A New Method in Fabric Drape Measurement and Analysis of Drape Formation Process

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Abstract

The paper presents the Sylvie 3D Drape Tester developed for fabric drape measurements and its special auxiliary device that exerts dynamical impact on fabrics during draping. Also, a new draping characteristic, namely the Drape Unevenness Factor, was defined to describe the evenness of the shape of draped textile material numerically. Three special cotton fabrics woven exclusively for this work differing only in twist direction of their weft yarns were used for analysis and effect of twist directions in a woven fabric and influence of the applied dynamical impact on drape test results were analyzed. Based on the test results, the paper also analyses the process of drape formation offering proposals for modification of fabric behavior models to contribute for better fabric simulations.

Keywords

Drapability, dynamically influenced drape, drape unevenness factor, image processing, yarn twist direction, modeling of fabric behavior

INTRODUCTION

Draping – i.e. the 3D deformation of textiles that occurs due to gravity – is a very important characteristic to describe the behavior of textiles. The fabric drapeability directly influences on its behavior in an article of clothing made from it. The research indicates that garment appearance quality is strongly affected by drapeability [1, 2]. The measured fabric properties can be used also for a more exact simulation of the 3D geometry of the fabric.

The most frequently applied measuring device for the determination of draping properties is the Cusick Drape Meter [3]. The equipment projects the contours of the circular draping textile sample placed on the circular sample holder with a parallel light bundle, and the analysis of the shadow image makes it possible to determine the drape coefficient (DC) and number of waves (n). Later, automatic evaluation software based on the photography of the shadow image was prepared as a supplement to this device [4]. The software analyzes the perimeter of the shadow image using Fast Fourier Transformation (FFT). The software determines the variance of the amplitude (the distance between the shadow image contour points and the center of the sample holder) as statistical data and a so-called fitness factor (the ratio of the area below two curves, namely the amplitude graphed as a function of the central angle and the dominant component obtained with FFT) besides the usual characteristics.

As the draping measurement method was improved, some researchers supplemented their devices with a sample holder that rotates the sample at adjustable angular speed and is necessary for the measurement of the draping coefficient. With this new method drapability could be examined under conditions more similar to the real using condition [5-8].

In addition to dynamic drape coefficient, researchers developed some other factors to describe draping as Circularity Factor is an example for these. The circularity factor, which is similar to the drape coefficient, is defined as the ratio of the perimeter and the area of the draping sample describing the extent of fabric draping [9].

A wide range of structural and mechanical properties of fabrics influence draping as well as the external conditions and impacts. The most extensively used system for the determination of the mechanical properties of fabrics is the Kawabata Evaluation System (KES) [10]. Several researchers have been dealt with the determination of the relation between the parameters measured with KES system and drapability as well as application of the obtained relations for modeling of fabric draping. These works reveal that KES parameters influencing draping behavior to the greatest extent are mainly the bending and shearing properties [11, 12].

The behavior of textile materials is a very complex mechanism as the interactions of the individual fibers or yarns result in special properties. Therefore, their mechanical modeling and realistic simulation are both quite complex tasks.

Gräff and Kuzmina [13] deal with the mathematical methods of material behavior simulation. According to their literature review, several attempts have been made in the field of textile modeling since the mid ‘80s as the elements of continuum mechanics and finite element method were applied in these models and textile material was modeled as a mechanism.

No solution that handles all aspects of the above mentioned complex problem has been found yet. Textiles deform to a great extent and in several different qualities already due to small forces, and this is the main difference compared to other materials that makes their modeling so difficult. Basically, models used in textile modeling can be classified into two groups: Finite element based models and particle system based models.

Jevšnik and Geršak present the use of finite elements method for modeling a fused panel drape. Their results show significant promise for further development of research regarding computer simulation of the behavior of fabrics [14].

The solution worked out by Gräff and Kuzmina [13] is a typical example of modeling based on particle system. A method based on the Second Newtonian Law was applied in which the fabric was modeled with a network of mass points. The material model consists of mass points, flexural, shearing and tensile structural connecting elements. All connecting elements are composed of a spring and damper arranged parallel, where the springs are linear while the dampers are proportional with speed. However, simulation based on this model is always symmetrical and evenly draped. These problems are common in case of all simulation programs. Another problem is that about the results of not providing any explanation or information on larger deviations making very difficult for efficient applications in 3D simulation of textile products.

Therefore, one of the aims of our research is to find out the reasons for having different stable draped shapes and different draping properties varying at a relatively large scale deformation. Our research results also enable us to draw conclusions that help in the improvement of material simulation programs. Furthermore, these programs will be able to characterize the fitting of reinforcing fabrics – applied also in composites – onto complex spatial shapes [15, 16].

On the other hand, this paper presents a drape tester with a special auxiliary device that exerts dynamical impact on fabrics so that dynamically influenced draping could be measured. Also, a new draping characteristic, named as Drape Unevenness Factor, is defined to express the evenness of the draped textile material objectively. For this aim, three special cotton fabrics were woven exclusively differing only in twist direction of their weft yarns. The effect of twist directions in fabric drape and influence of the applied dynamical impact on drape test results were analyzed offering proposals for the modification of fabric model so that it could contribute to improvement of fabric simulation programs further for a better outcome.

EXPERIMENTAL DETAILS

Material

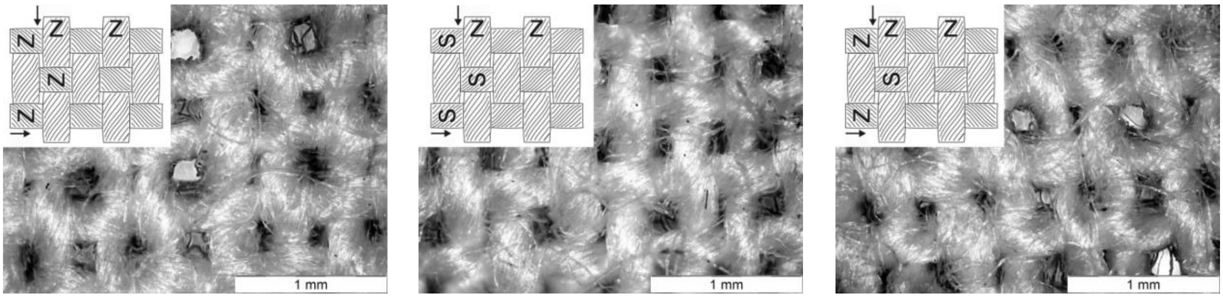
Three special fabrics used in the experiments were woven in Hungary by Csárda-Tex Ltd. The twist direction of yarns used for these three fabrics, which have the same structural properties and made of 100% cotton, was chosen as different so that the effect of twist on drape behavior could be studied. They were plain woven fabrics as the warp and weft densities as well as the linear density of the warp and weft yarns were the same, hence their area density was also the same (Table 1).

Table 1: Particulars of three special fabric samples

Denote	Material	Type		Density [g/m^2]	Type of weave	Yarn count		Yarn density [1/10mm]		Twist direction	
		warp	weft			warp	weft	warp	weft	warp	weft
P	cotton	OE-rotor	OE-rotor	156	plain	30 Tex	30 Tex	26	22	Z	Z
K	cotton	OE-rotor	OE-rotor	156	plain	30 Tex	30 Tex	26	22	Z	S
F	cotton	OE-rotor	OE-rotor	156	plain	30 Tex	30 Tex	26	22	Z	Z+S

The microscopic images of the samples (Figure 1) illustrate the different twist directions of the three fabrics. The warp yarns in all the three fabrics have Z-twist direction, the differences lie only in the twist direction of weft yarns as shown in Table 1.

Altogether 9 samples of 300 mm diameter, i.e.3 pieces per fabric type were prepared for the tests.



P K F

Figure 1: Z and S twist directions of the examined samples

Equipment

The fabrics were tested for their shear and bending properties by using Kawabata Evaluation System (KES) at University of Maribor.

The drapability of experimental samples was measured by the Sylvie 3D Drape tester developed at the Budapest University of Technology and Economics (Figure 2).

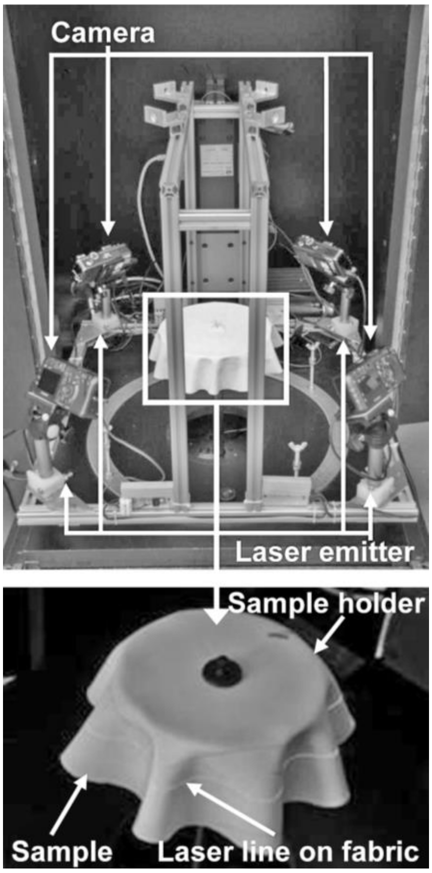


Figure 2: Sylvie 3D Drape Tester

This is a new, computer controlled 3D scanning based equipment. The software reconstructs virtually the measured surface from the measured data, and using that it calculates the ordinary parameters. The equipment can be supplement by rings of different diameters such as 210mm, 240mm and 270 mm, respectively to influence dynamically the evolving nodes.

Measuring Procedure

The table of the Sylvie 3D Drape Tester (Figure 2) at the initial state is in level with the base plate. The diameter of the table is 180 mm. The diameter of the fabric sample is 300 mm [17].

During the tests, the centre of the sample has to be set exactly on the centre of the table, and warp and weft directions have to be parallel with the specified directions. A computer controlled motor lifts the table, assuring that drapability is always studied at the same speed and under the same dynamic effects. During the measurements, four laser emitters project laser lines on the fabric sample in order to determine the cross-section and four cameras record the lines over the laser emitters (Figure 2). The cameras and the laser emitters are mounted on a measuring frame. The frame moves with a determined step distance during scanning the surface of the fabric sample. The computer controlled instrument is constructed in a black box in order to provide darkness during the measurement. After all photographs are taken, the computer downloads those [18].

On the other hand, the software of the device determines the desired draping properties automatically. The draping coefficient is calculated based on the generally accepted definition according to formula (1):

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

where 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 is the radius of the laid fabric (Figure 3).
Then a new parameter, *Drape Unevenness Factor*, was created for the description of the geometric asymmetry and unevenness of drapes of the fabric sample (Figure 4).

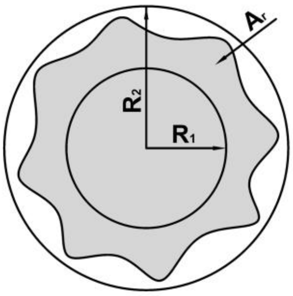


Figure 3: Projection of the plane and the draped fabric sample

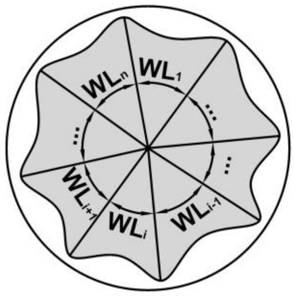


Figure 4: Wave length of the draped fabric sample

The new factor is denoted by DU that is physically the relative deviation of the wavelength of waves formed at the perimeter of the planar projection of the draping fabric (Equation 2).

$$DU = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}(WL_i - \overline{WL})^2}{n-1}}}{\overline{WL}} \quad (2)$$

where WL_i is the central angle between two adjacent maximum amplitudes (i.e. the wave length of single waves), $\overline{WL}$ is the average central angle on one wave (i.e. average wave length, $\overline{WL}$ = 360/n) and n is the number of waves.

The above relation indicates that smaller the value of DU is the more even drape of the examined fabric. Besides factors of DC and DU, the number of waves, the minimum and maximum amplitude and the deviation of amplitudes are also calculated by the software.

Dynamically influenced drapability

The Sylvie 3D Drape Tester was supplemented with exchangeable circular rings that had different inner diameters. The circular ring is placed in the equipment in a way that it pushes the sample through the opening of the ring when the sample holder rises (Figure 5) [19, 20].

The so-called "dynamically influenced draping coefficient" is measured using the rings. The reproducibility of this measurement is outstanding due to the constant speed of rising and same ring parameters. The inner diameters of the applied rings are 210, 240 and 270 mm, respectively (Figure 6), while the diameter of the sample holding table is 180 mm. In order to handle the results of measurements with and without rings uniformly, the static case – i.e. without ring – is considered as if a 300 mm diameter ring was applied. This consideration can be verified easily as a ring with 300 mm diameter would not influence draping, since it would not even contact the fabric sample which has 300 mm diameter itself before draping, i.e. it is absolutely irrelevant whether there is a ring or not in reality.

The measurement with rings of having different diameters simulates the impacts – that arise during the use of fabrics – at different intensity levels.

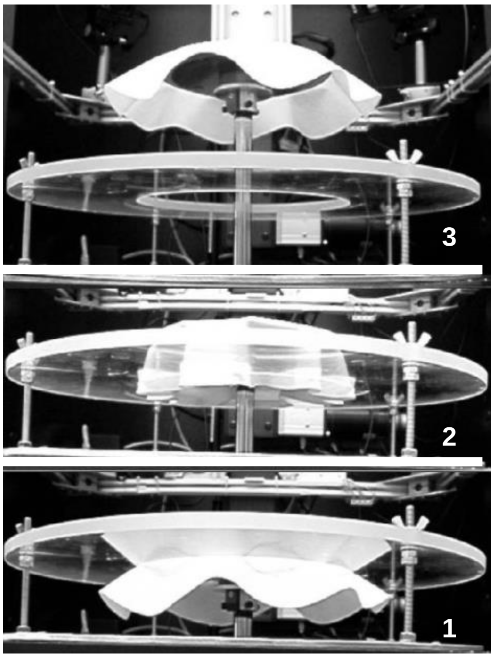


Figure 5: Ring influenced drape measurement

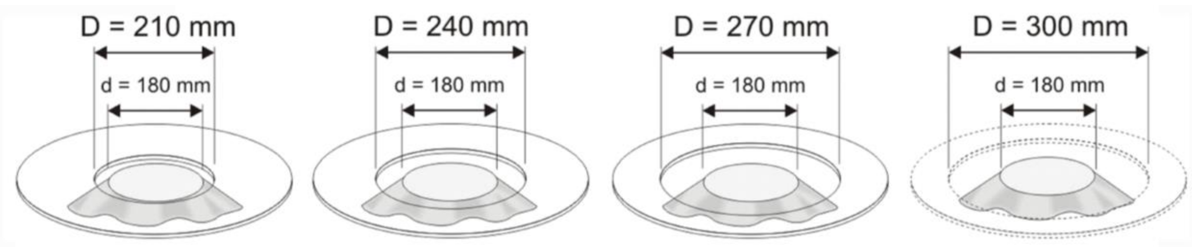


Figure 6: Rings with different inner diameters

RESULTS AND DISCUSSION

Effect of twist direction on drapeability

The twist direction of the warp and weft yarns in the fabric play an important role in the formation of draping, since it determines the circumstances of the contact of elementary fibers in the yarns. The results of present extensive experiments reinforce the conclusions of our previously presented test series [21].

The elementary fibers of the two yarns are almost parallel in case of material P (Z-Z twist direction) where two warp and weft yarns cross each other. In case of material K (Z-S twist direction) these elementary fibers lie on each other almost perpendicularly at the crossing point because of the opposite twist direction of the warp and weft yarns.

The crossing of elementary fibers is illustrated in Figure 7 a) and b) simply.

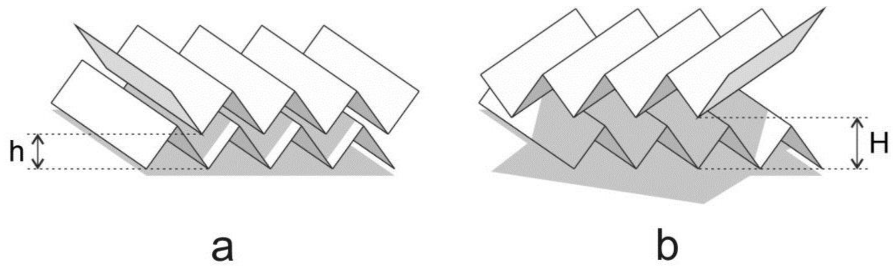


Figure 7: Simple representation of elementary fibers at fabric cross-over points which are parallel or perpendicular direction; a) Z-Z twist yarns; b) Z-S twist yarns

It is clearly shown in this figure that the almost parallel elementary fibers (Z-Z twist direction, figure a) can penetrate among each other – due to the force that compresses the yarn – when crossing, while in case of an almost perpendicular contact (Z-S twist direction, figure b) this is not possible. This phenomenon is also proven by the thicknesses of the fabrics. The thickness of material K is 0.79 mm, while fabric P (Z-Z twist direction) has a thickness of 0.66 mm opposed to the fact that their other structural properties are the same. Hence, the difference can only lie in the different twist directions of weft yarns.

In case of Z-Z twist direction, the almost parallel crossing of elementary fibers result in a larger contact surface, hence larger friction force, while the almost parallel parts of the yarns interconnect in the same way as the teeth of a gear, i.e. connection through shapes. These phenomena together decrease the rotation and slipping of warp and weft yarns and inhibit the formation of shearing and flexural deformation.

Oppositely, in case of Z-S twist direction, the elementary fibers cross almost perpendicularly, hence the contact surface is much smaller, the almost perpendicular ‘fibers’ of the yarns cannot connect into each other. Therefore, the warp and weft yarns can rotate and slide from each other more easily than in case of Z-Z twist direction.

These phenomena together explain that fabric sample P (Z-Z twist direction) is definitely stiffer, has larger drape coefficient and its number of waves is also higher although only to a small extent. Furthermore, it has higher flexural and shearing modulus and hysteresis (Z-S twist direction) than fabric sample K (Z-S twist direction) (Figures 8, 10 and 11).

The trends of drape unevenness (DU) (Figure 9) show an opposite direction than in case of DC values. The value of DU is much higher in case of fabric sample K (Z-S twist direction) than in case of fabric sample P (Z-Z twist direction), meaning that the draped shape of fabric P is smoother. Hence, we can conclude here that the twist direction of yarns influences the evenness of draping to a great extent.

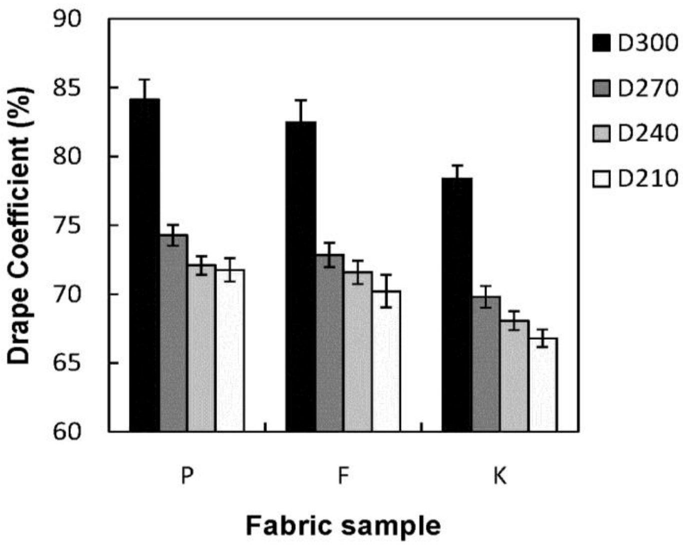


Figure 8: Drape coefficient (DC) measured at different ring diameters as a function of the fabric sample

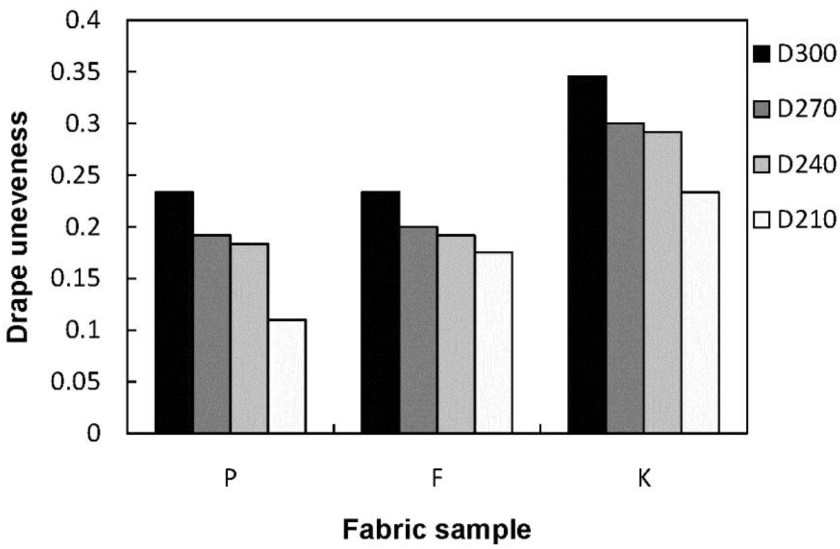


Figure 9: Drape unevenness (DU) measured at different ring diameters as a function of fabric sample

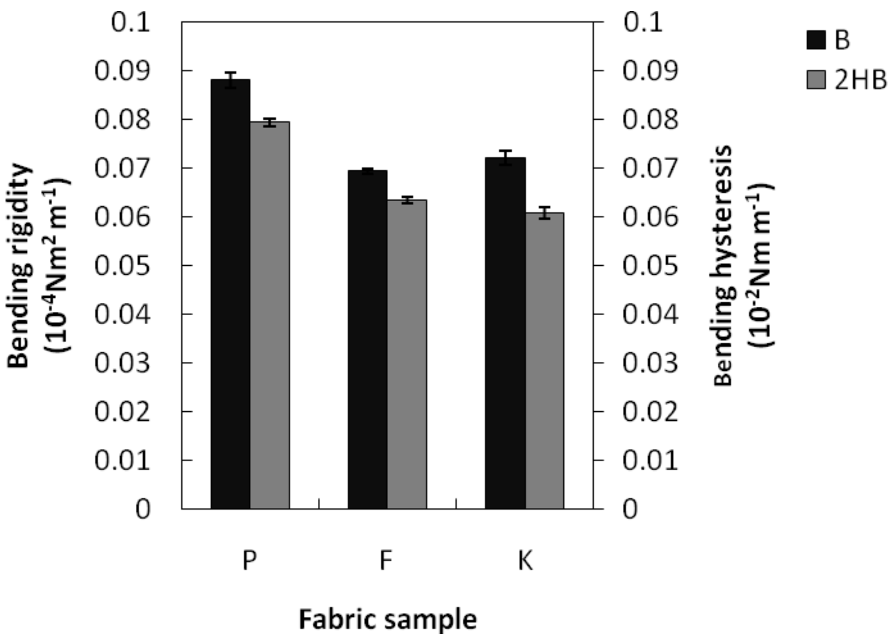


Figure 101: Bending behaviors of fabric samples as a function of fabric type, B - bending rigidity; 2BH - bending hysteresis

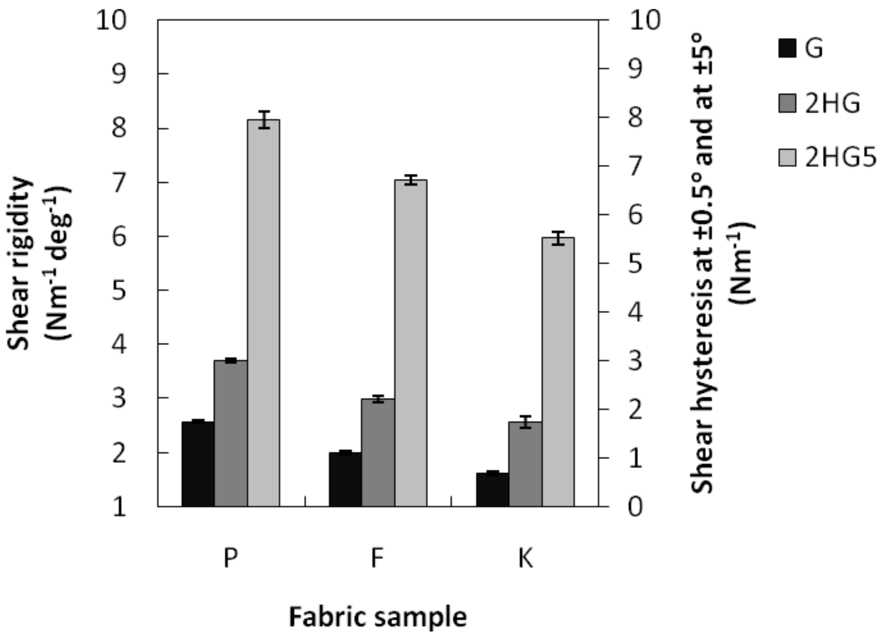


Figure 11: Shear behaviors of fabric samples as a function of fabric type, G - shear rigidity; 2HG - shear hysteresis at ±0.5°; 2HG5 - shear hysteresis at ±5°

The properties of the third fabric sample denoted by F (Z-Z/S) are between the values of the fabrics of K and P. This is logical since the structure of this fabric is almost exactly in the middle between the other two fabric samples. This also proves the conclusions drawn above.

Applied dynamic impact on drape measurements

During the tests, the drape measurement of every single sample was carried out 10 times per one ring size on both front and back face of fabrics according to DIN 54306 standard, keeping always identical – 12 minutes – relaxation time interval between the measurements. In evaluation of results, the average and deviation of drape coefficient (DC), drape unevenness (DU) and the number of waves (n) were determined and significance of difference between DC values was analyzed using bi-lateral student's t-test and F-test at 0.05 significance level.

The dynamic impact on drape test results was analyzed as a function of differing ring diameters, i.e. 210mm, 240mm, 270mm and 300mm, respectively. The effect of ring diameter on the drape coefficient is significant (Figure 12), while the number of waves is only slightly affected. If the ring size decreases, hence the dynamic influencing effect is larger, the value and deviation of drape coefficient (DC) decrease, the number of waves slightly increases (n) and drape unevenness (DU) decreases (Figure 13).

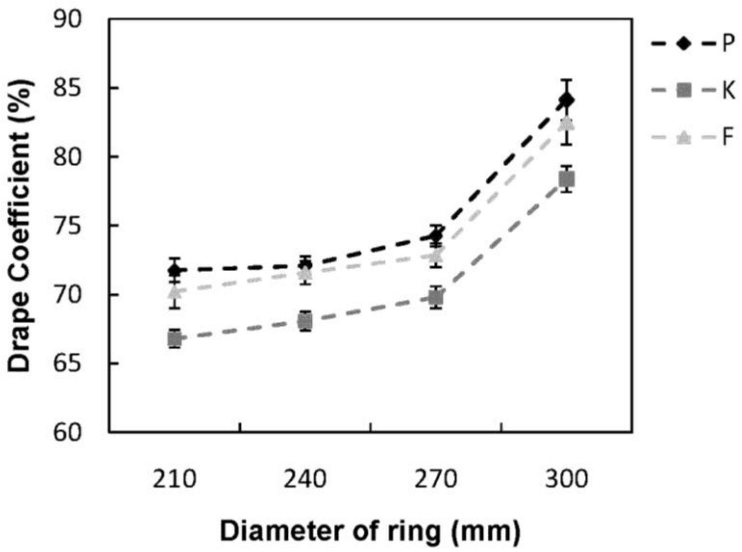


Figure 12: Drape coefficient as a function of the ring diameter

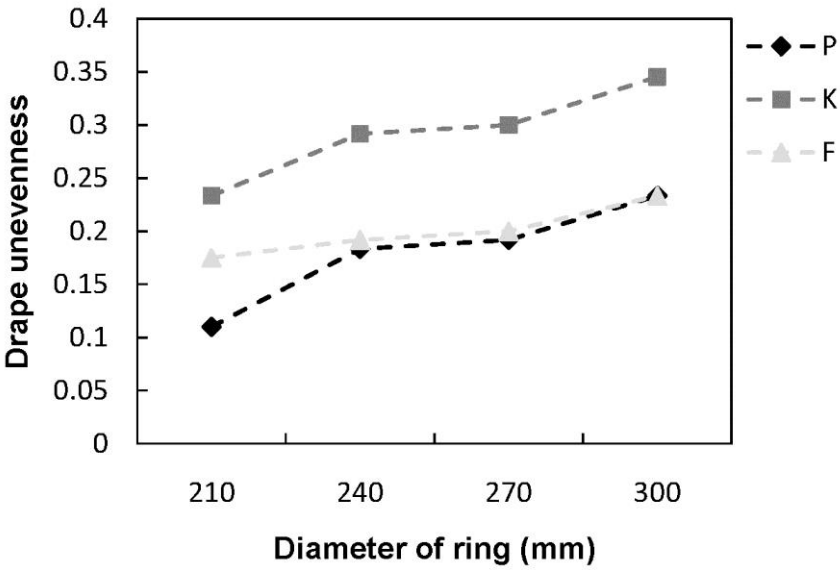


Figure 13: Drape unevenness as a function of ring diameter

Figure 14 shows the results obtained from the measurements with the different rings. The main tendencies of the measurements are well visible, i.e. in case of using rings the average radius of the drape image contour, i.e. DC decreases, and the draped shape becomes more even.

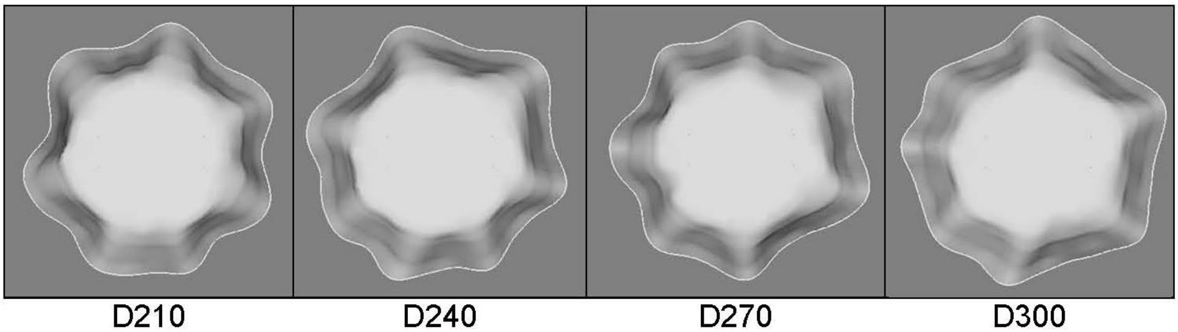


Figure 142: 3D shapes of fabric sample P influenced with 210, 240, 270 and 300 mm inner diameter rings

On the other hand, Student's t-test was applied for samples P and F, since the difference of the mean values is not obvious due to the overlapping deviation fields (Figure 8). According to the results, the DC of these two fabric types are significantly different in case of 300 mm, 270 mm and 210 mm ring diameter at a confidence level of 95%. However, the drape coefficient values measured with the 240 mm and 270 mm diameter rings are very close to each other when we consider the deviations in Figure 8, hence Student's t-test was also carried out in that case. The test proved that the difference of the mean values is significant at a confidence level of 95%.

The test results also prove that dynamic effects on the fabric during drape formation influence draping characteristics although the dynamic effect is not present yet at the time of data recording. This is the reason why the deviation is definitely larger in case of manual testing, compare to the results obtained using a motor driven sample holding table that provides always identical and even lifting speed with no dynamic effects.

In case of measurements with rings, the drapes of the fabrics that passes through the ring (Figure 5) are compressed, and after leaving the ring, they can get their shape back in an elastic way, but that shape is not exactly the same as it was before reaching the ring, and drape properties of the fabric can change. The fabric passes the ring quickly, hence this phenomenon cannot happen due to stress-relaxation as residual deformation cannot be caused this way. Since different results are experienced after dynamic effect ends as in the case without dynamic effects, other factors should play a role in fabric behavior as well as the actual and delayed elastic deformation. The change in the drape properties due to the effect of the ring can be explained with sticking-sliding friction among the yarns of the fabric that explains the hysteresis experienced in bending (Figure 10) and shearing (Figure 11) tests as well. The fact that the draped shape will become more even due to the ring refers to the presence of sticking-sliding friction as well because the ring has a balancing effect on different extent deformations at the different locations of the fabric due to the non-identical sticking-sliding friction forces. Hence, our results also prove that the deviation of sticking-sliding friction force has a significant impact on the formation of the asymmetric draped shape.

Analysis of drape formation process and a proposal for improvement of fabric behavior modeling

The ultimate aim of our investigations is to use our results as a contribution to a material simulation that estimates real case as much as possible. Proposals can be made for the modification of the fabric mechanical model based on the behavior of the examined materials at different ring diameters, KES measurements and the effect of twist direction on the drape coefficient.

Particle system based models take into consideration only viscous friction as an inner damping effect besides the spring that models elastic behavior. However, our measurements prove clearly that sticking and sliding Coulomb friction is also present as a kind of inner resistance. Considering all the previously mentioned facts, the behavior of materials experienced during the application of rings can be explained easily.

The modification proposal is presented through a simplified viscoelastic model of the draping textile (Figure 15). The simplified model is a one-mass oscillating system of the force balance which is described by Equation (3).

$$m \cdot \ddot{x} + k \cdot \dot{x} + s \cdot x + sign(\dot{x}) \cdot F_{\mu} = F_g \tag{3}$$

where x: displacement vector, $\dot{x}$: velocity vector, $\ddot{x}$: acceleration vector, m: mass, s: spring stiffness, k: damping factor of the viscous damping element, F_{μ}: sticking and slipping friction force, F_g: inciter forces.

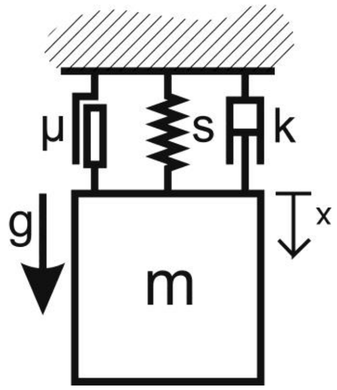


Figure 15: Simplified viscoelastic model of fabric behavior

According to the model in Figure 15, the deflection of the draping fabric – represented by mass “m” – is caused by gravity. The elastic and friction forces in the fabric that work against the deflection caused by gravity – movement of mass “m” – are represented by the stick and slip friction, viscous damping and the spring. The effect of the ring can be taken into consideration with inciter force F_g. The question is where the deflecting fabric – mass “m” – stops, i.e. how much the drape coefficient will be.

Figure 16 demonstrates the process of drape formation with the section of the fabric placed on the sample holding table. The fabric starts from position 1 at the beginning of the measurement and deflects due to gravity. If the fabric is raised at a controlled speed, and its deflection is retarded with an external force meanwhile (e.g. in case of the Sylvie Drape

Tester the base plate from which the sample holding table lifts up the fabric at a constant speed brakes the fabric during rising), the slowly forming drapes stop at the upper part of the uncertainty zone. This is the way how the largest drape coefficient of the examined material can be measured. If the fabric is dropped freely from position 1, the fabric enters the uncertainty zone and stops somewhere within (position 2), or passes through it, carries out dampening free oscillating movements, but finally stops within the uncertainty zone.

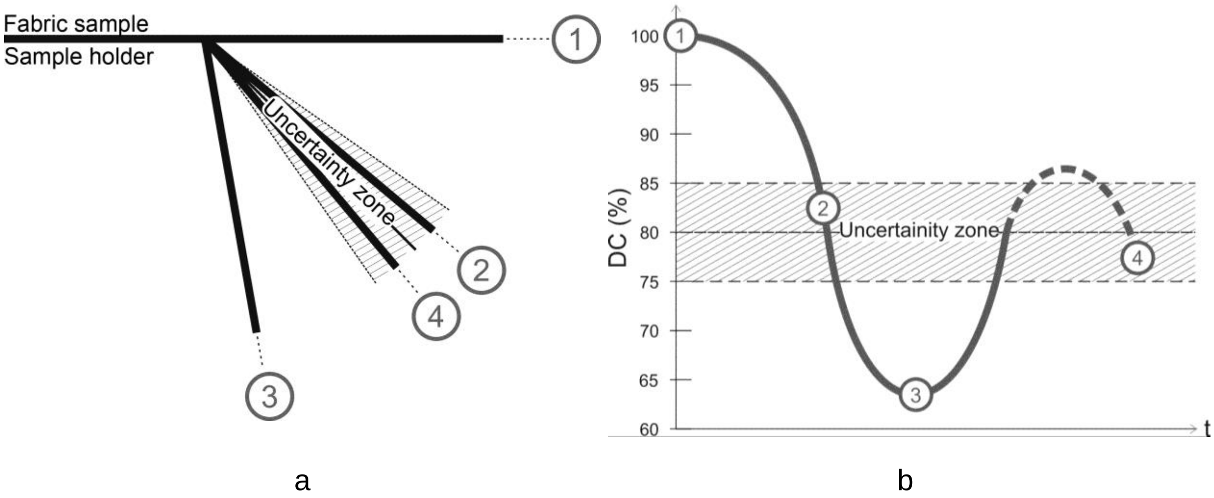


Figure 16: Process of drape formation

a) Section of the draping fabric; b) Change of the drape coefficient as a function of time

If a ring is applied in the measurements, the ring overcomes the resistance of the fabric and hence forces the already formed drapes under the uncertainty zone into position 3 – the extent of the force depends on the diameter of the ring. The fabric, which alternates back after, is not affected by the ring anymore and reaches the uncertainty zone where it stops or passes through it, carries out dampening free oscillating movements, but finally stops within the uncertainty zone (position 4).

The size of the uncertainty zone and the position where the fabric stops depend on the mechanical parameters of the fabric, i.e. the ratio of the specific weight, spring stiffness, viscous damping factor and the stick-and-slip friction coefficient. If the stick friction coefficient is high compared to the other values, the uncertainty zone is wide, and the fabric is likely to stop without oscillation. If the stick friction coefficient is low compared to the other values, the uncertainty zone is less wide, and it is possible that the fabric reaches its equilibrium state after carrying out dampening free oscillating movements.

Hence our proposal for modification is to take into consideration of an element that models the stick-and-slip friction in addition to the spring and viscous damper in particle system based models. Such a modification might make the solution of this already complex system even more complex, however the result of the simulation would be more realistic. On the other hand, further work is needed here which would worth to investigate in detail supported by more experimental data.

Effect of bending and shearing properties on drapeability

Apart from drape measurements, all three specific fabric samples were tested with the KES system. Figures 10 and 11 summarize the results of bending and shearing tests that are the most important ones considering draping behavior.

The results of bending and shearing tests are in line with the results of drape measurements as fabrics with higher shearing and bending stiffness have also higher drape coefficients.

CONCLUSION

Draping properties provide important information for the 3D modeling of fabrics. The most common properties are drape coefficient, DC and number of nodes, n. A new factor, drape unevenness (DU) that helps us to get a better picture of draping was created in our work.

Also in this work, a new method and a new device were described for measurement of draping properties, and with the help of this device the drape properties of the fabric are determined after dynamic influence. The special device is a ring that can exert different intensity dynamic forces on the fabric during drape formation depending on the actual size of the ring. This method makes it possible to measure the drape properties in a more reproducible way that approaches the real usage conditions better than in case of measurements without a ring.

A large number of measurements were carried out on three identical fabrics that differed only in the twist direction of its constituent yarns using Sylvie 3D Drape Tester. The main aims of the measurements were to determine the relation between the drape properties and yarn twist directions and to study the effect of rings.

The analysis of drape properties of fabrics, which composed of yarns with different twist directions, proved that although fabrics in which warp and weft yarns have Z-Z twist direction are thinner, they are mechanically more rigid, their drape coefficient values are higher and have more waves. If the warp and weft yarns of the fabric have Z-S twist direction respectively, the fabric is thicker but mechanically less rigid while their drape coefficients are lower and have less waves.

The analysis of the drape measurements, which was carried out at different dynamic impact, revealed that the stronger dynamic effect, i.e. smaller ring inner diameter, leads to smaller drape coefficient. Dynamic impact reduces the deviation of the drape coefficient as well, and hence makes measurements more reproducible and exact. The method increases the number of waves and makes the drape geometry more even.

Based on the test results obtained in this work, a simplified fabric behavior model was developed as well. Our results were supported by introduction and behavior analysis of the simplified model – one-mass oscillating system – of the fabric. But the analysis of the drape formation process indicates that stick-and-slip Coulomb friction has to be considered as well among the inner forces. With the help of such a modification in the model, we believe that the behavior of the fabric at different ring diameters and the simulation program would provide results closer to real material behavior. However, further work is needed here providing a detailed analysis with more experimental data.

The test results showing the effect of the twist direction of the warp and weft yarns and the dynamically influenced drape testing can contribute to the fabric behavior simulations so that the theoretical models can be improved further for more realistic representations.

Acknowledgements

This work was supported by the National Office for Research and Technology of the Hungarian Government [S&T TR-17/2008, SI-20/2009]; the TÜBITAK of the Turkish Government [Project No. 108M604]; the Hungarian Scientific Research Fund [K 68438 OTKA-NKTH] and the New Hungary Development Plan [Project ID: TÁMOP-4.2.1/B-09/1/KMR-2010-0002]. Furthermore, we would like thank our students, Ildikó Molnár, Kristóf Horváth and Orhan Kaya for their help in our measurements.

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