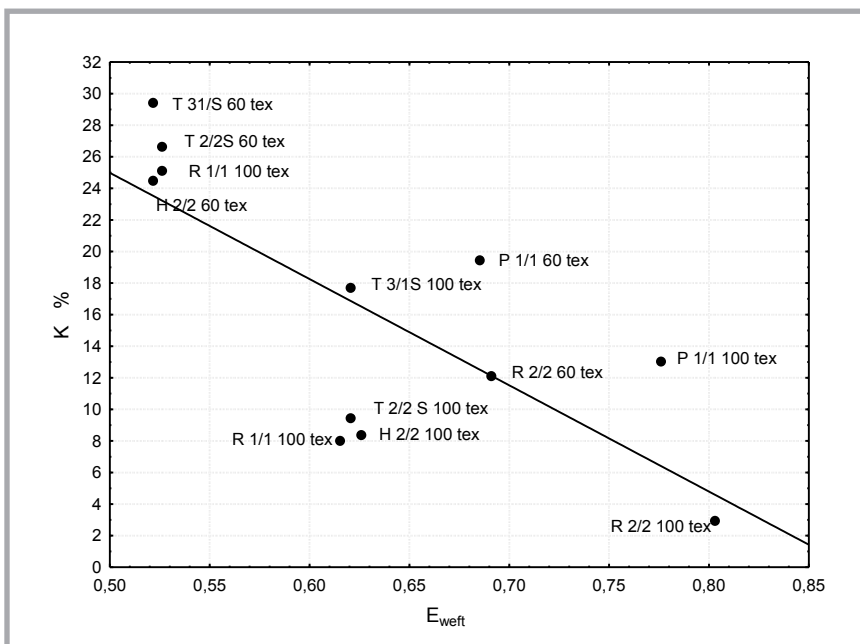


Figure 11. Relationship between the filling by weft and drape coefficient.

Table 5. Correlation between the drape parameters and parameters characterizing the fabric structure.

Parameter characterizing the fabric structure	Value of the correlation coefficient between the structural parameters of the fabrics and	
	drape coefficient K	shape factor k
Cover by warp	0.230	0.464
Cover by weft	-0.802	-0.697
Cover by both warp and weft	-0.665	-0.382
Filling by warp	-0.105	-0.230
Filling by weft	-0.756	-0.658
Total filling	-0.052	-0.148
Integrated fabric structure factor according to Milašius	-0.432	-0.348

mogeneity in the set of data from which a correlation was calculated can be a factor that creates bias in the value of the correlation.

The cover by weft is calculated on the basis of the weft yarn diameter and weft density. It does not take into consideration the warp yarn and weave. Within the framework of the fabrics investigated there are two groups: the fabrics made of 100 tex weft yarn and those made of 60 tex weft yarn. Both groups differ from each other in the range of the cover by weft due to the difference in the linear density of the weft yarn and, at the same time, in the weft yarn diameter.

When analysing both groups separately, in the group of fabrics made of 60 tex weft yarn we can distinguish two values of the cover by weft: 35.82% and 36.13%. Due to the fact that the diameter of the weft yarn is the same for all fabrics in the group, the difference results from the weft density of the fabrics, which is:

- 11.7 per cm for fabrics No. 2, 4 and 12,
- 11.8 per cm for fabrics No. 6, 8 and 10.

However, the difference in the weft density is very small, which can be in the range of measurement error. Due to this fact, in the group of fabrics made from 60 tex weft yarn, the difference in the cover by weft is also very small (0.31%) and does not explain the difference in the drape coefficient, ranging from 12.10% till 29.41%.

The same situation occurs in the group of fabrics made of 100 tex weft yarn, where the weft density ranges from 115 per dm to 119 per dm. The difference in cover by weft is a little bigger than in the case of fabrics made of 60 tex weft yarn, which is 1.58%, whereas the difference between the drape coefficients of the fabric in this group is 18%. In this group there is a negative correlation ($R_{x,y} = -0.549$) between the drape coefficient and cover by weft, but we cannot state that the cover by weft is a crucial factor influencing the drapability of fabrics. It can be explained by the fact that the cover factors calculated according to the *Equations* given: (58), (6) and (7) do not take into consideration the weave of fabrics. Due to this fact the cover factors for fabrics of the same weft and warp yarns and weft and warp densities have the same or very similar values irrespective of the fabric weave.

From the point of view of the filling by weft, the set of the fabrics investigated

is more homogeneous (Figure 11) than from the point of view of the cover by weft. Both filling parameters: filling by warp and filling by weft, take into consideration the weave of fabric. Due to this fact the fabrics made of the same warp and weft yarns and the same number of picks and ends but of different weave are characterized by different values of filling by warp and weft. This causes a difference in the drape coefficient K between fabrics of different weaves. Due to this fact we can state that the high value of the correlation coefficient between the drape coefficient K and filling by weft expresses a real influence of the filling by the weft on the drape coefficient K .

In the majority of the samples investigated, the shape factor k is equal or bigger than 1.0 (Table 4), which means that the maximal size of the folded fabric projection in the warp direction is bigger than the maximal size of the folded fabric projection in the weft direction. The value of shape factor k demonstrates how uniform the fabric drapeability is in both directions: warp and weft, which is very important information for clothing designers, especially from the point of view of clothing behavior during usage. An assessment of the shape factor k is also useful for correct simulation of clothing fit to the user's body by means of CAD/CAM systems commonly applied all over the world in the clothing industry to design clothing goods.

In the majority of cases, the fabrics investigated are characterized by better drapeability in the weft than in the warp direction. On the basis of the experimental results it was stated that the shape factor k is significantly influenced ($R_{x,y} = 0.736$) by the difference in fabric stiffness in the warp and weft directions. Figure 12 presents the relationship between the shape factor k and ratio of stiffness in the warp direction to stiffness in the weft direction, calculated according to the following equation:

$$S_r = \frac{S_{warp}}{S_{weft}} \quad (14)$$

where:

- S_r – stiffness ratio,
- S_{warp} – stiffness in warp direction,
- S_{weft} – stiffness in weft direction.

The value of shape factor k results from the relation between the warp and yarns, as well as their density and thickness, assuming that both yarns are made of the

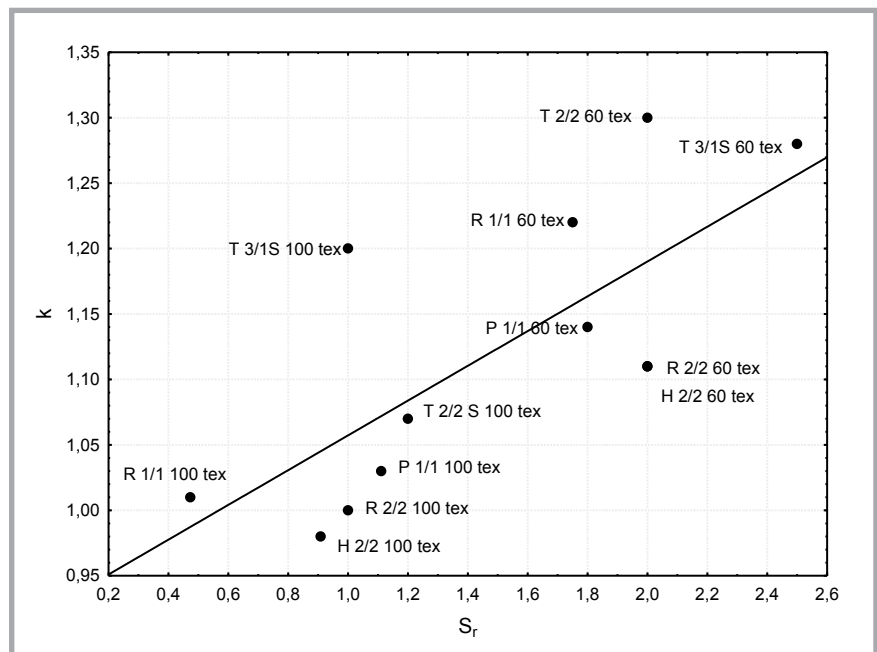


Figure 12. Relationship between the shape factor k and ratio of stiffness in warp direction to stiffness in weft direction.

same raw material. When warp and weft yarns are manufactured from different fibers, the properties of fibers, especially their stiffness, additionally influence the drapeability of fabrics in both directions and, at the same time, the shape factor k .

In experiment presented, values of the shape factor k of fabrics made from 100 tex weft yarn are much lower than for fabrics made from 60 tex weft yarn, resulting from higher stiffness in the weft direction of fabrics made from 100 tex weft yarn in comparison to that of fabrics made from 60 tex weft yarn. On the basis of the set of fabrics examined, it was also stated that in both groups of fabrics: made of 100 tex and 60 tex weft yarns, the highest value of shape factor k occurred for fabrics of twill 3/1 S and 2/2 S weaves.

Summary

On the basis of the investigations presented, it was stated that structural parameters of woven fabrics influence the ability of fabrics to drape. Fabrics of the same linear density of weft and warp as well as of the same number of picks and ends are characterized by different values of the drape coefficient K due to different weaves. Among the weaves investigated, the highest value of the drape coefficient K was noted for twill 3/1 S and 2/2 S weaves, and the lowest for the rep 2/2 (2) weave. The linear density of weft yarn

also influences the drapeability of woven fabrics. The fabrics made of 100 tex weft yarn are characterized by a lower value of drape coefficient K than those made of 60 tex weft yarn when other structural parameters are the same. This was due to the fact that higher linear density of weft yarn at the same level of other structural parameters caused higher stiffness of fabrics in the weft direction and, in consequence, higher total fabric stiffness.

Statistical analysis showed that there is a correlation between the filling by weft and drape coefficient K . The results obtained also confirmed a strong and statistically significant negative correlation between the drape coefficient K and fabric stiffness.

The shape factor k characterizes the anisotropy of fabric draping behavior, illustrating how uniform fabric drapeability is in both directions: warp and weft. The investigations performed showed that the value of shape factor k depends on the fabric weave and ratio of stiffness in the warp direction to stiffness in the weft direction.

The values of correlation coefficients between the parameters characterizing the drapeability of the fabrics investigated and their structural parameters are not very high. This is due to the fact that many factors: structural and mechanical, influence the drapeability of fabrics.

There are also interactions between the factors. A higher number of picks and ends as well as a higher linear density of threads cause higher stiffness of fabrics and, in consequence, lower drapeability. At the same time, a higher number of picks and ends and higher linear density of threads give a bigger mass per square meter, causing better drapeability. Finally the drapeability of woven fabric of given linear density of threads and given number of picks and ends is a result of the interactions between both factors mentioned. Additionally it is influenced by the fabric weave.

Conclusion

On the basis of the investigations performed, we can conclude that:

- fabric draping is an anisotropic feature and should be analysed in both warp and weft directions,
- the anisotropy of the draping behavior of the woven fabrics is well characterized by the shape factor k ,
- the value of the drape coefficient K cannot be the only measure of the draping behavior of woven fabrics because it does not take into consideration the anisotropy of fabric drapeability,
- the anisotropy of fabric draping should be taken into consideration while simulating fabric behavior and 3D virtual prototyping.



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