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Investigation of the Friction Coefficient of Seersucker Woven Fabrics

Abstract

At present, seersucker woven fabrics are increasingly used for the manufacturing of clothing. These fabrics are created in the weaving process as a result of the different tension of two sets of warp threads: basic and puckering. Seersucker woven fabrics applied in properly designed clothing have an ability to massage the body while wearing such clothing. In order to conduct a detailed analysis of the massaging process during the clothing usage, it is necessary to examine the phenomena occurring during the massaging. Friction is one of the most important phenomena influencing the massaging process. Due to the nature of seersucker woven fabrics, measurement of the friction coefficient is difficult. This paper presents the problems related to measurement of the coefficient of friction for an exemplary seersucker fabric. The work contains a description of the measurement method proposed and the consequences resulting from its application.

Key words: *seersucker woven fabrics, measurement, friction force, friction coefficient.*

◼ Introduction

The use of fabrics is mainly dictated by their properties. Where they are used as decorative materials, their appearance is the most important. On the other hand, if they have a protective function, then the strength properties will be important, e.g. resistance to mechanical loads, temperature and others. It is often required that fabric features are combined, for example, their appearance with specific properties. This combination is very often required in clothing, where the visual effect of the ready-made product must be combined with high parameters related to comfort or practicality. Practical features are most often associated with appropriate clothing design, for example, additional pockets, comfortable putting on as well as equipment with additional reflective systems.

In the case of properties related to comfort, we can mention here the following properties: thermal insulation, water-vapour permeability, moisture absorption, air permeability etc. [1-4]. The requirements for clothing properties are constantly increasing. In addition to the positive features, an important aspect related to the properties of fabrics is to reduce the negative effects that most often occur in the contact of clothing with human skin. Such properties include mechanical and chemical irritation, hazards of electrostatic discharge and others [5].

One of the main causes of mechanical skin irritation is incorrect sewing or improper fitting, especially too tight clothing. However, in addition to the above, the friction between fabric and human skin should be included in the features that increase skin irritation. The friction force between the human body and clothing is not always associated with negative features. It can give a positive effect. It is possible to design clothing for massaging individual parts of the body. With this type of clothing it is important that it adheres to the body. Then, through the movements performed by the wearer, it will massage individual muscle parts. For instance, this principle is applied in anti-cellulite clothing [6], where the movement of the body causes micro-movements of fabric fragments against the skin. Depending on the size of these displacements and the frictional forces between the skin and the fabric, it creates a certain amount of heat that is partially absorbed by the human body. This causes a slight increase in the temperature of the skin layer and thus accelerates fat burning.

The massaging effect of fabrics adhering to human skin was utilised in some kinds of anticellulite clothing already present on the market [7, 8]. According to the producer's declaration, such a kind of underwear improves blood circulation and removes liquid from the body. At the Textile Research Institute (Lodz, Poland), innovative woven fabric for anti-cellulite clothing was designed [9]. The seersucker woven fabric developed ensures the mechanical micro-massage and stimulation of blood circulation due to the convex – concave structure and special surface properties of the fabric.

In the application of clothing as a massaging tool, the main role is played by the surface properties of fabrics. The basic surface properties of textile materials are the surface friction and roughness. Surface roughness is a measure of the texture of a surface, quantified by the vertical deviations of the real surface from its ideal form. Roughness is typically considered to be the high frequency, short wavelength component of the surface measured [10-12].

Friction is defined as a force resisting relative motion between two bodies in contact. There are two classical laws of friction for a solid surface in contact. The first law states that the frictional force F is proportional to the load N acting perpendicularly to the surface. The proportionality constant μ is called the coefficient of friction. The second law states that the frictional force is independent of the geometric contact area of bodies that are sliding on each other [13].

Fabric friction is considered to be a property of textile materials which has considerable importance in the field of both technological and subjective assessment. The friction of a fabric on itself or on another fabric has a significant effect on fabric performance and the user's tactile comfort. The sensation is related to the mechanical interaction between the fabric and human skin. The friction properties of textile materials are significant components of the fabric hand.
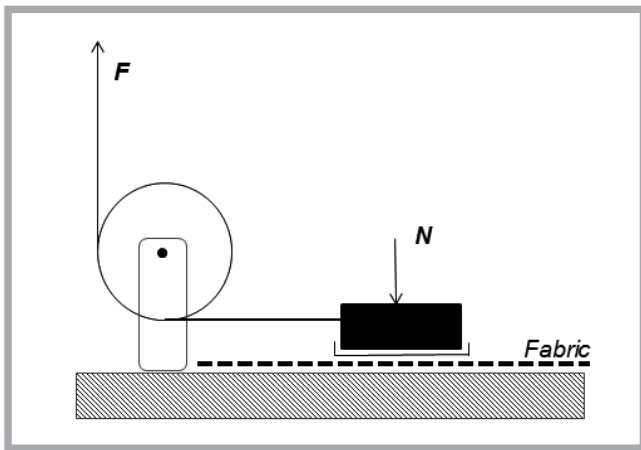
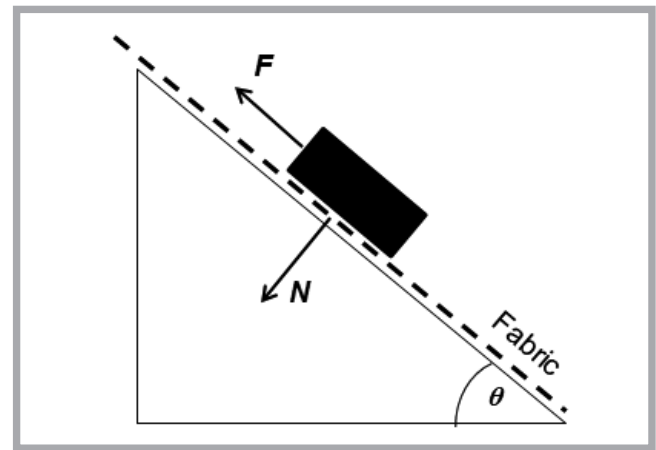*Figure 1. Concept of textile friction measurement.*

Figure 2. Textile friction measurement using an inclined plane.

Investigation showed that the coefficient of friction is constant for many solid materials, but it is generally not constant for textiles. Howell and Mazur introduced a friction index for textile materials and showed that it depends on the geometry of the asperities covering the surface and on the nature of the deformation that the surfaces undergo [14]. Studies reported by Wilson [15] showed that the dynamic friction between fabrics in contact is related to the apparent contact between them. Moreover experiments confirmed a decrease in the friction coefficient with an increase in the normal force. Frydrych and Matusiak demonstrated that the static and dynamic friction coefficients are affected by the raw material, weave and way of finishing of woven fabrics [16].

Two main ways are generally used to measure fabric friction [17]. The concept of the first method is shown in *Figure 1*.

In this method a block of mass *m* is pulled over a flat rigid surface which is covered with the fabric being tested. The line connected to the block is led around a frictionless pulley and connected to an appropriate load cell on a tensile testing machine. This method can measure the force *F* required both to start the block moving and also to keep it moving, thus providing the static and dynamic coefficients of friction from the relation:

$$\mu = \frac{F}{mg} \qquad (1)$$

where:
μ – friction coefficient,
F – force,
m – mass of the moving block,
g – gravitation acceleration.

This method can be performed using a standard tensile tester.

The second method used for measuring fabric friction is the inclined plane (*Figure 2*).

A block of mass *m* is initially lying on an inclined plane covered with the fabric tested. The angle θ of the plane is continuously adjusted until the block starts to slide. At this point the frictional force *F* is equal to that of of the block mass parallel to the plane, according to the equation:

$$F = m \cdot g \cdot \sin\theta \qquad (2)$$

The normal reaction *N* is equal to that of the mass perpendicular to the plane according to the formula:

$$N = m \cdot g \cdot \cos\theta \qquad (3)$$

The static friction coefficient above is equal to the tangent of the θ angle:

$$\mu = \tan\theta \qquad (4)$$

The coefficient of the dynamic friction may be measured by determining the angle at which the mass block is in continuous motion.

Nowadays both surface properties of fabrics: roughness and friction are usually measured by means of KES (Kawabata Evaluation System) – module KES – FB4 [17]. The KES is a system for the complex evaluation of textile materials. The system is applied to measure the low stress mechanical and surface properties of fabric, such as fabric extension, shear, bending compression, surface friction and roughness. It consists of four specialised moduli for measuring the tensile, shearing, bending and compression properties as well as the surface friction and roughness of fabrics [17]. By means of the KES – FB 4 module, the following surface properties can be measured [17, 18]:

■ coefficient of friction (MIU),
■ mean deviation of the coefficient of friction (MMD),
■ geometrical roughness (SMD).

Some problems can occur while measuring the surface properties of fabrics with a developed – textured surface. Seersucker woven fabrics can be an example of such a kind of fabric [19]. They are characterised by the occurrence flat and puckered strips in the warp direction (*Figure 3*). Especially the puckered strips can cause problems during measurement of the surface properties using a KES – FB 4 instrument.

The KES – FB 4 uses a single wire probe for surface roughness measurements and a finger-type probe consisting of 10 single wires for friction force measurement [20]. Both sensors move over the surface of the sample measured, registering changes in the thickness and friction force. The puckered strips of the seersucker fabric may impede the movement of the sensors on the sample surface and influence the results. Moreover the coefficient of friction is always determined for a given pair of materials. The KES-
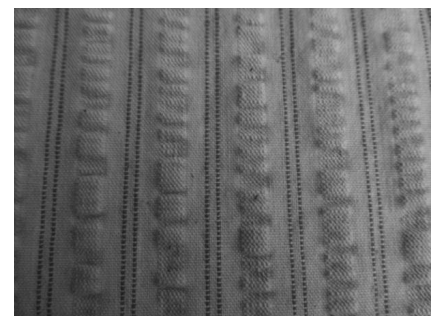

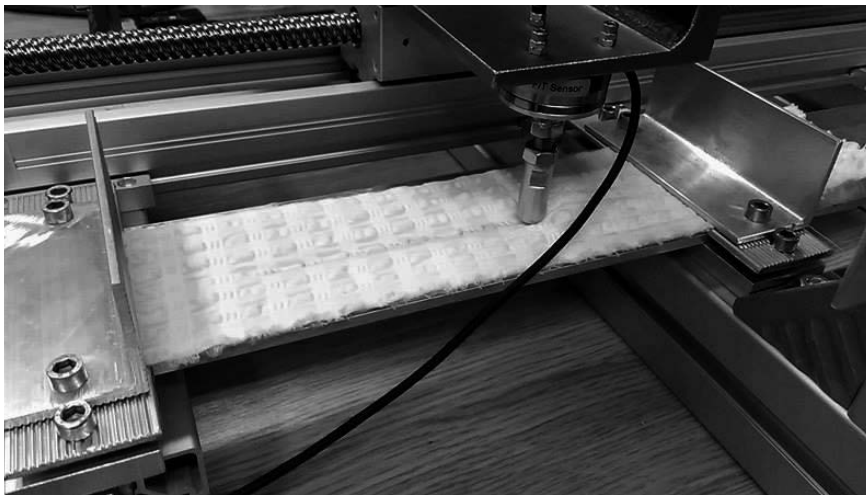*Figure 3. Example of seersucker woven fabric.*

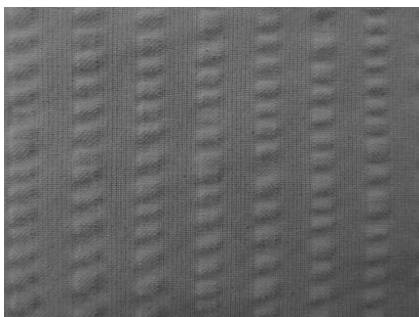*Figure 4. Test stand for friction measurement [21].*

Figure 5. Picture of the investigated fabric.

Table 1. Basic structural properties of fabric investigated.

Parameter	Unit	Value
Weave – warp I	–	plain
Weave – warp II	–	rep 2/2
Warp density	cm⁻¹	12.7
Weft density	cm⁻¹	11.4
Mass per square metre	g m⁻²	212.9
Take up – warp I	%	8.3
Take up – warp II	%	49.8
Take up – weft	%	7.1

FB 4 uses steel piano wire as a friction sensor, which means that it measures the friction coefficient between the fabric and steel. For different applications it is necessary to determine the friction coefficient between the fabric and another (not steel) surface.

Matusiak and Frączczak [21] investigated the friction of seersucker woven fabrics using the linear module MLAS16-0600-20EX (001). It is based on an aluminum profile and linear guide with a ball screw drive system. The screw drive was powered by a Maxon Motor 378536 electric motor controlled by an EPOS2 24/5 controller driven by a Matrix MPS-3005D lab power supply. Measurement of the friction coefficient was carried out using data collected from a 6-axes SI-40-20 Mini 40 F / T force sensor, mounted on the trolley of the linear module via an angle bracket. The measuring tip mounted on the sensor moves over the surface of the material tested that has been fastened between two clamping jaws (*Figure 4*).

The authors applied measuring tips made of different materials: aluminium, brass and plastic. It allowed a comparison of the values of friction coefficients between the seersucker woven fabrics and the tip's materials applied. The authors based their research on measuring the forces acting on the probe during its movement along the fabric. Thanks to the rounding of the probe, the authors measured the friction forces along both the puckered and flat strips.

Results obtained allowed to assess differences between the frictional properties of the puckered and flat strips of the seersucker woven fabrics. However, from the point of view of the application of seersucker fabrics in massaging clothing, it is important to consider the frictional properties of seersucker fabrics as a whole material. Thus it was decided to continue the studies on the coefficient of friction of these fabrics in order to obtain results characterising the massaging ability of the fabrics.

The aim of work was to develop a method of measurement of the friction coefficient of fabrics characterised by a textured surface. In order to do so, seersucker woven fabric was applied as an example of such a kind of textile material.

Material and method

In the work presented, seersucker woven fabric made of cotton was the object of investigation. The fabric had been manufactured on the basis of two warp sets made of 20 tex x 2 cotton yarn. The same yarn was applied in the weft. The fabric had been designed in such a way as to obtain puckered and flat strips of predetermined width of both puckered and flat strips in the warp direction: puckered strips – 5 mm and flat strips – 8 mm (*Figure 5*).

The basic properties of the fabric investigated are presented in *Table 1*.

As mentioned earlier, the coefficient of friction is always determined for a given pair of materials, which will be different for a pair of leather – fabric, steel – fabric or aluminium – fabric. It is also worth emphasising that this coefficient will also be different for a given fabric and, for example, for different species and skin finishes. Due to the fact that the investigation considers the potential acting of the material as a massaging tool, in the Authors' opinion it was necessary to measure the friction coefficient of the seersucker fabric in contact with skin. In order to do this, cowhide leather with a chrome finish was applied as one of the materials being in contact with the fabric investigated while measuring the friction coefficient.

The measuring stand is presented in *Figure 6*.

The measurement was carried out in such a way that a suitably cut sample of the seersucker woven fabric tested was placed on the flat bar (4). Then it was gently stretched by hand to smooth the unevenness of the fabric that could influence the measurement of the coefficient of friction. Smoothing was delicate and did not cause the straightening of the puckered strips. Then the fabric was left free to return to its natural position. One of the ends of the fabric was attached so that it did not move during the measurement. Next a cuboid was placed on the fabric, which was attached with a lightweight and non-stretchable cord to the force sensor (6). The orientation of the cuboid relative to the sensor was such that the cord was horizontal and that the cuboid lay freely on the fabric measured. Then the cuboid was moved a distance of 10 cm. Thanks to the rigid attachment of

one end, the fabric remained motionless and the cuboid slid on its surface. During the movement, the sensor measured the value of the force with which the cuboid was pulled. In order to avoid statistical error due to inaccuracy in mounting the force sensor (setting the measuring axis of the sensor contrary to the direction of the pulled parallelogram), the value measured was determined by means of the following equation:

$$f_i = \sqrt{x_i^2 + y_i^2} \qquad (5)$$

where:
x_i, y_i – force measured in x and y directions.

The coefficient of friction was determined for seersucker woven fabric in a pair with 4 different technical materials: aluminium, steel, silicone and cowhide leather.

For each friction pair 10 measurements were made in two different fabric positions where the cuboid was drawn both in the warp and weft directions. For each direction, the coefficient of friction was determined separately.

■ Results and discussion

Exemplary results are presented in *Figures 7* and *8*, presenting the course of changes in the friction force in time.

As can be seen in *Figures 7* and *8*, the course of values of friction forces as a function of time is not linear. You can distinguish 5 stages on them. The first and fifth are stages where the forces measured are equal to 0, i.e. before the start of the movement and after the end, and removing the cuboid from the fabric (step 5). Stage 2 is associated with the start of the movement. On the basis of large changes in the force, it can be noticed that in the first phase there is a significant increase in the force, and then the value of the static friction force is exceeded, which causes a sudden drop in the force. In addition, in *Figure 7*, the step changes in the force measured follow each other, which is related to self-excited vibrations that occur when the rectangle is accelerated and the puckered strips are lying under the cuboid. Such violent changes in the force stabilise after some time. The next, stage 3, is where the cuboid was drawn at a constant speed.

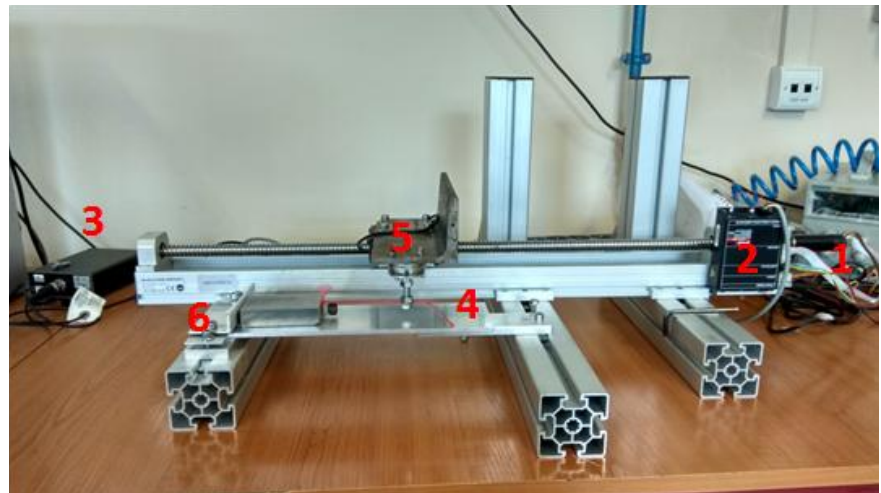During measurement in the weft direction (*Figure 8*), periodic increases in

Figure 6. Measuring stand applied in the measurement of the friction coefficient of seersucker woven fabric: 1 – laboratory power supply, 2 – Maxon Motor EPOS2 servo motor controller with motor, 3 – signal amplifier and data converter, 4 – flat bar on which the fabric is placed, 5 – force sensor, 6 – grooved angle fixing fabric on one side.
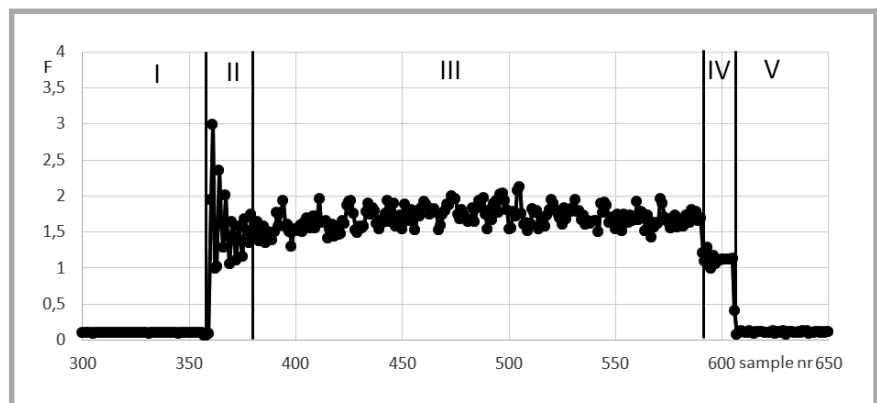

Figure 7. Exemplary course of measurement of the friction force in the warp direction.
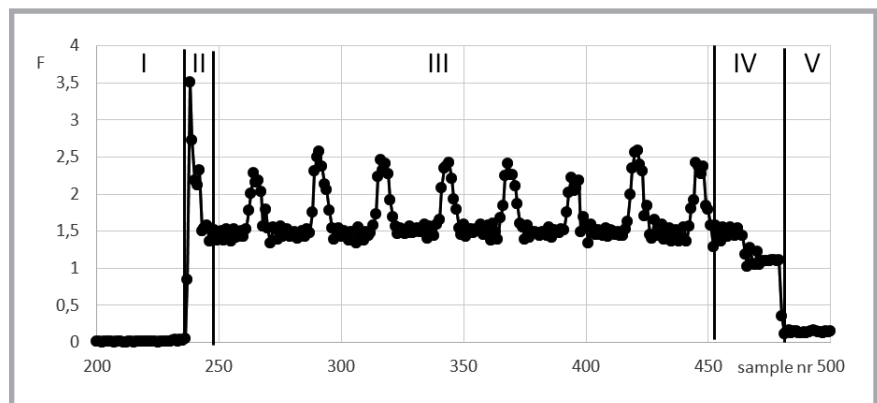

Figure 8. Exemplary course of measurement of the friction force in the weft direction.

strength are visible, related to pulling the rectangle over the puckered strips. It is worth noting that in this study the puckered strips are perpendicular to the direction of movement. The frequency of occurrence of force increases is the same as that of the puckered strips over which the cuboid was moving. Hence the number of force increases is the same as

that of puckered strips which the cuboid encountered during movement.

On the other hand, in the warp direction (*Figure 7*), periodic increases in the force do not occur. However, larger changes in force values are clearly visible in the warp direction. These changes are similar to the measurement noise, but
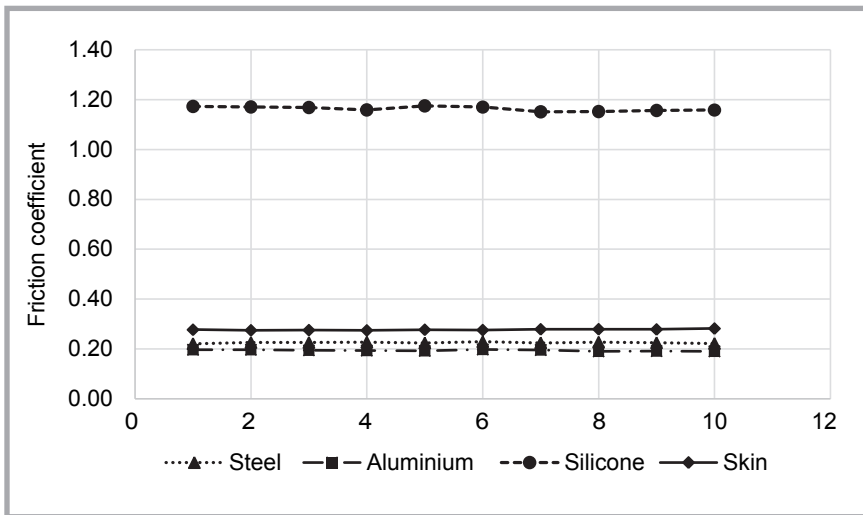
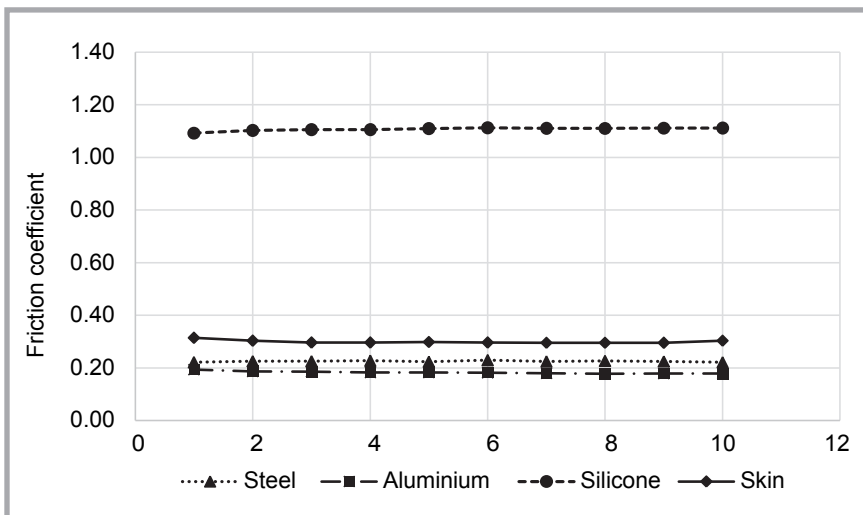**Figure 9.** *Friction coefficients in warp direction.*

Figure 10. *Friction coefficients in weft direction.*

Table 2. *Values of friction coefficients determined in the experiment. Legend: O – warp direction, W – weft direction, Aver. – mean value.*

		Friction coefficient										
		1	2	3	4	5	6	7	8	9	10	Aver.
Steel	O	0.22	0.23	0.23	0.23	0.22	0.23	0.22	0.23	0.23	0.22	0.225
	W	0.23	0.22	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.222
Aluminium	O	0.20	0.20	0.19	0.19	0.19	0.20	0.20	0.19	0.19	0.19	0.194
	W	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.183
Silicone	O	1.17	1.17	1.17	1.16	1.18	1.17	1.15	1.15	1.16	1.16	1.164
	W	1.09	1.10	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.107
Leather	O	0.28	0.28	0.28	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.278
	W	0.31	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.300

they are caused by dragging the cuboid on the puckered strips, which are irregular and cause chaotic changes in the forces measured.

As the last part of the experiment, step 4 should be specified, where there is a fragment on which the drawn rectangle prism has already stopped. It can be seen that there is a sharp decrease in forces, but

they do not decrease to 0. This indicates that during the test, the fabric is stretched, and when the cuboid stops, the internal stresses in the fabric affect it, which is visible in the form of forces measured.

The analysis above shows that only the measurements from step 3 can be taken to determine the friction coefficient value. It should be emphasised here that these val-

ues must be averaged due to the changes in forces caused by the puckered strips. Thus the friction force measured can be expressed by the following equation:

$$F = \sum_{i=1}^{n} f_i \qquad (6)$$

where: $i = 1,2,...,n$ are measuring points occurring in step 3,
n – is the last measuring point in step 3.

Then the coefficient of friction was determined by means of the following formula:

$$\mu = \frac{F}{N} = \frac{F}{m*g} \qquad (7)$$

where:
N – the pressure force with which the cuboid acts on the fabric,
m – the mass of the cuboid,
g – the gravitational acceleration (in the tests it was assumed that g = 9.81 [m/s^2]).

The friction coefficient was determined separately for the warp and weft directions. Results of the measurement are presented in **Table 2**.

Figures 9 and **10** present a comparison of friction coefficients determined for different pairs of materials, according to the plan of the experiment.

The next figures (**Figures 11-14**) present a comparison of values of friction coefficients in the warp and weft directions for particular pairs of materials.

The tests show that the highest value of the friction coefficient was stated for the friction pair: seersucker woven fabric and cuboid covered with silicone: 1.16 in the warp direction and 1.11 in the weft direction, respectively. The lowest value occurred for the fabric-aluminium pair: 0.18 in the weft direction and 0.19 in the warp direction. It should also be stated that the coefficient of friction for the fabric – steel pair was higher than for the fabric – aluminium pair and lower than for the fabric – leather pair.

Measurement of the coefficient of friction for seersucker woven fabric is not an easy matter. Many factors have to be taken into account, such as the stretchability of the fabric and the ability to hook the cuboid drawn on the puckered strips. In the tests carried out, the first problem was solved by pulling the cuboid a long distance – 10 cm. The second problem was solved by cutting the edge of the cuboid (**Figure 15**), thanks to which it could
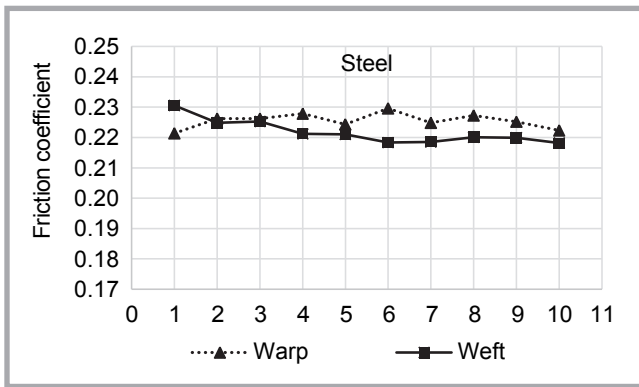
Figure 11. *Friction coefficients between the seersucker woven fabric and steel.*
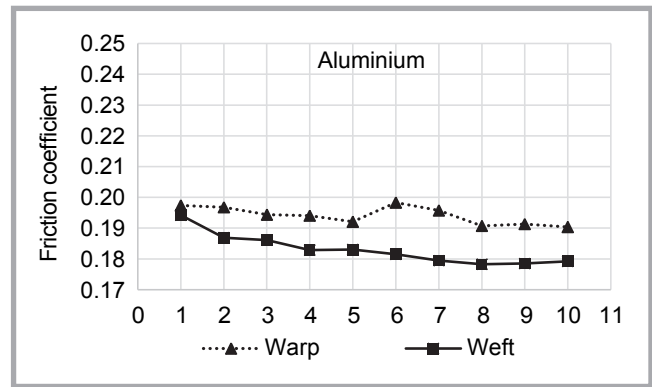

Figure 12. *Friction coefficients between the seersucker woven fabric and aluminium.*
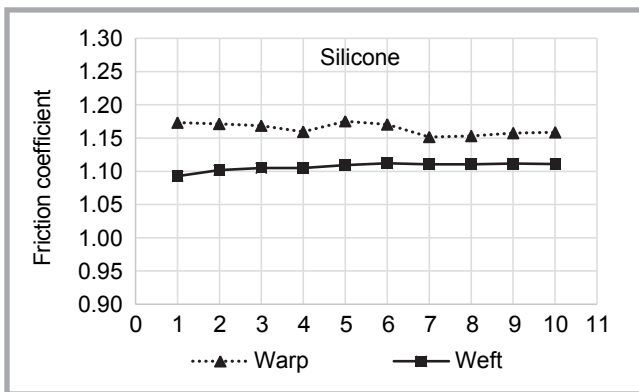

Figure 13. *Friction coefficients between the seersucker woven fabric and silicone.*
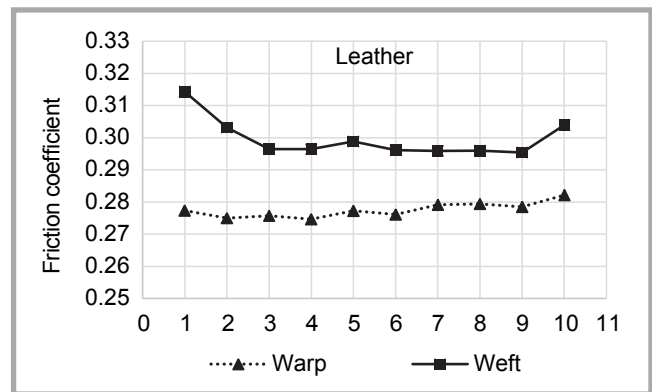

Figure 14. *Friction coefficients between the seersucker woven fabric and cowhide leather.*

gently slide on the puckered surface of the seersucker fabric.

Based on the results of the experiment, it can be stated that in most cases a higher coefficient of friction occurs for the direction of the warp than for that of the weft. An exception here is the friction pair cowhide leather – fabric, where a higher coefficient of friction occurred in the weft direction, which is a very important point taking into account that the friction between the fabric and leather is the nearest to that between the fabric and human skin. Other results for the following pairs: fabric – steel, fabric – aluminium and fabric – silicone do not reflect the friction between the fabric and human skin predicted. The results for silicone, steel and aluminium can be interesting from the point of view of other applications of seersucker woven fabrics.

Conclusions

Within the framework of the work presented, a method of measurement of the friction coefficient between seersucker woven fabric and other surfaces was developed. The method was checked for one variant of cotton seersucker woven fabric with a predetermined width of flat and puckered strips. Results obtained showed that the values of friction coefficients depend on the direction of measurement: warp and weft. Moreover very important is the material of the surface adjacent to the fabric during the measurement. It was stated that the highest value of the friction coefficient occurred between seersucker woven fabric and silicone, while the lowest values of the friction coefficient were noted for metal surfaces: steel and aluminium adjoining the fabric.

In order to assess the friction between the fabric and human skin, it is necessary to apply material of surface characteristics close to those of human skin.

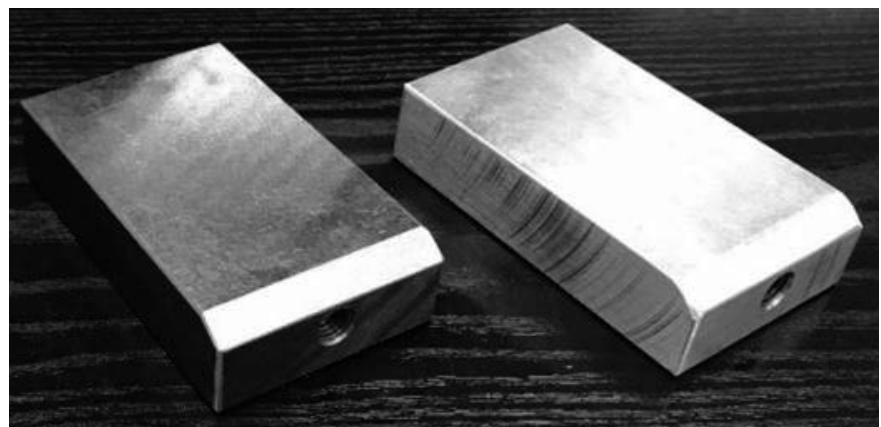The investigations presented are preliminary. Next the method will be applied

Figure 15. *Cuboids applied in measurement.*

in the measurement of other seersucker woven fabrics with a different repeat of the seersucker effect. It is also necessary to compare the results of measurement using the method described with those of another method applied in the measurement of the friction coefficient of textile materials. This will be the subject of the next publication.

References

1. Bhattacharjee D, Kothari VK. Heat transfer trough woven textiles. *International Journal of Heat and Mass Transfer* 2009; 52: 2155-2160.
2. Hes L. Alternative Methods of Determination of Water Vapour Resistance of Fabrics by Means of a Skin Model. *Proceedings of the 3rd European Conference on Protective Clothing and NOKOBETEF* 8, Gdynia, 2006.
3. Tokarska M, Gniotek K. Determination of Woven Fabric Impact Permeability Index. *Indian Journal of Fibre & Textile Research* 2009; 34: 239-244.
4. Matusiak M. Thermal Insulation of Woven Fabrics for Clothing. Monograph. *Works of Textile Research Institute.* Special edition. Lodz: Textile Research Institute; 2011.
5. Lumelsky VJ, Shur MS, Wagner S. Sensitive Skin. IEEE Sensors Journal. 2001; 1, 1: 41-51.
6. Matusiak M, Wilk E, Zieliński J. Seersucker woven fabrics with therapeutic properties. *FIBRES & TEXTILES in Eastern Europe* 2018; 26, 5(131): 54-58. DOI: 10.5604/01.3001.0012.2531.
7. de Godoy JMP, de Godoy MFG. Treatment of cellulite based on the hypothesis of a novel pathophysiology. *Clinical, Cosmetic and Investigational Dermatology* 2011; 4: 55-59.
8. Alizadeh Z, Halabchi F, et al. Review of the mechanisms and effects of noninvasive body contouring devices on cellulite and subcutaneous fat. *Int J Endocrinol Metab.* 2016.
9. Matusiak M. Investigation of Woven Fabrics for Anticellulite Clothing. *Proceedins of Clotech 2010 Conference,* Radom, 2010.
10. Ningtao Mao, Yiyi Wang, Jianguo Qu. Smoothness and Roughness: Characteristics of Fabric-to-Fabric Self-Friction Properties. *Proceedings of TIWC*; 2016; 25-28 April, Poznan.
11. Kang TJ, Kim SC, Sul IH, Youn JR, Chung K. Fabric Surface Roughness Evaluation Using Wavelet-Fractal Method. Part I: Wrinkle, Smoothness and Seam Pucker. *Textile Research Journal* 2005; 75(11): 751-760.
12. Militky J. Bajzík V. Surface roughness of heat protective clothing textiles. International *Journal of Clothing Science and Technology* 2003; 15, ¾: 258-267.
13. Carr WW, Posey JE, Tincher WC. Frictional Characteristics of Apparel Fabrics. *Textile Research Journal* 2007; 59, 3: 129-13.
14. Wilson D. A Study of Fabric-on-Fabric Dynamic Friction. *Journal of Textile Institute* 1963; 54.
15. Saville BP. Physical testing of Textile. Woodhead Publishing Limited, 1999.
16. Frydrych I, Matusiak M. Effect of woven fabrics on the fabric hand of cotton and CO/PE fabrics assessed on the Instron tensile tester. In: *Behery HM. Effect of mechanical and physical properties on fabric hand*. Woodhead Publishing in Textiles. Woodhead Publishing Ltd.; 2005: 239-286.
17. Gupta BS, Ajayi JO, Kutsenko M. Experimental methods for analyzing friction in textiles. In: *Gupta BS. Friction in textile materials*. Woodhead Publishing Limited, Cambridge England 2008: 174-221.
18. De Boss A. Concepts and understanding of fabric hand. In: *Behery HM. Efefct of mechanical and physical properties on fabric hand*. Woodhead Publishing in Textiles, Woodhead Publishing Ltd. 2005: 11-44.
19. Matusiak M, Frącczak Ł. Influence of Kind of Weft Yarn on Properties of the Seersucker Woven Fabrics. *Autex Research Journal* 2016; 16, 4: 214-221.
20. Sang-Hyup Lee, Hyoung-Jin Kim, Young-Chan Ko, Jin-Hee Lee, Jung-Yoon Park, Byoung-Geun Moon, Jong-Moon Park. Characterization of Surface Properties of Hygiene Paper by Fractal Dimension Analysis Technique. *Journal of Korea Technical Association of the Pulp and Paper Industry* 2017; 49, 6: 90-101.
21. Frącczak L, Matusiak M. Investigation of Surface Friction of the Seersucker Fabrics. In: Frydrych I, Bartkowiak G, Pawłowa M. Innovations in Clothing 3D Design, Products, Fashion, Technologies and Testing of Clothing Materials. Lodz University of Technology. Lodz. 2017: 235-249.

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