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SURFACE CHARACTERISTICS OF SEERSUCKER WOVEN FABRICS

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Abstract:

The surface characteristics of fabrics are important from the point of view of the sensorial comfort of clothing users. Surface friction and surface roughness are the most important surface parameters of fabrics. These parameters can be measured using different methods, the most important and well-accepted method being that using the Kawabata evaluation system (KES)-FB4 testing instrument. In this work, the surface roughness and surface friction of the seersucker woven fabric have been determined using the KES-FB4. However, the measurement procedure needs modification. On the basis of the results, the influence of the repeat of the seersucker effect and the linear density of the weft yarn on the surface parameters has been determined.

Keywords:

Seersucker woven fabrics, surface friction, surface roughness, KES-FB4, measurement

1. Introduction

Sensorial comfort is defined as a sensation on how the fabric feels when it is worn close to the skin [1]. It is a very important type of comfort, especially while using underwear and clothing directly adherent to the human skin. Surface properties, such as friction and roughness, of fabrics are important for sensorial comfort during usage of clothing. Both surface friction and surface roughness are measured using the Kawabata evaluation system (KES).

The surface friction of fabrics is defined as resistance to motion [2]. More precisely, it is considered as a force resisting the relative motion between two bodies in contact. There are two classical laws of friction for solid surfaces in contact. The first law states that the frictional force F is proportional to the load N acting perpendicular to the surface.

$$F = \mu N \qquad (1)$$

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 the bodies that are sliding over each other. It depends on the kind of surface [3].

Fabric friction is a considerably important property of textile materials in the context of both technological and subjective assessments. 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 the human skin. The frictional properties of textile materials are significant components of the fabric hand.

The surface roughness, often shortened to roughness, is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. Roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. There are a lot of parameters characterizing the surface roughness. However, the most frequently used ones are the following [4]:

- the mean absolute deviation (MAD) of the assessed profile;
- standard deviation (SD) or surface roughness;
- the mean height of picks (MHP); and
- the surface average mean curvature (SAMC).

Different methods and testing devices are applied for measurement of the surface friction and roughness of textile fabrics. The surface friction is measured either by pulling a block of mass over a flat rigid surface covered with the fabric being tested or by using the inclined plane [5]. FrictorQ is an instrument developed at the University of Minho (Portugal), which measures the surface friction of textile materials [6]. Fracczak and Matusiak [7] have measured the surface friction of seersucker fabrics using the six-axis SI-40-20 Mini 40 F/T force sensor, mounted on the trolley of the linear module via an angle bracket. The authors applied measuring tips made of different materials, such as aluminum, brass, and plastic.

The roughness of the engineered surfaces has been traditionally measured by the stylus profiling method, creating a surface profile called the surface height variation trace [8, 9]. Modern methods are based on the image processing of surface images of fabrics [10–12].

Nowadays, the KES is widely accepted and commonly used all over the world as an assessment method for both these surface properties of fabrics. The KES is used for the complex evaluation of textile materials, and it measures the fabric's low-stress mechanical and surface properties, such as fabric extension, shear, bending compression, surface friction, and roughness. It consists of four specialized modules for measuring the tensile, shearing, bending, and compression properties, as well as the surface friction and roughness, of fabrics [13]. By means of the KES-FB4 module, the following surface properties can be determined [14, 15]:

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

Measurement of the surface roughness and friction is performed simultaneously in one cycle of measurement. As mentioned earlier, the KES measurement method is commonly accepted and widely applied. However, some problems can arise while measuring the surface properties of patterned fabrics characterized by unconventional topography, as discussed in some previous papers [5, 7]. Seersucker woven fabrics are examples of such unconventional textile structures. Their main feature is the occurrence of alternating flat and puckered stripes in the warp direction (Figure 1). Such a structure is typically received on the loom due to the application of different tensions for the warp yarns. The puckered stripes can disturb the movement of both the sensors measuring the friction and roughness and, at the same time, they can influence the KES results.

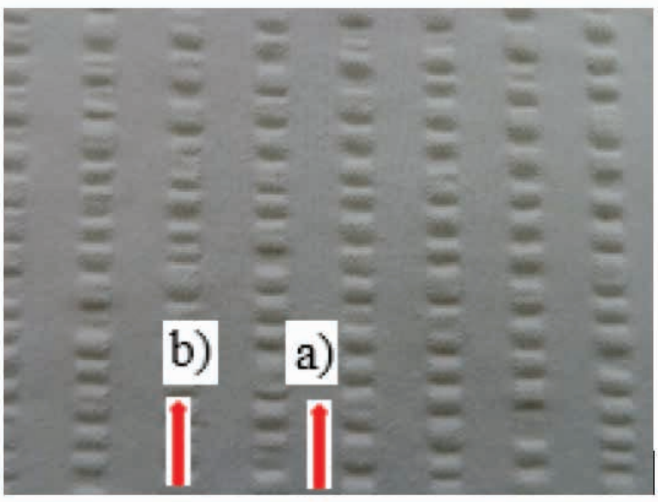

Figure 1. An example of a seersucker woven fabric and the area of the measurement: (a) smooth part and (b) puckered part.

The aim of this work was to investigate the surface properties of seersucker woven fabrics having different structures using the KES-FB4 module and to analyze the influence of the finishing, repeat of the seersucker effect, and linear density of the weft yarn on the measurement results.

2. Materials and methods

Seersucker woven fabrics having different structures were the objects of the investigations. Totally, nine variants of the seersucker woven fabrics were analyzed in terms of their surface properties. They differed from one another in the range of the repeat of the seersucker effect and the kind of weft yarn. The fabrics were manufactured from cotton yarns. In the experimental set of fabrics, three kinds of repeats of the seersucker pattern and three kinds of weft yarns were applied. Both warps, namely, basic and puckering, were made from the same yarn, i.e., 20 tex x 2 cotton. For the weft, the following yarns were used: 20 tex x 2, 25 tex x 2, and 30 tex x 2.

The following variants of the seersucker pattern were applied:

- Variant 1 – width of puckered and flat stripes 5 mm and 8 mm, respectively;
- Variant 2 – width of puckered and flat stripes 9 mm and 18 mm, respectively; and
- Variant 3 – width of puckered and flat stripes 11 mm and 41 mm, respectively.

Measurement was performed for gray and finished fabrics. The fabrics were finished using a tensionless method. The finishing process included washing, rinsing, and drying. Because the fabrics were manufactured from 2-ply yarns, the warps did not need to be sized. Consequently, the desizing process was unnecessary.

The basic properties of the gray and finished fabrics are presented in Tables 1 and 2, respectively.

The fabrics were analyzed in terms of the ranges of the surface roughness and surface friction using the KES-FB4 device. The conditions of measurement were set in accordance with the operation manual.

Measurement was performed separately for the smooth and puckered areas of the fabric. First, the fabric was fixed in the jaws such that the contactor measured only the smooth part of the fabric (see Figure 1a). Next, the fabric was fixed in the jaws such that only the puckered area was measured (see Figure 1b). Each measurement was performed three times, and only the warp direction was studied.

Table 1. Basic structural properties of the investigated gray fabrics

	Unit	Value								
Weave – warp I	**–**	**Plain**								
Weave – warp II	**–**	**Rep 2/2**								
Repeat variant	**–**	**Variant 1**			**Variant 2**			**Variant 3**		
Weft yarn	–	20 tex x 2	25 tex x 2	30 tex x 2	20 tex x 2	25 tex x 2	30 tex x 2	20 tex x 2	25 tex x 2	30 tex x 2
Symbol	–	MM 1/1	MM 1/2	MM 1/3	MM 2/1	MM 2/2	MM 2/3	MM 3/1	MM 3/2	MM 3/3
Warp density	cm^{-1}	12.7	11.9	12.8	12.6	12.5	12.3	11.4	11.8	11.6
Weft density	cm^{-1}	11.4	11.1	10.4	11.5	11.0	10.4	11.4	11.1	11.4
Mass per square meter	$g\ m^{-2}$	212.9	233.0	253.0	207.8	226.1	245.6	192.8	212.5	230.0
Take up – warp I	%	8.3	7.3	7.9	6.0	6.3	8.2	5.2	6.6	11.1
Take up – warp II	%	49.8	56.0	60.2	48.8	50.4	49.6	49.7	46.3	47.2
Take up – weft	%	7.1	8.6	8.7	6.4	6.4	6.2	8.2	5.0	6.7

Table 2. Basic structural properties of the investigated finished fabrics

	Unit	Value								
		Variant 1			**Variant 2**			**Variant 3**		
Symbol	–	MM 1/1	MM 1/2	MM 1/3	MM 2/1	MM 2/2	MM 2/3	MM 3/1	MM 3/2	MM 3/3
Weft yarn	–	20 tex x 2	25 tex x 2	30 tex x 2	20 tex x 2	25 tex x 2	30 tex x 2	20 tex x 2	25 tex x 2	30 tex x 2
Warp density	cm^{-1}	13.8	13.5	13.8	13.7	13.8	13.4	12.8	13.0	13.1
Weft density	cm^{-1}	12.0	11.6	10.8	11.8	11.0	10.6	11.7	11.2	10.5
Mass per square meter	$g\ m^{-2}$	221.9	253.0	262.5	217.0	236.8	254.8	205.4	227.0	243.5
Take up – warp I	%	16.2	6.4	10.1	5.8	7.9	8.6	6.3	8.3	12.1
Take up – warp II	%	53.8	62.4	60.4	41.6	52.2	44.8	44.0	48.0	45.4
Take up – weft	%	14.7	15.8	13.5	14.8	14.0	13.0	15.3	15.2	17.9

3. Results and discussion

The results of the measurement of surface friction and surface roughness using the KES are presented in Tables 3 and 4 for the gray and finished seersucker woven fabrics, respectively.

3.1. Surface friction

The surface friction values of the smooth and puckered areas of the analyzed fabrics are presented in Figure 2 (gray fabrics) and Figure 3 (finished fabrics).

It is clearly seen that the values for the smooth areas of the fabrics differ from the values for the puckered areas of the fabrics. In the case of the gray fabrics (Figure 2), in the majority of cases, the values of the coefficient of friction for the smooth area are higher than those for the puckered area. This variation may result from the difference in quality of the surface in both these areas of the fabrics and the different contact points between the fabric and the sensor, which is difficult to explain. Such types of fabrics have not been analyzed in the context of the range of friction using the KES system. It is necessary to compare the results with the results obtained from other testing devices. However, the FrictorQ and the inclined plain methods measure the surface friction on bigger areas of fabrics. Probably, it is impossible to perform separate measurements for the puckered and flat areas of the seersucker woven fabrics using both these methods.

The difference in coefficient of friction values can also be explained based on the phenomenon of coefficient of friction of textile materials. The coefficient of friction is constant for many hard materials but not for fabrics [16]. In the case of textile materials, the frictional forces usually depend on the geometric area of contact. In the case of seersucker woven fabrics, the geometric area of contact is different for both phases of the fabric, namely, flat and puckered.

Table 3. Results for the gray seersucker woven fabrics

Sample	MIU		MMD		SMD [µm]	
	Smooth	Puckered	Smooth	Puckered	Smooth	Puckered
MM1/1	0.195	0.178	0.033	0.039	5.835	8.337
MM1/2	0.211	0.171	0.041	0.038	7.007	7.080
MM1/3	0.168	0.166	0.041	0.027	7.373	7.434
MM2/1	0.190	0.183	0.019	0.027	5.457	7.227
MM2/2	0.183	0.178	0.038	0.065	7.288	7.532
MM2/3	0.184	0.182	0.040	0.035	7.544	9.668
MM3/1	0.195	0.178	0.027	0.026	8.008	8.875
MM3/2	0.187	0.178	0.049	0.038	5.945	9.290
MM3/3	0.198	0.179	0.035	0.049	7.251	7.788

Table 4. Results for the finished seersucker woven fabrics

Sample	MIU		MMD		SMD [µm]	
	Smooth	Puckered	Smooth	Puckered	Smooth	Puckered
MM1/1	0.164	0.153	0.026	0.014	5.176	5.603
MM1/2	0.149	0.160	0.021	0.025	5.969	7.153
MM1/3	0.177	0.167	0.071	0.066	5.566	7.556
MM2/1	0.159	0.179	0.018	0.023	4.724	6.653
MM2/2	0.164	0.177	0.050	0.065	6.482	8.118
MM2/3	0.157	0.165	0.036	0.041	5.518	6.580
MM3/1	0.165	0.177	0.028	0.034	8.472	8.386
MM3/2	0.155	0.171	0.033	0.031	6.348	5.151
MM3/3	0.184	0.165	0.077	0.068	5.286	7.068

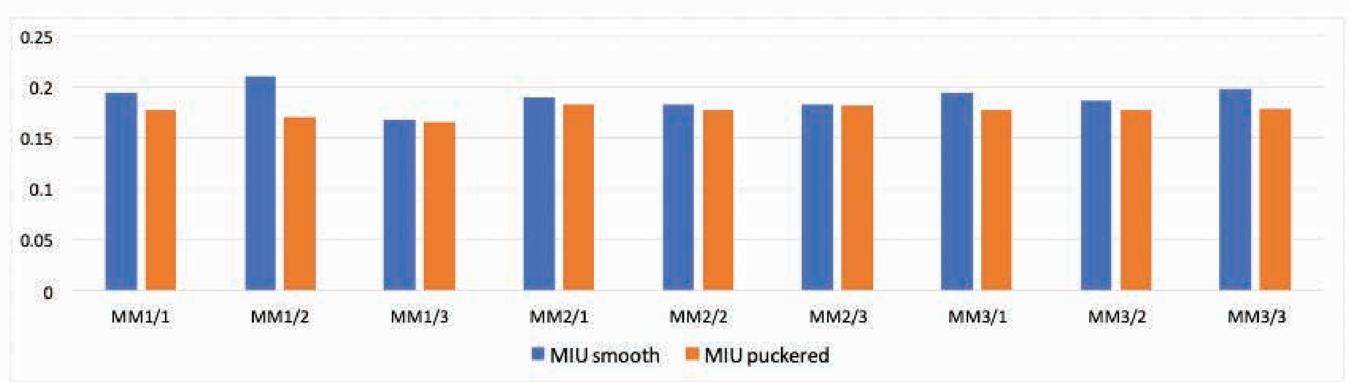

Figure 2. Coefficient of friction of the gray seersucker woven fabrics.

According to the literature, the frictional behavior of easily deformed materials such as fabrics, which are essentially viscoelastic, is better expressed by the following nonlinear relation [16, 17]:

$$F = C \cdot N^n \quad (2)$$

where F is the frictional force, N is the normal force, C is the coefficient of contact, and n is the friction index.

The friction index n is different depending on the roughness geometry of the surface and the nature of deformation of the surface during movement while measuring the surface friction. The fabrics being investigated differ from one another in the

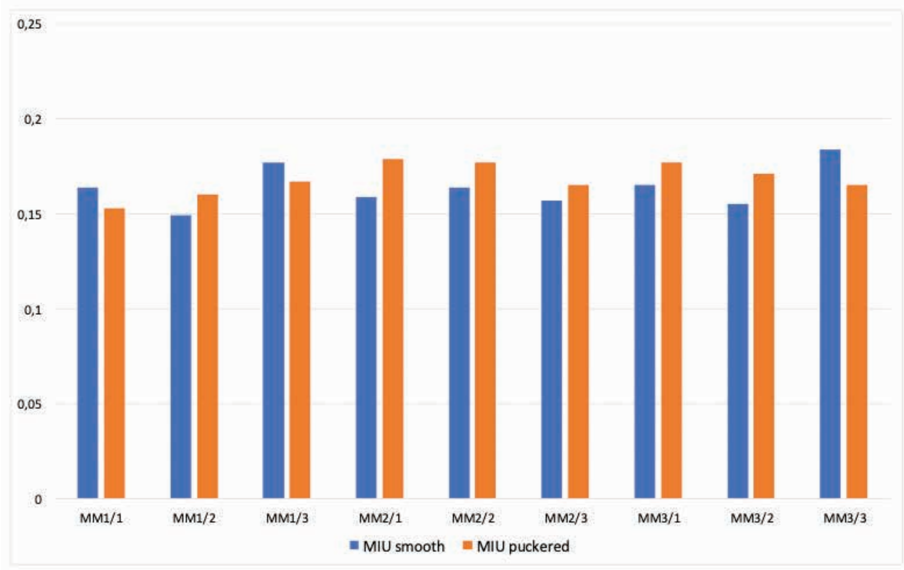

Figure 3. Coefficient of friction of the finished seersucker woven fabrics.

range of their surface topography and elasticity. It is difficult to assess the deformation of the surface during measurement of the surface properties and this topic should be the object of further investigations.

The relationships are different in the case of the finished fabrics (Figure 3). In some cases (the MM1/1, MM1/3, and MM3/3 samples), the values of the coefficient of friction for the smooth area are higher than those for the puckered area. It is the same relation as stated for all gray fabrics. For the remaining variants, there is an opposite relationship: the values of the coefficient of friction for the puckered area are higher than those for the smooth area of the investigated fabrics. This relationship is in agreement with expectations.

Figures 4 and 5 present the comparisons of the values of the coefficient of friction for gray and finished fabrics for the smooth and puckered areas, respectively.

Results show that the coefficient of friction has higher values for the gray fabrics than for the finished fabrics, but the differences are significantly higher for the smooth areas of the fabrics.

Based on the presented results, it is difficult to assess the influence of the linear density of weft yarn on the values of the coefficient of friction. Probably, the surface topography of the investigated fabrics is a factor determining the value of the coefficient of friction.

We observe a more visible influence of the linear density of the weft yarn in the range of the mean deviation of the coefficient of friction, i.e., MMD (Figures 6 and 7). For both puckered and smooth areas of the finished fabrics with the repeat variants No. 1 and No. 3, the highest value of the MMD was obtained for fabrics with the 30 tex x 2 weft yarn. In the case of the repeat Variant No. 2 for the finished fabrics, the highest value of the MMD was observed for fabrics with the 25 tex x 2 weft yarn.

For the gray fabrics, the value of the MMD for the smooth area rather increases with increase in the linear density of the weft yarn (Figure 6). For the puckered area of the fabrics, the tendency of changes in the MMD, which depends on the weft yarn's linear density, is different for each variant of the repeat of the seersucker effect (Figure 7).

This variation can be explained by the interaction between both the structural factors, namely, repeat of the seersucker effect and linear density of the weft yarn.

As mentioned earlier, the seersucker woven fabrics are flexible materials. Their frictional behavior can be described by Eq. (2). However, we do not know the values of the friction index *n* and constant *C* for such kinds of fabrics. It should be mentioned here that the influence of deformation on the frictional behavior of the seersucker fabrics has been confirmed by previous investigations [18]. Taking into account the possibility of deformation during the measurement of frictional properties of fabrics, it is necessary to take into consideration the stiffness of fabrics. The gray fabrics are significantly stiffer than the finished fabrics. On the other hand, the stiffness of the fabrics is higher for the fabrics containing coarser weft yarn. In addition, the stiffness of the smooth parts of the seersucker woven fabrics is different from the stiffness of the puckered parts of the fabrics. All these above-mentioned factors and the interactions between them influence the values of the surface friction determined using the KES.

3.2. Surface roughness

A comparison of the surface roughness values for the smooth and puckered areas of the gray fabrics is presented in Figure 8. In all cases, the surface roughness values of the puckered area of the fabrics are higher than the surface roughness values of the smooth area. However, in some cases, such as MM1/2, MM1/3, and MM2/2, the difference between the values for the puckered and smooth areas is very low.

The tendency is the same in the case of the finished fabrics. Generally, the surface roughness of the puckered area is higher than the surface roughness of the smooth area (Figure 9). It

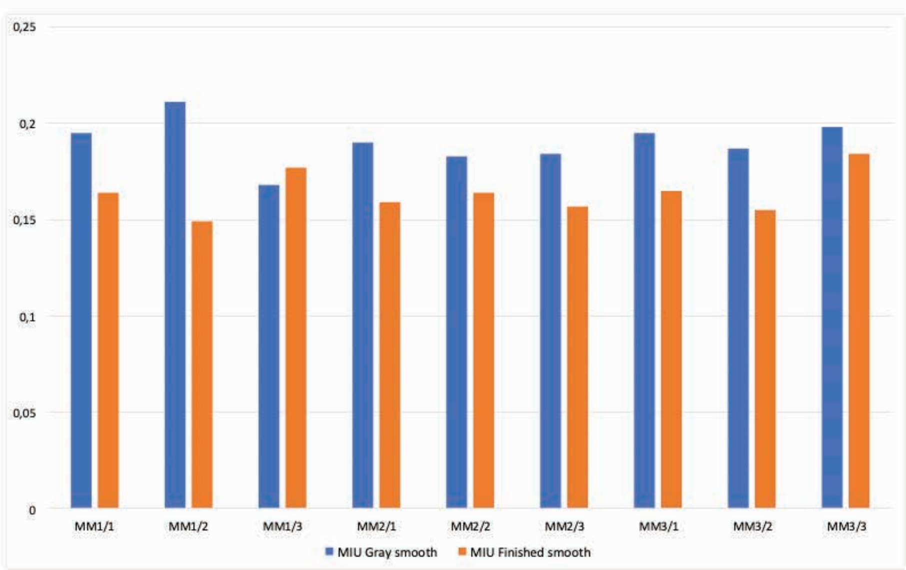

Figure 4. Coefficient of friction values for the smooth areas of the gray and finished seersucker woven fabrics.

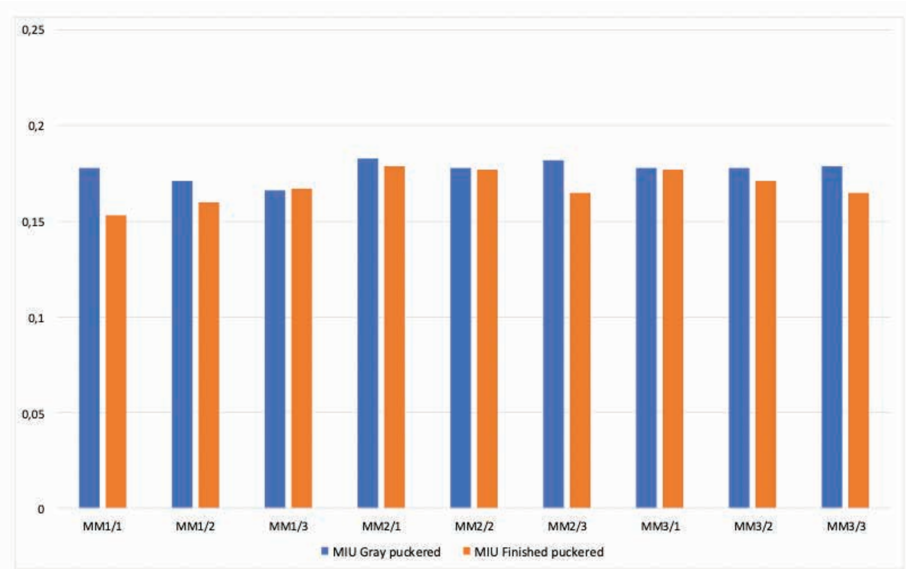

Figure 5. Coefficient of friction values for the puckered areas of the gray and finished seersucker woven fabrics.

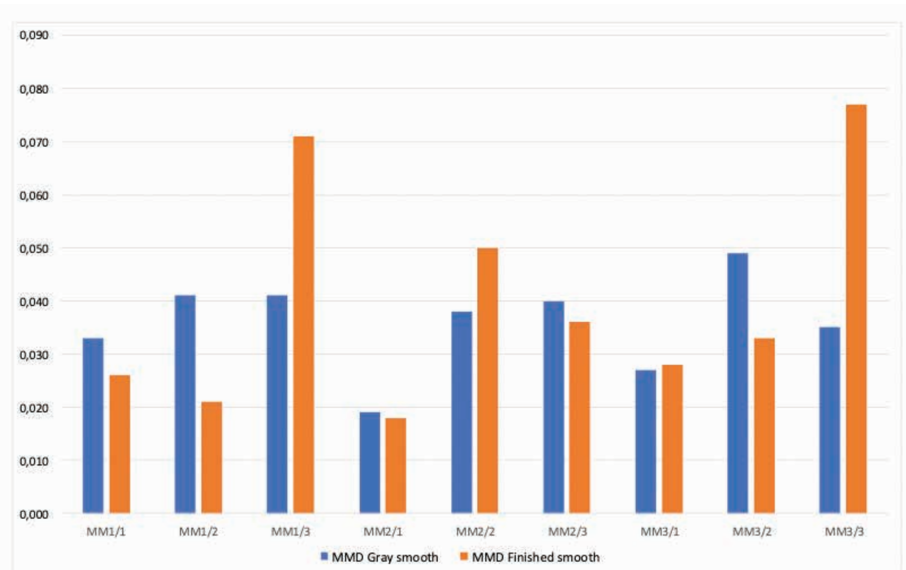

Figure 6. The mean deviation of the coefficient of friction for the smooth areas of the gray and finished seersucker woven fabrics.

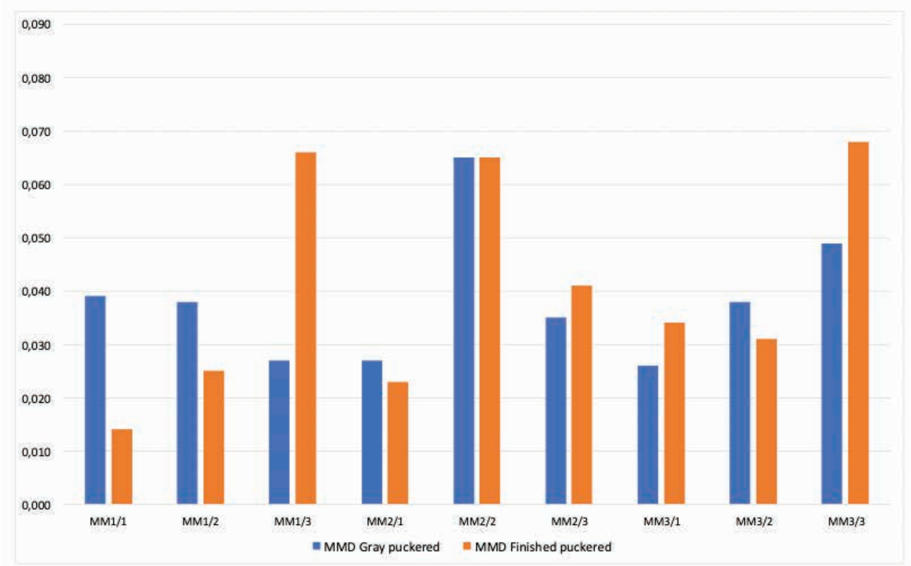

Figure 7. The mean deviation of the coefficient of friction for the puckered areas of the gray and finished seersucker woven fabrics.

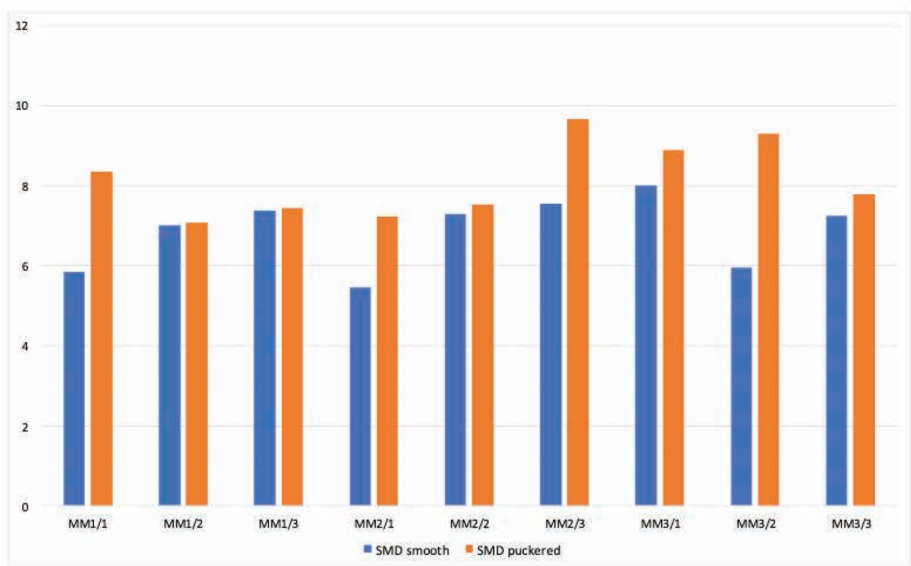

Figure 8. The surface roughness of the gray seersucker woven fabrics.

is according to expectations. However, in two cases, namely, MM3/1 and MM3/2, the relationship is the opposite.

A comparison of the surface roughness of the smooth areas of the gray and finished fabrics is presented in Figure 10, whereas the comparison for the puckered areas is presented in Figure 11. Generally, the results are according to expectations. The surface roughness of the gray fabrics is higher than that of the finished fabrics. It results from fabric relaxation during the finishing process. However, in some cases, mostly the puckered areas of the fabrics being investigated, the results do not agree with expectations. . This can be explained by the fact that the structure of the fabrics, especially the puckered topography, can disturb the movement of the roughness sensor, which can influence the results.

The question that arises is as follows: Is the KES system appropriate for assessment of the surface properties of seersucker woven fabrics? The question also concerns other patterned fabrics with a not-smooth surface caused by the design pattern.

In the case of fabrics in direct contact with the human skin, there is also another question: Does it make sense to study a smooth fabric surface if only the puckered surface is in direct contact with the human skin?

It is also interesting to compare the results from the KES approach with the results from other methods and devices used for measurement of the surface properties of fabrics.

4. Conclusions

On the basis of the presented results, it can be stated that the measurement of surface properties of seersucker woven fabrics using the KES-FB4 device needs modification of the measurement procedures. It is necessary to perform

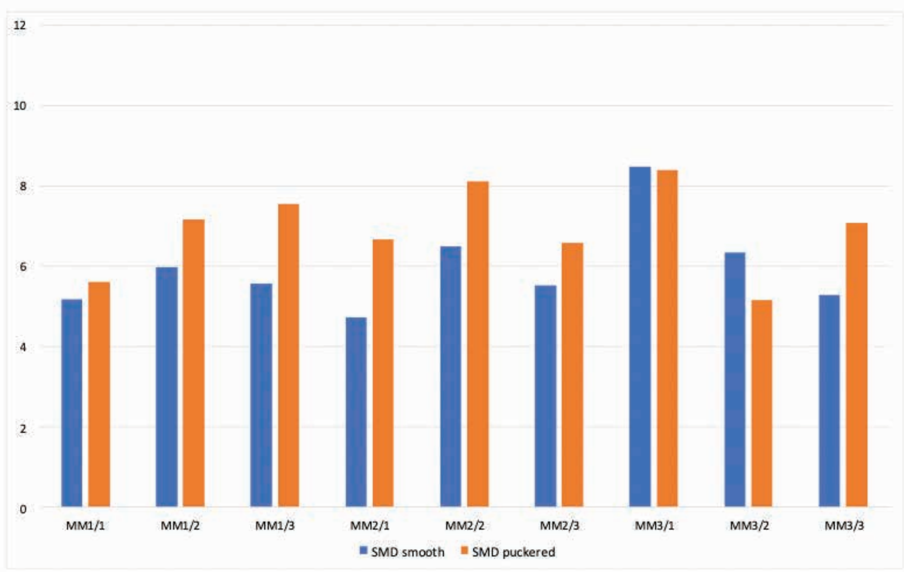

Figure 9. The surface roughness of the finished seersucker woven fabrics.

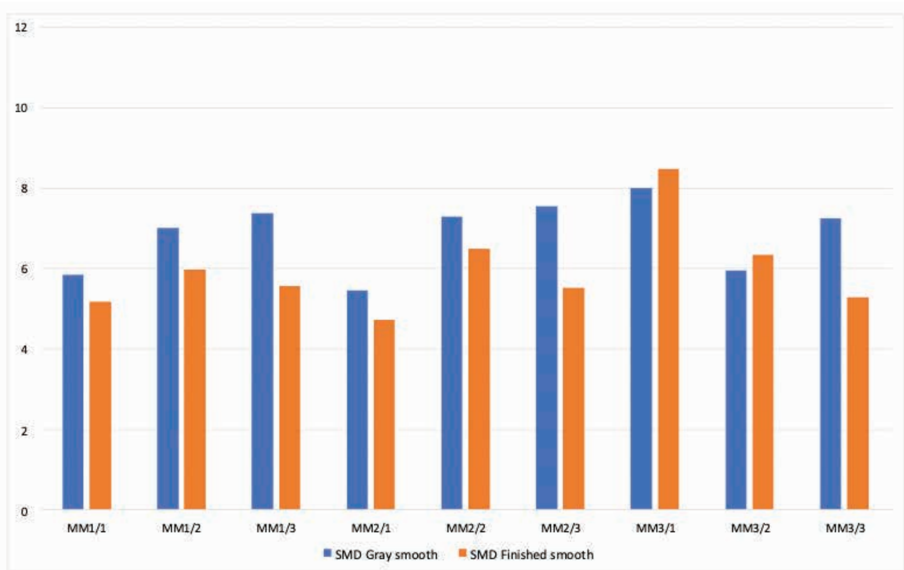

Figure 10. The surface roughness values for the smooth areas of the gray and finished seersucker woven fabrics.

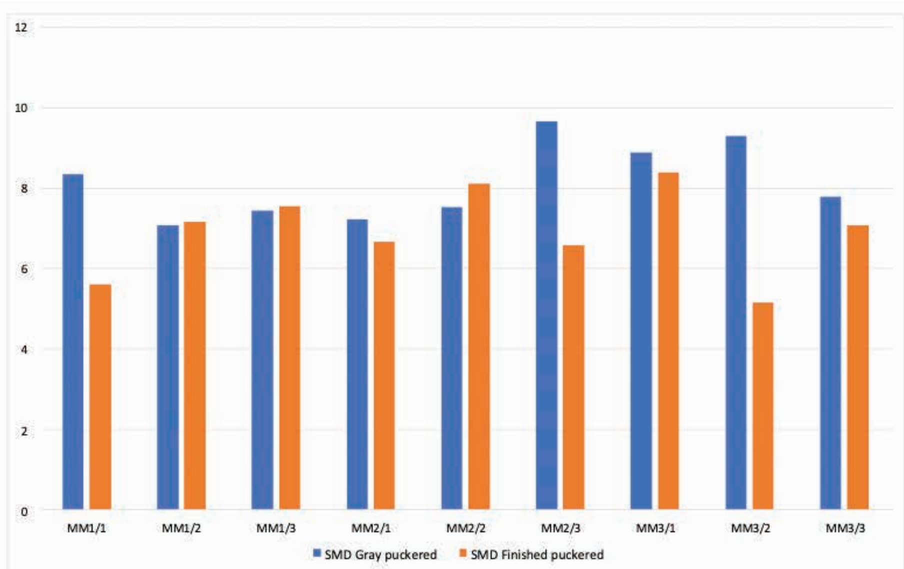

Figure 11. The surface roughness values for the puckered areas of the gray and finished seersucker woven fabrics.

measurements separately for surface friction and surface roughness. In addition, measurement has to be done twice, once for the puckered area and again for the flat area of the fabric. This process takes significantly more time compared with measurement of standard woven fabrics of basic or derivative weaves. On the other hand, using the KES-FB4 device, it is possible to determine the surface parameters separately for the flat and puckered areas of seersucker woven fabrics. It is important to distinguish the surface characteristics of the puckered area of the seersucker woven fabrics because while wearing clothing made of seersucker woven fabric, the puckered area of the fabric directly touches the skin.

Some results from the KES-FB4 are not in agreement with expectations, which is associated with the relationships between the coefficients of friction of the puckered and smooth areas of the seersucker fabrics. These results need further deep analysis and more measurements. It is also necessary to compare the results from the KES-FB4 approach with results obtained using other testing instruments applied to measure the surface properties of fabrics. This will be the goal of further investigations.

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References

[1] Rossi, R. (2005). Interaction between protection and thermal comfort. In: Scott, A. (Ed.). Textiles for Protection. Woodhead Publishing Ltd. (Cambridge, England). pp. 233-260.

[2] Moorthy, R. R., Kandhavadivu, P. (2015). Surface friction characteristics of woven fabrics with nonconventional fibers and their blends. Journal of Textile and Apparel Technology and Management, 9(3), 1-14.

[3] Carr, W. W., Posey, J. E., Tincher, W.C. (2007). Frictional characteristics of apparel fabrics. Textile Research Journal, 59(3), 129-136.

[4] Mooneghi, S. A., Saharkhiz, S. S., Varkiani, M. H. (2014). Surface roughness evaluation of textile fabrics: A literature review. Journal of Engineered Fibers and Fabrics, 9(2). Available at: http://www.jeffjournal.org.

[5] Frączczak, Ł., Matusiak, M., Zgórniak, P. (2019). Investigation of friction coefficient of seersucker woven fabrics. Fibres and Textiles in Eastern Europe, Vol. 27 3(135), 36-42.

[6] Lima, M., Hes, L., Vasconcelos, R., Martins, J. (2005). FRICTORQ, accessing fabric friction with a novel fabric surface tester. Autex Research Journal, 5(4), 194-201.

[7] Fracczak, L., Matusiak, M. (2017). Investigation of surface friction of the seersucker fabrics. In: Frydrych, I., Bartkowiak, G., Pawłowa, M. (Eds.). Innovations in clothing 3D design, products, fashion, technologies and testing of clothing materials. Lodz University of Technology (Lodz). pp. 235-249.

[8] Kawabata, S. (1980). The standardization and analysis of hand evaluation (2nd ed.). The Hand Evaluation and Standardization Committee, The Textile Machinery Society of Japan (Osaka).

[9] Greenwood, J.A. (1984). A unified theory of surface roughness. Proceedings of Royal Society, London, A393, 33.

[10] Semnani, D., Hasani, H., Behtaj, S., Ghorbani, E. (2011). Surface roughness measurement of weft knitted fabrics using image processing. Fibres and Textiles in Eastern Europe, 19(3), 86.

[11] Sul, I. H., Hong, K. H., Shim, H., Kang, T.J. (2006). Surface roughness measurement of nonwovens using three-dimensional profile data. Textile Research Journal, 76(11), 828-834.

[12] Militky, J., Mazal, M. (2007). Image analysis method of surface roughness evaluation. International Journal of Clothing Science and Technology, 19(34), 186-193.

[13] Gupta, B. S., Ajayi, J. O., Kutsenko, M. (2008). Experimental methods for analysing friction in textiles. In: Gupta, B. S. (Ed.). Friction in textile materials. Woodhead Publishing Limited (Cambridge, England). pp. 174-221.

[14] Savvas, G. V., Provatidis, C. G. (2004). Structural characterization of textile fabrics using surface roughness data. International Journal of Clothing Science and Technology, 16(5), 445.

[15] Krucińska, I., Konecki, W., Michalak, M. (2006). Measurement systems in textile industry (in Polish). Lodz University of Technology (Lodz). pp. 252-329.

[16] Carrera-Gallissà, E., Capdevila, X., Escusa, M. (1951). Assessing friction in silk-like finished polyester fabrics. The Journal of the Textile Institute, 109(1), 113-120.

[17] Bowden, F. P., Tabor, D. (1951). Friction and lubrication of solids. American Journal of Physics, 19, 428.

[18] Frączczak, Ł., Matusiak, M. Influence of the structure of seersucker woven fabrics on their friction properties. Autex Research Journal (In press – accepted for publication).