Examination of Dependence of Drape Coefficient on the Samples Size

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The Sylvie 3D Drape Tester is a new measuring device developed for the analysis of the draping properties of fabrics and operates based on optical principles. The other member of the equipment range developed at BME is the Sylvie 3D Body Scanner that measures the human body. The two devices together form a new measuring environment that makes it possible to consider factors neglected before such as the impact of size on the drape coefficient. The drape coefficient of 6 different fabrics was determined at 7 different table and fabric sample size. The paper presents the measurement and the results obtained.

1. Introduction

The spatial deformation of fabrics is a result of a multi-axial loading the impact of which on textiles is usually studied by draping measurements, ball pressure test, hydraulic splitting [1] or biaxial tensile tests [2]. Draping is the 3D deformation of fabrics that occurs due to gravity. Draping is usually measured at a given fabric and table size. However, a value characteristic of a material is the best if it is absolutely or at least in a given range independent from the parameters of the measurement. If a characteristic is not independent from dimensions, then its relation to size has to be determined, hence size-impact studies have to be made.

Size impact in this case refers to the way how the drape coefficient of fabrics changes or whether it changes at all if the size of the table and the fabric is modified proportionally. When this experiment was prepared, not only the measuring systems had to be adapted but also the environment that acts on the fabrics had to be unified. The aim is to carry out a measurement series that consists of six size steps and is completed on three garment and three technical textiles. The results obtained are compared and analyzed by size steps and fabric types.

2. The principle of draping measurement and drape coefficient determination

This chapter details the structural set-up and operation principle of the generally known Cusick Drape Meter as well as the Sylvie 3D Drape Tester and Sylvie 3D Body Scanner developed at BME. The measurements were carried out on the latter two devices.

2.1 The measurement method of fabric draping

Drapability can be characterized in the most direct and complex way with the help of a drape test. During the examination of fabric draping a 300 mm diameter, circular fabric sample is placed on the 180 mm diameter circular table in a way that their centers are exactly fitted. The part of the fabric that overhangs from the table, referred to as the fabric ring, bends down owing to its own weight, and it wrinkles. The size ratio above is selected since in case of most fabrics the fabric ring bends down from the table but does not fall under the table at this size. During the measurement, the projection of the wrinkled fabric ring to the horizontal plane has to be determined. The drapability of the fabric is characterized with the drape coefficient (1) that is the ratio of the area of the planar projection of the wrinkling fabric ring and the area of the non-wrinkling part (Fig. 1).

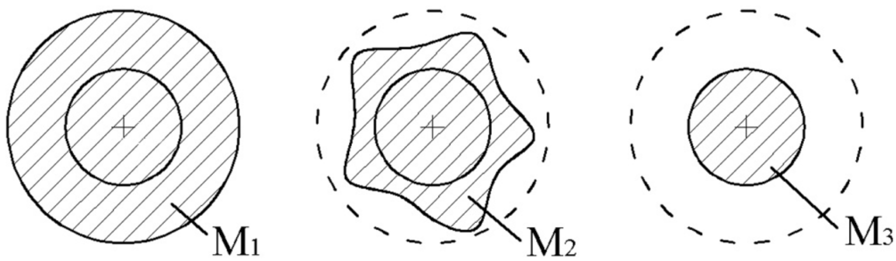


Fig. 1 The planar fabric ring and the planar projection of the wrinkling fabric ring

The drape coefficient:
$$k_D = \frac{M_2 - M_3}{M_1 - M_3} * 100[\%] \tag{1}$$

where: k_D = drape coefficient
M_1 = area of the fabric sample [m^2]
M_2 = area of the planar projection of the wrinkling fabric sample [m^2]
M_3 = area of the sample holding table

Equation (1) clearly reveals that the stiffer the fabric is, the higher the value of the drape coefficient, while softer textiles that are easier to shape have lower drape coefficients. In case of the different measurement devices, the area of the projection of the wrinkling fabric ring is determined in a different way. The measurements provide results for more parameters that also characterize the drapability of textiles. These parameters are – among others – the following:

- Number of waves (pieces)
- Minimal radius (mm)
- Maximal radius (mm)
- Average radius (mm)
- Radius deviation (mm)

2.2 Set-up and operation principle of the Cusick Drape Meter

Fig. 2 illustrates the structural set-up of the Cusick Drape Meter.

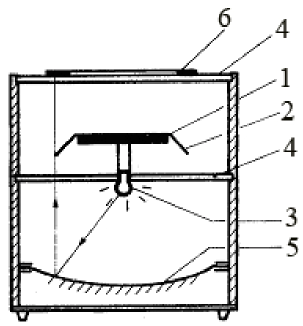


Fig. 2 Cusick Drape Meter

1. Machine table
2. Sample
3. Light source
4. Top and bottom glass plate
5. Concave mirror
6. Ring of paper

The parallel light beam formed by the light source (3) and the concave mirror (5) found below the circular sample holding table (1) projects the shadow of the bent, wrinkled sample (2) to the transparent paper (6) placed on the top glass plate (6). The shadow is recorded with a camera, and based on it the drape coefficient and other parameters can be determined with computer image processing. The 300 mm, circular sample is cut out with a special cutting device that belongs to the measuring equipment. Due to the structure and construction of the system (Fig. 2) fabrics that bend down below the table cannot be measured this way.

2.3 Measuring drapability with the Sylvie 3D Drape Tester

Recently image processing is applied in a wider and wider range, also in materials testing [3, 4] in order to scan a deformed shape or surface and to determine material characteristics this way [5]. The Sylvie 3D Drape Tester [6] developed at BME measures the wrinkling of textiles based on spatial scanning, and it is also capable of determining the mechanical parameters necessary for the computer simulation of textiles. The computer program package that belongs to the measuring device first reconstructs the spatial shape of the wrinkling textile, calculates the drape coefficient and other parameters, and then runs the simulation program with the changed parameters until it finds the simulated shape that approximates the reconstructed shape in the best way. The mechanical parameters of this simulated shape are the simulation parameters of the examined textile. The further development, testing and fine tuning of this system is still in progress.

Fig. 3 illustrates the Sylvie 3D Drape Tester. The 180 mm diameter, circular table of the device is sunk into the base plate so that they are at one level and form a plane. The 300 mm diameter, circular fabric sample to be examined has to be placed on the table in a way that its center is exactly fixed to the center of the table with the help of a pin. It is important to have the warp and weft yarns of the fabric parallel to the requested direction. The table is raised with a motor driven by a computer and this way it is ensured that the wrinkles of the textiles are always formed at the same speed under the same dynamical circumstances.

During the measurement the 4 laser line emittents project a light line on the fabric, and it is recorded by the 4 cameras placed on the measuring frame above the line emittents. The height of the frame is moved with a set step distance every time and the equipment scans the wrinkling textile and reads its surface. The equipment driven by the computer is built in a black box and this way it is ensured that the measuring space is black. The images are downloaded on the computer after each step of photography.

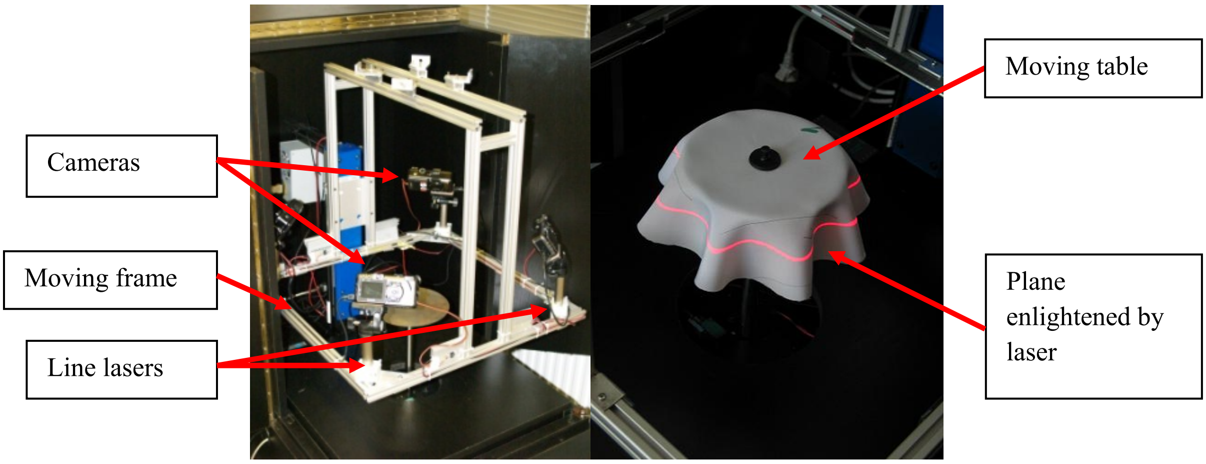


Fig. 3 Sylvie 3D Drape Tester

The image processing software processes the images recorded by the cameras (Fig. 4 left side) from the 4 sides using the calibration data, and unites the points of the curve characteristic of the section and the data obtained from the 4 images into one file.

Cross section curves are approached by a slice of Fourier series in the polar coordinate system (2). Size of the slice can be defined by the software.

$$R_{(\varphi)} = \frac{1}{2}a_0 + \sum_{i=1}^{n} a_i \cos(i\varphi) + \sum_{i=1}^{n} b_i \sin(i\varphi) \qquad (2)$$

Fourier coefficients are defined by the least square method. If the N measured cross section points of the actual level are (R_k,φ_k) then the a_i, b_i coefficients are defined by the minimum of a function (3).

$$\sum_{k=1}^{N}\left\{R_k-\left[\frac{1}{2}a_0+\sum_{i=1}^{n}a_i\cos(i\varphi_k)+\sum_{i=1}^{n}b_i\sin(i\varphi_k)\right]\right\}^2=\text{minimum} \tag{3}$$

The point distribution determined at the current level and its approximation curve can be seen in Fig. 4.

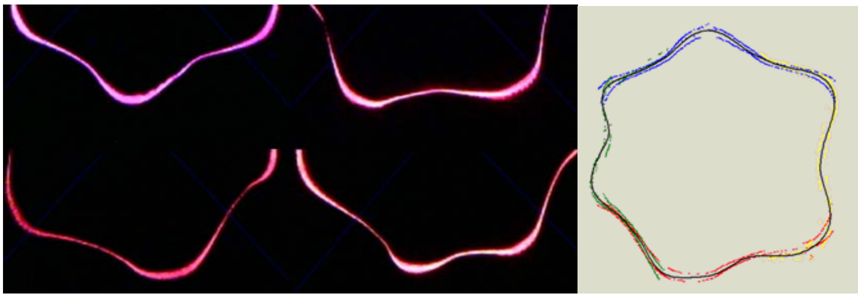


Fig. 4 Four pictures of cross section curves and the reconstructed cross section

Since this equipment take the photographs from the sides, it can see under the table (not like the Cusick Drape Meter), hence the drape coefficient can be calculated even if the wrinkles of the fabric fall under the table. In this special case the drape coefficient can be negative, but can be interpreted.

2.4 Measurement of drapability with the Sylvie 3D Body Scanner

The equipment was developed originally for taking unique sizes by the same research group at BME that also prepared the Sylvie 3D Drape Tester [7, 8]. The operation principle of the device is basically the same as that of the drape tester, however there is a significant difference since the spatial surface of humans or objects of the size of a human being can be scanned with this device. This fact makes it possible to use different table and fabric sizes.

The measuring device consists of three major parts (Fig. 5).

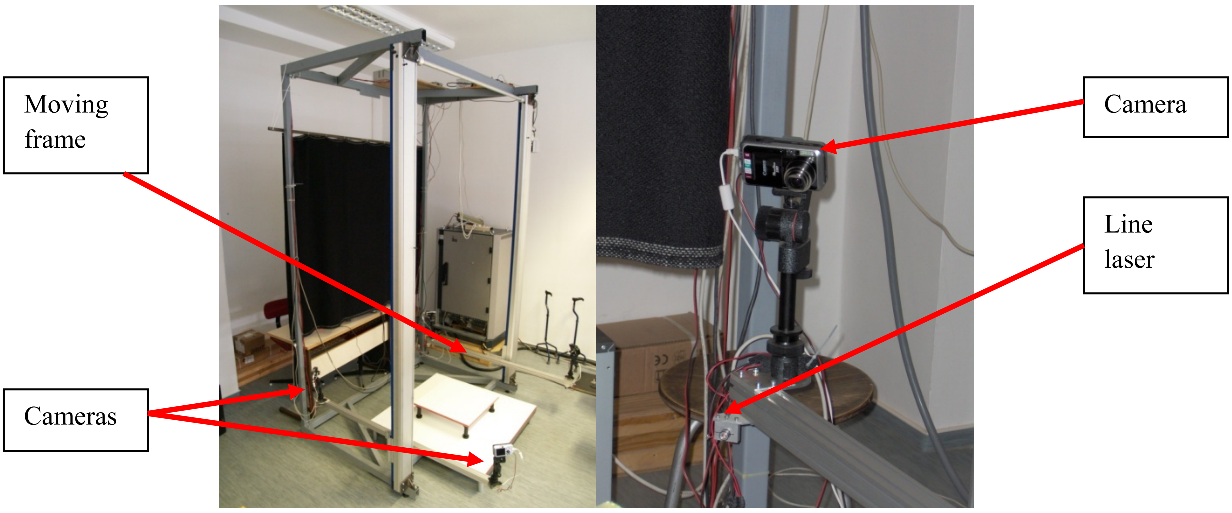


Fig. 5 Sylvie 3D Body Scanner

The first part is the mechanical structure of the equipment, the stability of which as well as the size accuracy and surface quality necessary for the guidance of the optical unit are provided with an aluminum frame. The second major part is the optical unit that involves the moving frame as well as the 4 line lasers and the 4 cameras that take the images. These parts are fixed at a given distance and move up and down together in the vertical direction. The third main part is the computer control, data collection and evaluation system that is the same as in case of the Sylvie 3D Drape tester, hence the measurements can be carried out under the same circumstances with the two devices.

3. Experiments

With the help of the two measuring devices that operate on the same principle, a special measurement series could be carried out.

3.1 Experimental materials

6 different fabrics, three garment and three technical textiles were chosen for the measurements. The selection criteria were that the fabrics should have different structures and raw material content, and hence represent a wide range of samples to be tested. Table 1 summarizes the most important characteristics of the selected fabrics, while Table 2 involves the images that show their structure.

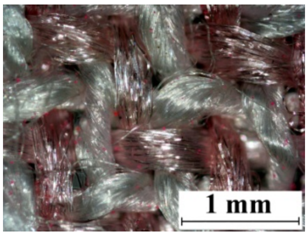
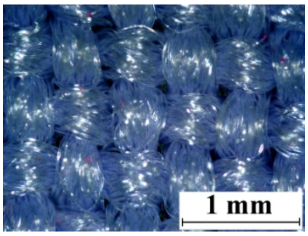
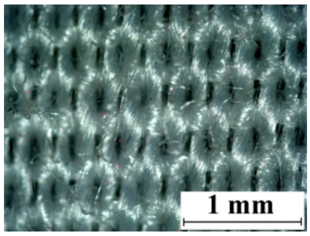
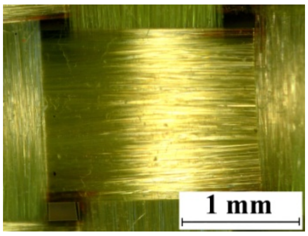
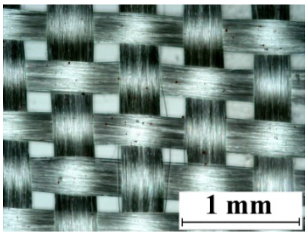
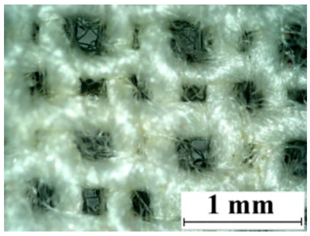
Tab.1 The properties of the fabrics

Nr.	**Raw material content**	**Weave**	**Warp**	**Weft**	**Fabric thickness* [mm]**	**Fabric mass [g/m²]**
			Density [yarns/10 cm]			
1.	65% Cotton 35% PES	2/2 Twill	260	260	0.40	170
2.	100% PES	Plain	220	220	0.50	175
3.	50% Cotton 50% PES	Plain	540	280	0.25	110
4.	100% Kevlar®	Plain	70	70	0.26	170
5.	100% Glass	Plain	240	180	0.04	49
6.	100% Cotton	Plain	230	220	0.47	140

* Fabric thickness at the load of 0.49 cN cm^{-2}

Technical textiles were chosen from three base materials that all behave differently. The application of Kevlar and glass fiber is well known from the field of composites [9]. In case of the glass weave, the specific weight was chosen to be low (49 g/m^2) so that the fabric is adequately flexible and show a draping that can be registered at the selected size ratios although glass fiber itself is rigid and brittle. The third technical textile is a cotton weave applied as a carrier material for canopy production.

Tab.2 The view of the fabrics

<table>
<tr><td rowspan="2">Garment textiles</td><td>Sample Nr.: 1.</td><td>Sample Nr.: 2.</td><td>Sample Nr.: 3.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Technical textiles</td><td>Sample Nr.: 4.</td><td>Sample Nr.: 5.</td><td>Sample Nr.: 6.</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

3.2 Preparation of samples

The aim was to measure the drape coefficient at different table sizes. In this case, it had to be ensured that all the other factors influencing the measurement should remain the same so that the examinations can be compared. The question is what size of fabric samples should be used for the different table sizes so that the other circumstances that influence the measurements remain the same. The size of the tables and the correspondent fabric size were determined in a way that the linear stress that acts on the fabric along the perimeter of the table remain the same as in case of the usual table-fabric size ratio. This linear stress can be calculated based on Fig. 6 with Equation (4).

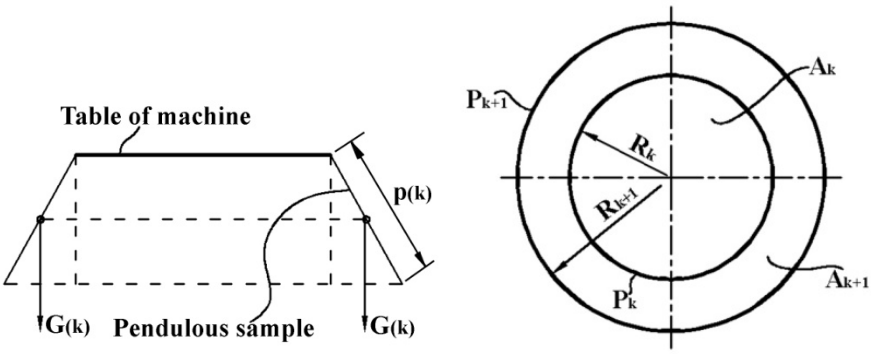


Fig. 6 The relation of table and fabric size applied in drape tests

$$f_k = \frac{G_k}{P_k} = \frac{(A_{k+1} - A_k) * Q * g}{P_k} \tag{4}$$

A further aspect was that the larger table sizes were also templates for cutting out the circular examination samples, since the unique cutting of exactly circular fabric samples is not a simple task. Hence a special size range was formed in which the fabric sample (300 mm diameter) that belongs to the usual table size (180 mm) is the size of the next table, as well. Then the fabric size was calculated and it was chosen as the next table size, and so on. Equations (5) and (6) show that the linear stress is the same in case of all successive t where :s.

$$f_k = f_{k+1}, \qquad k = 1,2,3,\ldots,n \tag{5}$$

$$\frac{(A_{k+1} - A_k) * Q * g}{P_k} = \frac{(A_{k+2} - A_{k+1}) * Q * g}{P_{k+1}} \tag{6}$$

After simplification and reordering the following equation is obtained:

$$\frac{P_{k+1}}{P_k} = \frac{A_{k+2} - A_{k+1}}{A_{k+1} - A_k} \rightarrow A_{k+2} = A_{k+1} + (A_{k+1} - A_k)\frac{P_{k+1}}{P_k} \tag{7}$$

After the substitution of perimeter and area values and reordering:

$$R_{k+2} = \sqrt{R_{k+1}^2 + (R_{k+1}^2 - R_k^2)\frac{R_{k+1}}{R_k}} \tag{8}$$

Where:	Q	=	area density [kg/m^2]
	k	=	number of the table
	k+1	=	number of the fabric that belongs to the k-th table
	A	=	area of the table and the fabric [m^2]
	R	=	radius of the table and the fabric [m]
	G	=	weight of the bent fabric part [N]
	g	=	gravitational acceleration [m/s^2]
	f	=	linear stress from the weight force along the perimeter of the table [N/m]
	P	=	perimeter of the table [m]

Based on the initial condition, recursive formula (8) can be defined for the calculation of successive table sizes that is independent from the area density of the examined fabric since the first two elements of the series are known. Table 3 involves the radius values calculated from radius index, k=2 with formula (8). The series can be continued for table radii smaller than R_2. These can be calculated with Equation (9) that is the reordered form of Equation (8).

$$R_{k+1} * R_k^2 + (R_{k+2}^2 - R_{k+1}^2)R_k - R_{k+1}^3 = 0 \tag{9}$$

Tab. 3 Radius values calculated with the recursive formula

k	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R_k [mm]	9,628	40,415	90,000	150	215,638	284,608	355,724	428,317	501,982	576,457	651,564
q_k [-]	4,197	2,226	1,666	1,437	1,319	1,249	1,204	1,171	1,148	1,130	1,116
p_k [mm]	30,786	49,584	60,00	65,638	68,970	71,115	72,592	73,665	74,475	75,107	75,622
r_k [-]	0,761	0,551	0,404	0,304	0,242	0,199	0,169	0,146	0,129	0,115	0,104

q_k = ratio of the successive radii, i.e. $q_k=R_{k+1}/R_k$

p_k = difference of the successive radii, i.e. $p_k=R_{k+1}-R_k$ (Fig.6)

r_k = ratio of the difference and the radius, $r_k=p_k/R_k$

The radius series obtained this way has valuable properties. Table 3 contains the ratio (q_k), difference (p_k) of the successive radii and the ratio of the difference and the radius (r_k). Fig. 7 illustrates the dependence of q_k, p_k and r_k on the radius.

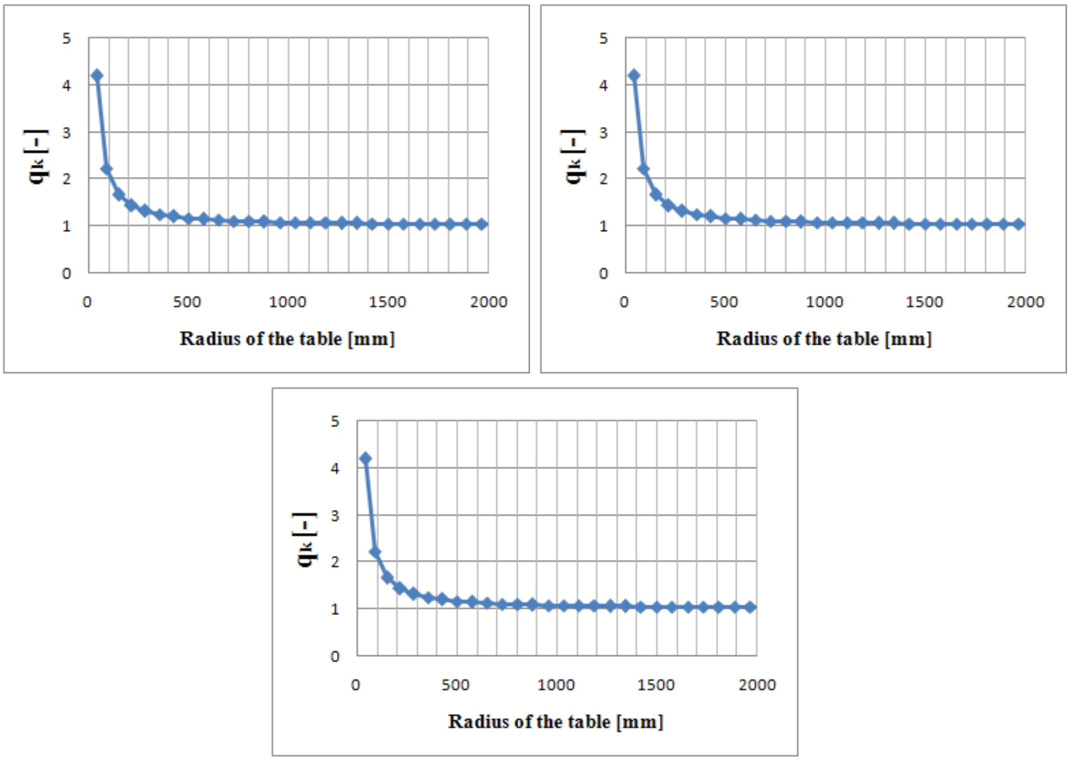


Fig. 7 Relations of the successive radii

If q_k, p_k and r_k are graphed as a function of radius R_k (Fig. 7), it can be seen that if R_k converges to infinity, then all the three values converge to a finite limit value but p_k in a monotonously increasing, while q_k and r_k in a monotonously decreasing way.

Due to the geometrical sizes of the Sylvie 3D Body Scanner the maximum table size cannot be more than 1000 mm. Based on all these, 6 table-fabric pairs were created. Table 4 summarizes the data of the 6 measurement series.

There was no problem with the table of 180 mm diameter that belongs to measurements series A since it is a standard accessory of the Sylvie 3D Drape tester. However, the tables of other sizes (B,…F) had to be manufactured separately, in a unique way. Fig. 8 shows the prepared tables.

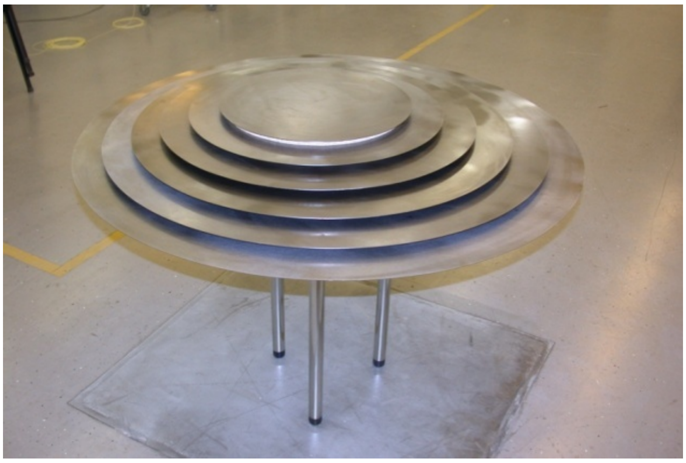


Fig. 8 Tables used in the measurements

Finally, the samples to be examined were cut out of the selected fabrics using the prepared tables as cut-patterns in the sizes revealed in Table 4.

Tab. 4 Sizes of the tables and the fabrics, measurement plan

Series	Diameter of Table (mm)	Diameter of Sample (mm)	Measuring equipment
A	180	300	Sylvie 3D Drape Tester
B	300	431,26	Sylvie 3D Body Scanner
C	431,26	569,20	
D	569,20	711,44	
E	711,44	856,62	
F	856,62	1003,96	

3.3 The measurement

The fabric measurements were carried out according to the measurement plan shown in Table 4. The images of Fig. 9 illustrate the measurements carried out with the tables of different size.

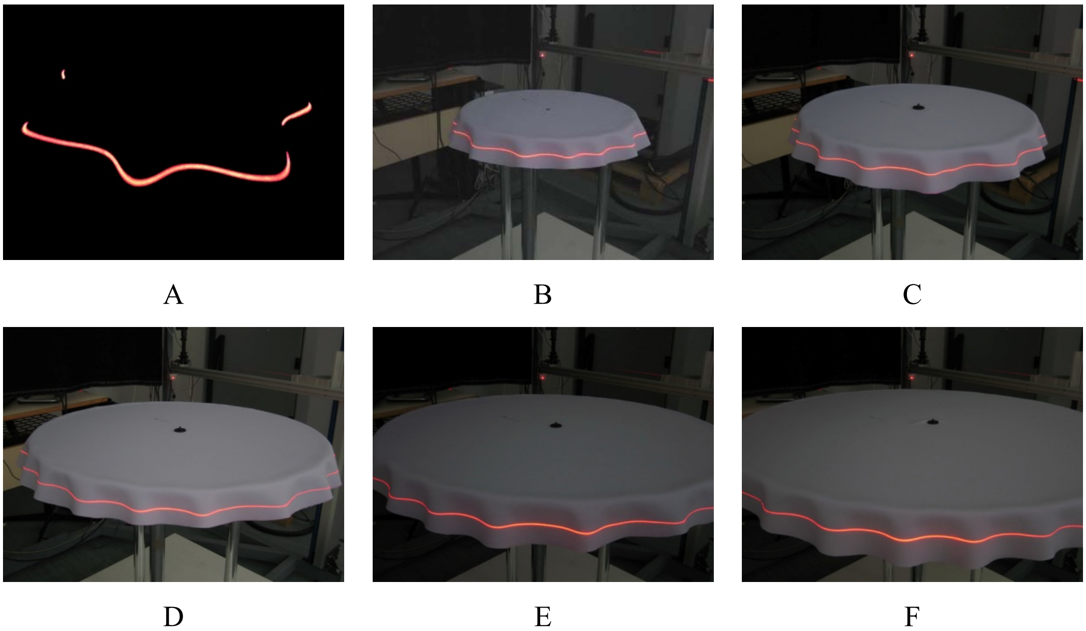


Fig. 9 Measurement with tables of different size (A…F table-fabric series)

A result obtained from the measurements for sample Nr. 1 as an example is summarized in Table 5.

Tab. 5 Data available from the processing program

Sample - Nr.: 1.						
Series	A	B	C	D	E	F
Diameter of Sample (mm)	300	431.26	569.20	711.44	856.62	1003.96
Diameter of Table (mm)	180	300	431.26	569.2	711.44	856.62
Drape coefficient (%)	**40.7**	**32.4**	**28.8**	**27**	**23.7**	**13.4**
Number of waves (pieces)	7	10	15	18	20	18
Minimum radius (mm)	94.9	132.3	155.3	222.6	290.5	229.2
Maximum radius (mm)	143.9	286.3	326.8	398.8	465.5	505.3
Average radius (mm)	117.5	162.6	232.6	301.6	371.3	437.8
Radius deviation (mm)	14	48	51.6	51.9	52.3	41.4

4. Results and discussion

The most characteristic parameter among the measured ones is the drape coefficient, hence the results are compared based on it. The obtained drape coefficients are summarized in Table 6.

Tab. 6 Drape coefficients obtained from the measurement.

Series	Rad. of Table	Drape coefficient (%)					
		Nr. 1.	Nr. 2.	Nr. 3.	Nr. 4.	Nr. 5.	Nr. 6.
A	90	40.7	50.3	49	97.3	77.7	95.7
B	150	32.4	40.8	44.9	93.6	62.6	79.1
C	215.63	28.8	36.5	43.1	93.5	57.3	71.4
D	284.6	27	34.4	39.3	96.3	55.4	73.8
E	355.72	23.7	29.4	35.2	79.4	46.5	63.1
F	428.31	13.4	16.3	22.5	46.9	19.9	44.9

Table 6 clearly reveals that the answer to the question whether the drape coefficient of woven fabrics changes with increasing the table size is obviously yes. The obtained results are illustrated in Fig. 10.

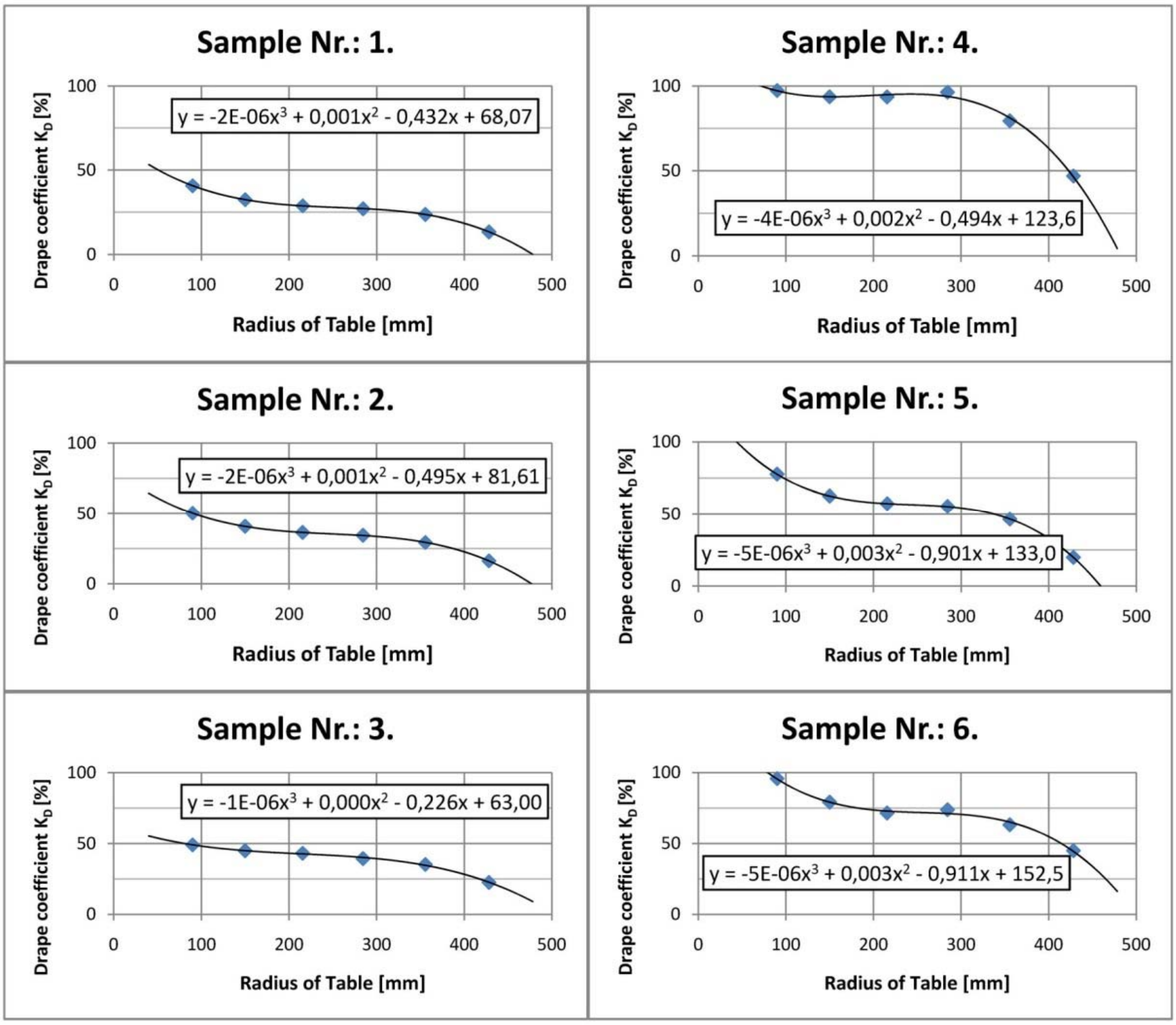


Fig. 10 Drape coefficients as a function of table radius by different fabric materials

It can be concluded from the diagrams that for all material types the drape coefficient decreases if the table radius increases in case of the applied table-fabric size ratios. A polynomial of third order can be fitted to the measurement points in case of all materials as a good approximation (Fig. 10).

Similar characteristics can be found in case of all examined materials if the approximation curves are studied. The decrease of the drape coefficient is a logical consequence of the increase in the table radius. This is supported by the fact that the value of q_k (Table 3) converges to 1 in a monotonously decreasing way, while the value of p_k (Table 3) approaches 80 mm in a monotonously increasing way if k, or the table radius converges to infinity (Fig. 7). Let us characterize the fabric part that has to wrinkle with the difference between the perimeter of the fabric sample and table and relate it to the perimeter of the table. This characteristic can be expressed using r_k (Table 3).

$$\frac{2\pi R_{k+1} - 2\pi R_k}{2\pi R_k} = \frac{R_{k+1} - R_k}{R_k} = \frac{p_k}{R_k} = r_k \tag{10}$$

If the value of r_k (Fig. 7) is examined, it can be seen that if k or the table radius converges to infinity, since p_k converges to a finite limit value, r_k converges to 0. The larger the table radius is, the smaller ratio of the difference between the fabric perimeter and the table perimeter belongs to one unit of the table perimeter, i.e. less material has to wrinkle. In limit cases, if R converges to infinity, meaning that the perimeter of the table converges to a line, the fabric bends down in a less and less wrinkled way, and finally without wrinkling, and the drape coefficient converges to 0.

According to our measurements (Fig. 10) the drape coefficient can reach 0 already at ca. 500 mm table radius, even though the fabric still wrinkles. This is a consequence of the fact that the wrinkles at this size already fall under the table. The wrinkles that fall under the table result in negative areas on the planar projection of the wrinkling fabric based on the definition of the drape coefficient (1). If the table radius increases, the amount of the negative area parts can reach or even surpass the amount of positive area, and hence the drape coefficient in this case can be around 0. The advantage of the applied measuring device is – among others – that it can also be used when the wrinkles are under the table. However, the fact that the value of the drape coefficient can be 0, while the fabric still wrinkles raises the need for the reconsideration of the definition of the drape coefficient.

It is an interesting fact that according to the third order approximation curve (Fig. 10) the drape coefficient approaches 0 at around 500 mm table radius, apparently independently from the material type.

If the value of the radius is not increased but decreased, then the drape coefficient increases. The drape coefficient of the much stiffer technical textiles reaches the maximal 100% already at 50-90 mm table radius. This means that these fabrics at this table-fabric size ratio cannot produce any wrinkles, and behave as rigid discs. The drape coefficient of softer garment textiles supposedly would not reach 100% even at R=0.

5. Conclusion

The paper presented the application of the two new measuring devices, the Sylvie Drape Tester and the Sylvie Body Scanner for a new task. The size dependence of the draping properties of fabrics was examined successfully. It can be concluded based on the measurement results that the drape coefficient decreases if the table radius increases, and this corresponds to the theoretical considerations. If the work is continued, i.e. more size steps and more fabric samples are examined, several other questions can be answered such as why the table radius – drape coefficient graph has an inflection point or why the drape coefficient becomes 0 at 500 mm table radius. This measurement could also contribute to the determination of the mechanical properties that influence draping. To sum it up, this examination can be a good starting point of a comprehensive research work on the draping behavior of fabrics.

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