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MEASURING THE SHAPE-CHANGING ABILITY OF TEXTILES BY DRAPE TEST WITH ANGULAR SAMPLE-HOLDING TABLE

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Abstract:

The goal of this work was to make the results of the drape measurement clearer. Draping is a 3D, complex shape change caused by gravity. It characterizes the ability of textiles, with low bending stiffness to adapt to the shape of an object in a complex way. In a draping test, a circular sample is placed on a circular sample-holding table, its edges are allowed to bend down, and then the draping coefficient and the number of waves are calculated based on its planar projection. However, both factors have a large standard deviation, and strangely, the number of waves is not unambiguous. In our research, we replaced the circular table with regular, polygonal sample-holding tables of 3-15 corners, which had the same area. We compared the results obtained on the polygonal sample-holding tables with the results measured on the circular table. In our article, we present the course of the research, the testing equipment, the tested 7 types of fabrics, and the results obtained. Our results prove that with the use of a polygonal sample-holding table, the number of waves can be clear, the size and arrangement of the waves can be uniform, and so the uncertainty of the measurement results can be reduced. Based on the data, the optional use of the hexagonal sample-holding table can be recommended, especially for comparative testing of fabrics for the same purpose.

Keywords: *Material science, Engineering, Textile testing, Draping, Shape change, Sheet-like materials*

1. INTRODUCTION

One of the important properties of textiles is the ability to adapt to the shape of an object. We can speak of low bending stiffness if the tested sheet-like material bends under its own weight and is unable to retain its shape. Draping is a 3-dimensional, complex change in shape caused by gravity, which characterizes the ability of the given material to adapt to the shape of an object in a complex way. Draping deformation is a very important and much-researched property of textiles in terms of both their use and the computer simulation of their behaviour.

Draping is measured according to the ISO standard [1], which uses the most accepted Cusick method [2]. During the test, the circular sample, usually 300 mm in diameter, is placed on the circular sample-holding table of 180 mm in diameter, letting the sample edges bend under the influence of gravity, i.e., to drape. The image of the draping sample is projected onto a horizontal plane, and the draping coefficient and the number of waves are determined from this image. Fabrics are usually compared based on these parameters (Fig. 1). The draping coefficient (*DC*) is calculated based on the generally accepted definition according to Formula (1). The lower the draping coefficient, the more flexible and softer the sample is; the higher the value of *DC*, the stiffer the sample is. In addition to the draping coefficient and the number of waves, some other parameters are also determined [3].

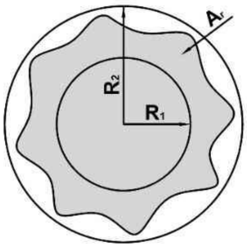


Figure 1: Planar projection of the draped sample

$$DC = \frac{A_r - \pi R_1^2}{\pi R_2^2 - \pi R_1^2} \cdot 100\ [\%] \tag{1}$$

where:
DC is the draping coefficient,
A_r is the area of the planar projection of the draping textile,
R_1 is the radius of the sample-holding table, and
R_2 the radius of the sample before draping (Fig. 1)

The most widely used equipment is the Cusick Drape Tester [2]. In it, the light of a point light source placed under the sample table is converted into a parallel light beam by a concave mirror and directed upwards. This parallel light beam creates the planar projection shadow image of the draped sample on the surface of limited translucency placed above the sample table. This shadow image was initially copied by hand onto a sheet of paper, and the area of the shadow image was then determined based on the specific mass of the used paper. Much research has been devoted to automating the collection and evaluation of the data required to determine the draping coefficient and the number of waves [4-10].
However, it became obvious that the draping coefficient and the number of waves also have a large standard deviation, and their value greatly depends on the circumstances of the formation of the waves [3, 11-14]. Determining the number of waves is often a challenge. The draping coefficient is clear based on the projection area, while the number of waves must be counted separately. However, the number of waves is not clear in many cases, and even for the same sample, it is often not the same in successive measurements. Sometimes, it is not possible to clearly decide where a wave begins and where it ends based on the outline of the planar projection. It is also a problem that if the number of waves is not the same in two draping tests of the same fabric sample, the draping coefficient will also be different. Another problem is that the number of waves of an already draping fabric can be changed with a small external intervention, for example, by hand [15].
In this study, we aimed to make the number of waves unambiguous and investigate how this intervention affects the draping coefficient. In order to do this, we replaced the circular sample-holding table of the Cusick Drape Tester with polygonal tables of the same area and investigated how the number of corners of the table affects the draping coefficient and the number of waves.

2. EXPERIMENTAL

2.1 Materials

We chose seven fabrics of different materials and structures for our tests. The data of the fabrics is contained in Table 1. We defined the data as the average of 5-5 measurements in order to make the fabrics comparable. We calculated the bending length based on the Cantilever test and shear stiffness as the slope of the specific shear force – shear angle diagram between the shear angles of 0.5 and 5 degrees, according to the Kawabata Evaluation System.
From each of the selected fabrics, three circular test samples were cut with a diameter of 300 mm so that the samples came from areas containing different yarns.

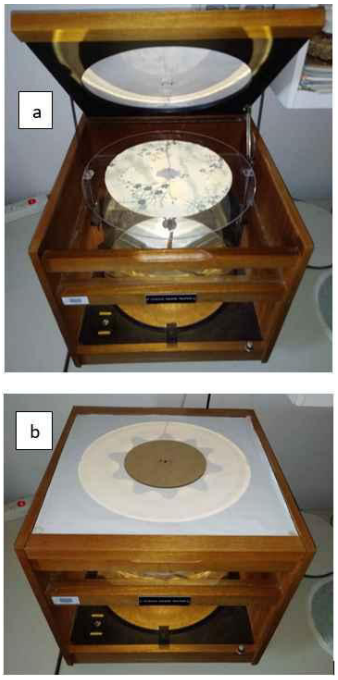
Table 1: The basic parameters of the examined fabrics

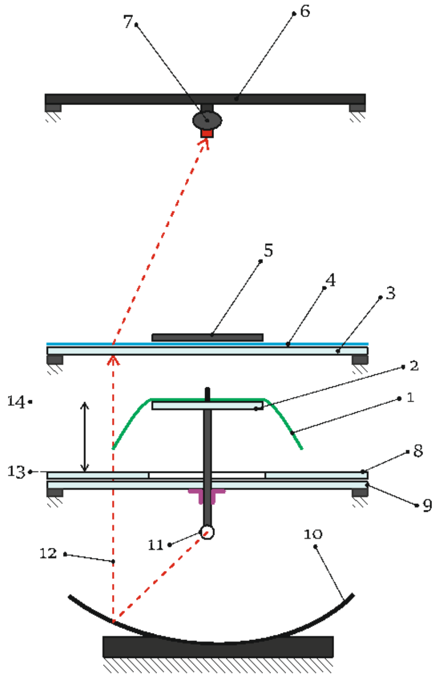
Designation of sample	Material	Fabric structure	Mass [g/m^2]	Thickness [mm]	Bending length [mm]		Shear rigidity $[\frac{N}{m \cdot °}]$	Yarn density [piece/cm]		Yarn count [Tex]	
					warp direction	weft direction		warp	weft	warp	weft
1	PES	Plain woven	158,7	0,35	25,0	18,0	2,86	57	32	11,7	8,3
2	PES	Nonwoven	52,6	0,28	51,0	56,0	20,14	-	-	-	-
3	Flax	Plain woven	132,3	0,32	27,5	20,5	1,62	21	21	43,7	26,1
4	Cotton	Plain woven	107,6	0,25	19,5	14,0	2,71	39	28	14,5	21,5
5	PES	Knitted fabric	181,5	0,75	29,0	20,0	0,83	-	-	27,5	
6	PES	Twill woven	192,7	0,38	26,0	13,0	1,95	30	42	28,3	21,9
7	Flax	Plain woven	192,3	0,50	16,0	13,0	1,79	18	15	56,7	58,6

From each of the selected fabrics, three circular test samples were cut with a diameter of 300 mm so that the samples came from areas containing different yarns.

2.2 Methods

For the tests, we used the Cusick Drape Tester equipment, whose operation we mostly presented in the introduction. Fig. 2 shows the Cusick Drape Tester equipment, and Fig. 3 shows its operation.
We supplemented the equipment (Fig. 3) with a digital camera placed above the device and a computer performing the evaluation. During the preparation of the test, the lifting-lowering table (8) is in the preparation position (14), at the same level as the sample-holding table (2) (Fig. 2a). The 300 mm diameter test sample must be placed centrally on the sample-holding table at this point. This is followed by the lowering of the lifting-lowering table (8) to the measurement position (13), as a result of which waves form on the fabric. The light beam created by the parabolic mirror (10) projects the planar projection image of the draping fabric onto the transparent paper sheet (4) (Fig. 2b). The shadow image that appears on the paper is transmitted to the computer by the camera. The evaluation program provides the area of the shadow image of the draping textile, from which the draping coefficient can be calculated with Equation (1). The number of waves can be determined by manual counting.
We performed tests with the usual 180 mm diameter, circular sample-holding table and regular, polygonal sample-holding tables with the same area too. For our tests with polygonal tables, we had to make not only the polygonal versions of the sample-holding table (2) but also the transparent lifting-lowering tables with the shape of the tables (8) and the shading shapes (5) as well (Fig. 3). Every time we want perform a test with a differently shaped table, these elements have to be replaced. To make it easier to replace these elements, we also remanufactured the original circular structural elements. We cut the sample-holding tables and their lifting-lowering tables from 3 mm thick, transparent polystyrene sheets and the shading shapes (with the same shape as the sample-holding table) from fibreboard with the use of the laser cutting equipment available in our laboratory (Alpha Laser LCE2 CO_2-Infra Laser Cutter).





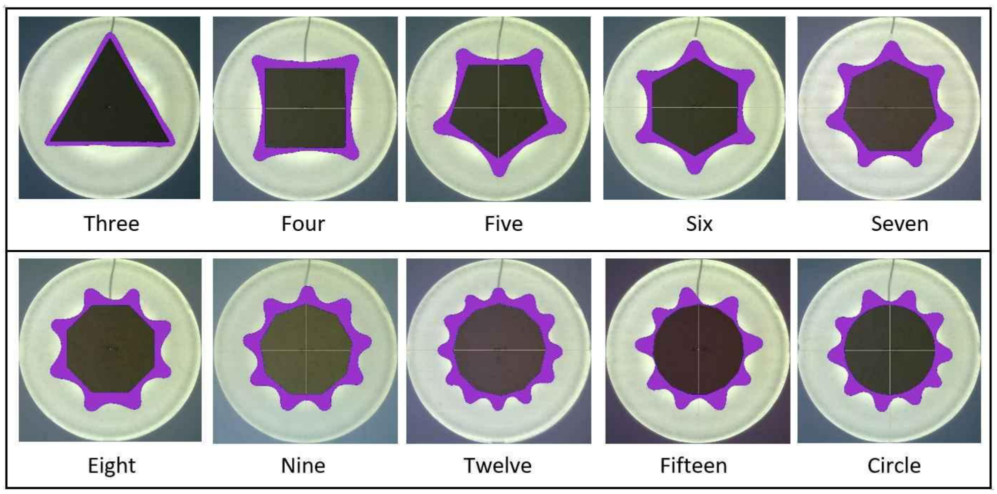
1 *examined sample*
2 *sample-holding table*
3 *upper transparent surface*
4 *translucent sheet of paper*
5 *shadowing figure of the same shape and size as the sample table*
6 *camera stand*
7 *webcam*
8 *transparent lifting-lowering table*
9 *lower transparent surface*
10 *parabolic mirror*
11 *light source*
12 *beam of light*
13 *the measuring position of the lifting-lowering table*
14 *the preparation position of the lifting-lowering table*

Figure 2: Cusick Drape Tester, a: preparation position, b: Testing position

Figure 3: Schematic diagram of the Cusick Drape Tester

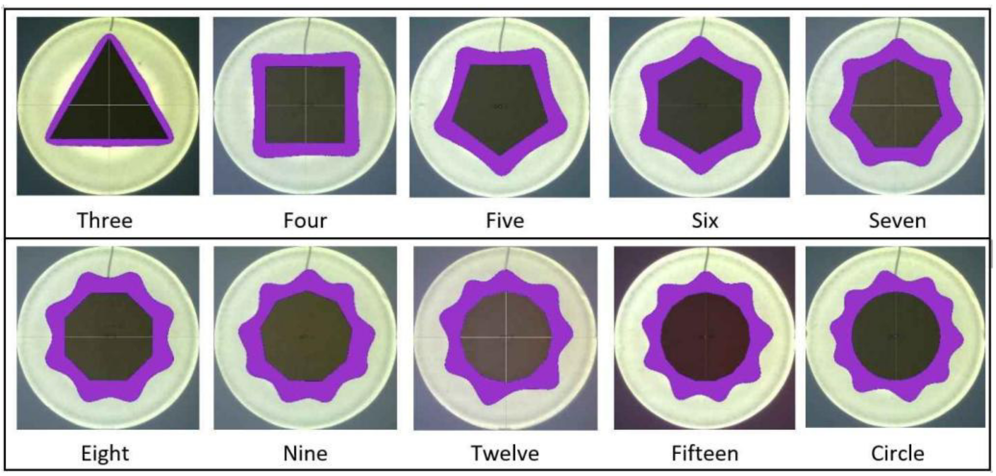
3. RESULTS

As an illustration, we present images of the draping of Fabric 1 (Fig. 4) and 7 (Fig. 5).



Figures 4: Images of the draping of Fabric 1 (PES fabric) depending on the number of table corners

In our tests, we measured each sample placed first with its right side up and then with its reverse side up on the sample holder table. We carried out the test series twice, maintaining a constant temperature (24 °C) and relative humidity (40%) throughout the tests. Since we cut out three samples from each selected fabric, so for each fabric, we performed altogether 12 tests on each different table. Figures 6-7 show the average draping coefficient with standard deviation, as well as the number with standard deviation of the waves for Fabric 1 and 7, depending on the shape of the table.



Figures 5: Images of the draping of Fabric 7 (Flax fabric) depending on the number of table corners

The change in the *DC* as a function of the number of table corners can be described with the trend function (2) with a monotonous increase tending to the horizontal asymptote. Table 2 contains the values of the parameters of the trend function (2) for the examined fabrics.

$$DC(n) = DC(3) + DC_{diff}\left[1 - e^{-\frac{n-3}{n_0}}\right] \qquad (2)$$

Where:

- n is the number of corners of the sample-holding table, $n \geq 3$, and an integer.
- n_0 is an estimated scaling parameter influencing the course of the function that has no physical meaning for the given fabric, $n_0 > 0$.
- $DC(n)$ is the draping coefficient depending on the number of table corners.
- $DC(3) = DC_{min}$ is the starting point of the trend curve, the smallest DC of the given fabric measured on the triangular sample-holding table.
- DC_{max} is an estimated *DC* value, to which the function tends asymptotically.
- $DC_{diff} = DC_{max} - DC(3)$

Table 2: The parameters of the approximating function (Equation 2)

Designation of sample	$DC(3)=DC_{min}$ [%]	DC_{max} [%]	$DC_{diff}=DC_{max}-DC(3)$ [%]	n_0 [-]	Mean squared error [%]
1	14,526	31,664	17,137	1,501	0,656
2	67,804	92,762	24,957	0,908	0,858
3	38,273	66,245	27,972	1,174	1,064
4	31,607	67,641	36,034	1,174	2,091
5	18,651	36,647	17,997	1,537	5,149
6	43,979	73,932	29,953	1,156	3,141
7	23,689	54,567	30,878	1,145	1,870

We determined the values of the DC_{max} and n_0 parameters with the Microsoft Excel Solver extension so that the mean squared error calculated from the difference between the trend curve and the measured data would be minimal. The DC_{max} value is almost the same as the *DC* value measured on the nine-sided sample-holding table for all materials except Fabric 5. The mean squared error of the approximation with the calculated parameters is given in the last column of Table 2. These data confirm that the trend function (2) describes the change in the DC with a very good approximation.

The *DC* diagrams in Figures 6-7 also contain the trend curves calculated with Equation (2). The trend curves were calculated and plotted for up to the nine-sided sample-holding table because the number of waves and table corners is mainly the same up to 9 table corners but if the table has more than 9 corners, none of the examined fabrics have the same number of waves as the number of table corners. It is clear that these curves approximate the measurement results very well and thus clearly illustrate the relationship between the number of table corners and the *DC*.

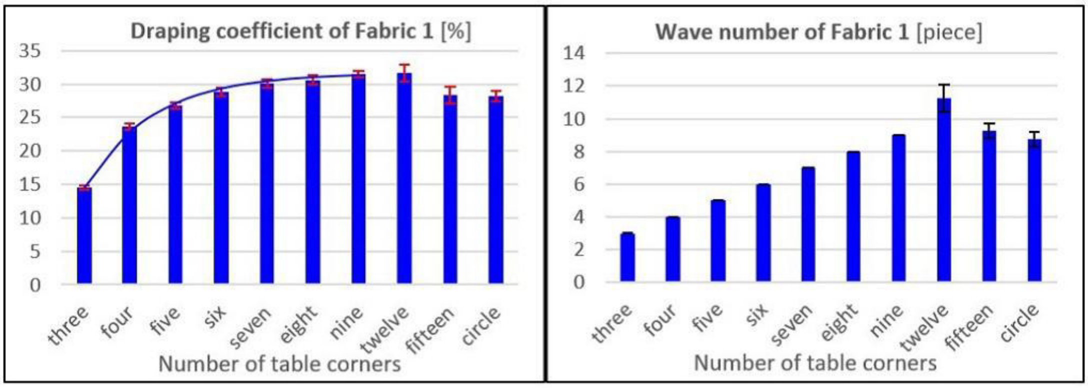


Figure 6: The draping coefficient and the number of the waves for Fabric 1 (PES fabric)

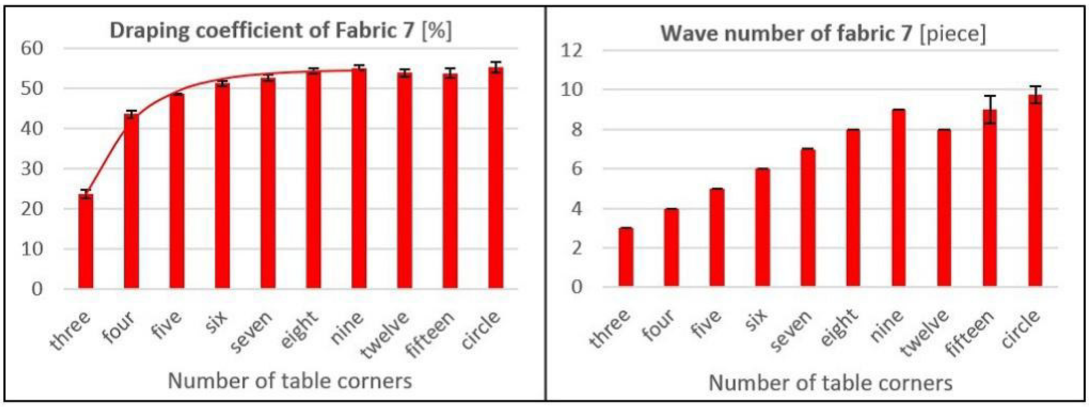


Figure 7: The draping coefficient and the number of the waves for Fabric 7 (Flax fabric)

As Figures 6-7 show, for polygonal tables, the number of waves follows the number of corners of the table when the number of corners is low. However, in the case of a circular table, as we mentioned in the introduction, the number of waves is not clear, their size and arrangement are often not uniform, and also, their number can change due to even a small external influence. Therefore, we carried out a series of experiments in which the draping of the test samples was modified by hand to another stable state, so that the number of waves in the new state differed from the original number of waves. The recordings made in this way show the Figures 8-9 of Fabric 1 and 7.

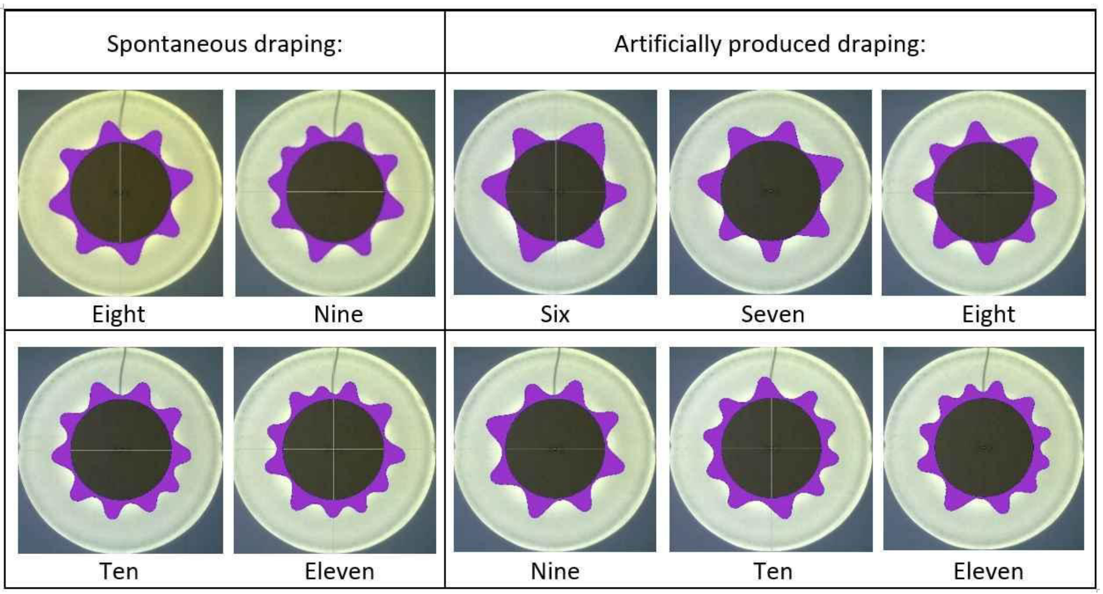


Figure 8: The images of the spontaneously and artificially formed waves of Fabric 1 (PES fabric) on the circular sample-holding table depending on the number of waves

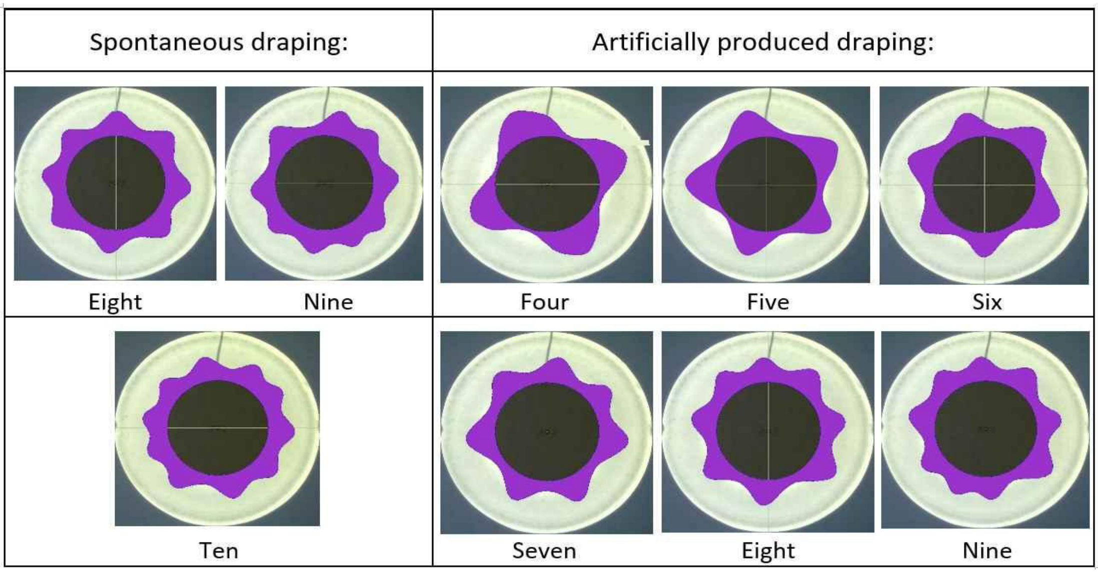


Figure 9: The images of the spontaneously and artificially formed waves of Fabric 7 (Flax fabric) on the circular sample-holding table depending on the number of waves

Figures 10–11 show the draping coefficient depending on the number of waves for each fabric on polygonal sample-holding tables and the circular sample-holding table in the case of spontaneous and artificially induced draping.

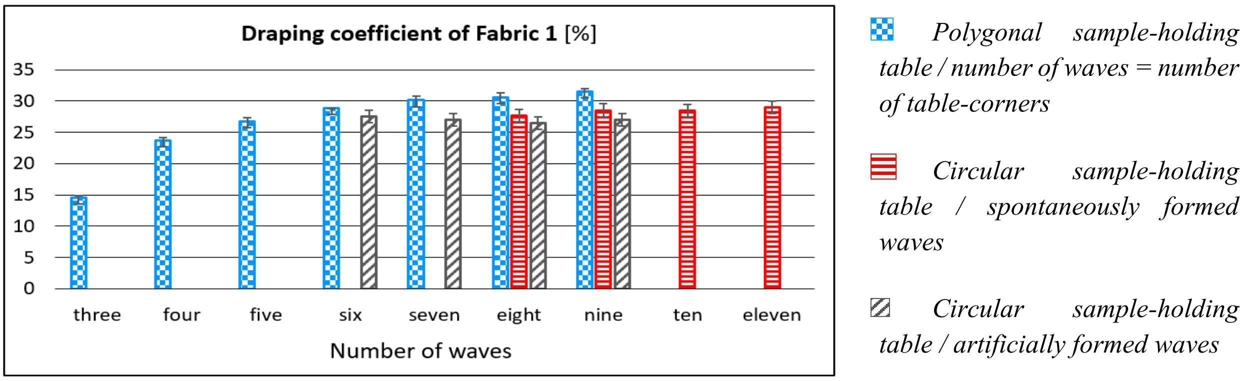


Figure 10: The draping coefficient depending on the number of waves for Fabric 1 (PES fabric)

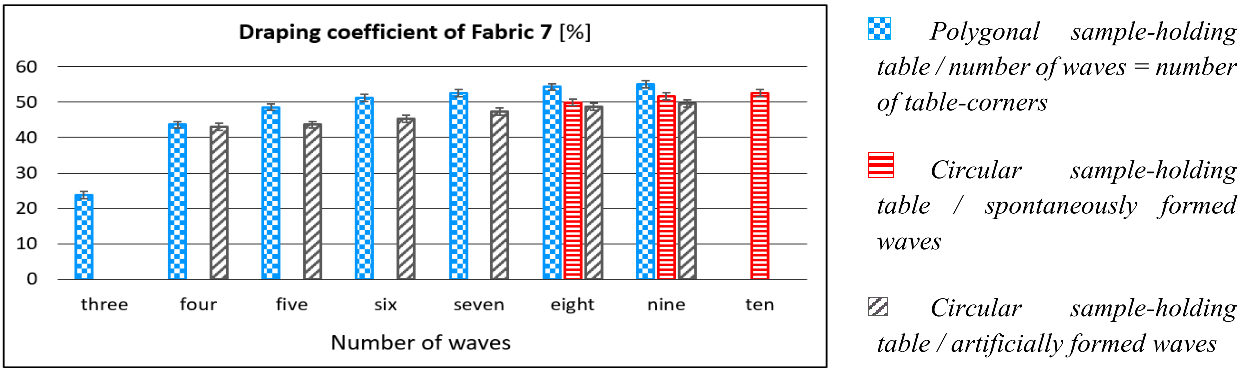


Figure 11: The draping coefficient depending on the number of waves for Fabric 7 (Flax fabric)

4. DISCUSSION

As was mentioned in the introduction, the conditions of the formation of the waves greatly influence the resulting draping image and, therefore, the draping coefficient and the number of waves. Our results support this. The images of Figures 4-5 and the diagrams of Figures 6–7 clearly show that if regular polygonal sample-holding tables are used instead of circular ones, the waves form at the corners of the tables, and their number follows the number of corners up to a limit. The extent to which the number of waves follows the number of corners of the table depends on the properties of the examined fabric and the dimensions used. The softer the fabric, the larger number of corners the waves can follow. The behaviour of a fabric can be considered soft if its draping coefficient measured on a circular table is below 60% and stiff if its draping coefficient is greater than 85%.

Among the tested textiles, Fabric 1, 5, and 7 have a soft behaviour, as the test performed on a circular table shows. These three textiles even follow the corners of the 9-sided table with their waves. The data suggest that Fabric 7 would follow the corners of a 10-sided table, and Fabrics 1 and 5 would even follow the corners of an 11-sided table with their waves. In the case of the 12-sided and 15-sided tables, none of our fabrics were able to follow the corners.

Fabric 2 was particularly rigidly and paper-like, with the highest bending length and shear rigidity. This is also confirmed by its behaviour on the circular table, where its draping coefficient was very high, and also the fact that its waves only followed the corners of the triangular and square tables. Fabric 4 and 6, whose waves followed up to eight corners, and Fabric 3, whose waves followed up to seven corners can be considered to have average behaviour.

When the waves of the tested fabric can no longer follow the corners of the table, its behaviour starts to resemble its behaviour on the round table, but the standard deviations are quite large. If the number of sides of a table increases more and more, its shape approximates a circle, and the behaviour of the fabric also corresponds to its behaviour on a circular table.
In general, Figures 6-7 show that *DC* increases as a function of the number of table corners while the number of waves is the same as the number of table corners and asymptotically approaches a maximum. This maximum is the draping coefficient that the fabric approaches when the number of waves is the same or almost the same as the number of the corners of the table.
Our series of experiments in which we set the number of waves manually on the circular table, also points to the importance of the conditions of the draping. The diagrams in Figures 10–11 show the draping coefficient as a function of the number of spontaneously formed waves on the polygonal table and the round table and as a function of the number of artificially formed waves on the round table. These results also confirm that the number of waves on a circular table is not deterministic, and the draping coefficient depends on the number of waves. It can also be seen that in the case of the same number of waves; the draping coefficient is also influenced by the conditions of the draping.

5. CONCLUSION

We performed draping tests on selected fabric samples using the usual circular and the special regular polygonal sample-holding tables with the same area as the circular table. The tests showed that the stiffer a sample is, the less it can follow the corners of a table with its waves, and the softer it is, the more it can follow the shape of the table with its waves; that is, the more table corners it can follow with its waves. In the case of polygonal tables, as long as the number of waves follows the number of table corners, the draping coefficient increases and trends asymptotically to a maximum value as a function of the number of table corners or waves. With the same number of waves, the draping coefficient measured on polygonal tables is significantly higher than in the case of circular tables.
Our series of experiments, in which we set the number of waves manually on the circular table, points to the importance of the conditions of draping. The results confirm that the number of waves on a circular table is not deterministic, and the draping coefficient depends on the number of waves. The same number of waves may be formed spontaneously and artificially but the corresponding *DC* may be different. This proves that the dynamic conditions of draping also influence the draping coefficient.
Using a polygonal sample-holding table, the deviation in the number of waves can be eliminated, and draping can be made uniform. When the waves of the sample follow the corners of the polygonal table, than the number of waves is clear, the size and arrangement of the waves are uniform, and the standard deviation in the draping coefficient is smaller compared to the value measured on the round table. In light of this, it could be advisable to perform the draping test on a polygonal table, thus excluding the measurement uncertainty resulting from the unevenness of draping and improving the repeatability of the tests. Based on the data, the regular six-sided sample-holding table can be recommended for the drape test; only very rigid samples cannot follow its corners with their waves, the draping coefficient is almost the same as that measured on a round table, and its standard deviation is smaller; therefore, the hexagonal table is suitable for testing the vast majority of sheet-like materials with low bending stiffness. We believe measurements made according to the ISO 9073-9:2008 standard could be worth supplementing optionally with measurements made on a hexagonal sample-holding table. This testing could be particularly useful when comparing fabrics for similar purposes in the fashion industry, in order to select the most suitable fabric in terms of draping.

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