Correlation analysis of the relationship between the structural parameters of fabrics and the parameters characterizing the geometric structure of the fabric surface

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Abstract

The geometric structure of the surface of textile materials has a very important functional, operational and aesthetic significance. Generally, the geometric structure of surface consists of three components: shape, waviness and roughness. Textile materials, such as woven fabrics, knitted fabrics or nonwovens, are flexible materials, and therefore, with some exceptions, the shape of their surface is not discussed or determined. It is assumed that their surface is mostly flat. Roughness is one of the surface quality features most often assessed using quantitative indicators, called surface roughness parameters. The aim of the presented research is to analyse the correlation between selected parameters characterizing the geometric structure of surface of the cotton woven fabrics and the structural parameters of the fabrics. Surface topography measurements were performed using the MicroSpy® Profile profilometer from FRT the art of metrology™. The correlation analysis was carried out using the TIBCO Statistica software, version 13.3. Obtained results showed that there is a correlation between the structural parameters and the surface geometry parameters of the fabrics. However, the strength of these relationships varies and sometimes is not too high.

Keywords: woven fabrics, roughness, surface, structure, correlation, profilometer

1. Introduction

Surface quality is one of the characteristics of all kinds of objects. The surface is a kind of coating that "covers" the interior of the object, separating the object

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from its surroundings. The surface of an object determines its appearance, as well as its interaction with other objects and media surrounding the object, such as fluids or gases. The surface characteristic is a very important feature of textile materials. Unlike other objects, textile materials come into contact with the human body, especially the skin. This is due to the fact that one of the most important applications of textile materials is clothing. The properties of clothing are shaped mainly by the selection of appropriate materials. Especially, in the case of clothing that is worn next to user's skin, the surface properties, including the geometric structure of the material surface, can play a crucial role. It influences such functions and performance of clothing as: light reflectance, thermal radiation, thermal resistance, wettability, tactile features, abrasion resistance and of course the clothing appearance [1 – 4].

The most common and recognized method of measuring the roughness of textile materials is the contact/stylus method used in the KES (Kawabata Evaluation System) FB4 module. The instrument measures the roughness of surface of textile materials by the profile method measuring the surface irregularities along the line, separately in the warp and weft direction. This device provides information on the value of only one parameter characterizing the surface quality of textile materials – SMD (Surface Mean Deviation) [5, 6]. It is the equivalent of the arithmetic mean of the ordinates of the roughness profile R_a, which is commonly called roughness. Like any average, the R_a parameter can take the same value for diverse sets of individual values. Therefore, scientists dealing with the issues of geometric structure of the surface believe that the R_a parameter does not fully characterize the surface topography. With the same R_a value, you can deal with a very diverse surface geometry. In addition, contact tests do not fully reflect the shape of the tested surface, because surface irregularities smaller than the dimensions of the measuring sensor are not recorded. It is also important to note, that textile materials are flexible. They can be deformed by the sensor sliding across the surface of the fabric. All above factors are disadvantages of the contact methods of surface geometry measurement.

Contactless optical methods are much more precise than contact methods. In addition, contactless methods provide information on a number of parameters and functions that comprehensively describe the geometric structure of the surface. They are:

- the amplitude parameters such as: maximum height (R_z), maximum profile peak height (R_p), maximum profile valley depth (R_v), mean height (R_c) and total height (R_t),
- amplitude average parameters: arithmetic mean deviation (R_a), root mean square deviation (R_q), skewness (R_{sk}), kurtosis (R_{ku}),
- hybrid parameters,
- material ratio curve and related parameters: material ratio ($R_{mr(c)}$), profile section height difference (R_{dc}), relative material ratio (R_{mr}),
- parameters of surface having stratified functional properties: core roughness depth (R_k), reduced peak height (R_{pk}), reduced valley depth (R_{vk}), material portion (Mr_1) and (Mr_2).

Particular parameters: amplitude, hybrid and derived from the material curve are defined in the ISO 4287:1996 standard [7] whereas, the parameters form the last group are standardised in the ISO 13565-2:1996 standard [8]. Which of these parameters are important depends on the object being examined, its purpose and desired properties. In the field of textile materials, knowledge on this subject is very limited. A number of studies of surfaces of the textile materials using non-contact methods have already been published, but these were rather case studies, focused on assessing the method used, selecting filters, or assessing a specific textile product [9 – 11].

The aim of presented work was to analyse the relationships between the structure of the cotton woven fabrics and their surface geometry parameters. In order to do it 21 cotton fabric variants were measured in the range of their surface geometry using the contactless optical method. The fabrics were characterized by different and intentionally diversified structure. The structural parameters of the investigated fabrics were measured using the standardized methods. Correlation analysis allowed to assess the relationship between the structural parameters of the investigated cotton woven fabrics and their surface geometry parameters.

2. Material and Methods

The woven fabrics of different structure have been the objects of the investigations. There were 21 variants of fabrics made of cotton. The fabrics were produced on the basis of the same warp – 50 tex CO OE (Open End), warp density – 32/cm. The fabric were manufactured in six weaves: plain, twill 1/1 S, twill 2/2 S, rep 1/1 (010), rep 2/2 (2) and hopsack 2/2(020) using two kinds of weft yarn: 60 tex CO OE and 100 tex CO OE. Additionally the weft density was changed. The fabrics were finished in the same way using standard cotton finishing: dyeing, washing and drying. The basic parameters of the cotton woven fabrics being analysed are presented in Table 1.

Tab. 1. The basic properties of the investigated woven fabrics

Fabric variant	**Weave**	**Weft yarn tex**	**Warp density cm^{-1}**	**Weft density cm^{-1}**	**Mass per square meter, g/m^2**	**Thickness mm**
1.	plain	100	31.2	11.5	292	0.67
2.	plain	60	31.6	11.7	240	0.59
3.	plain	100	31.4	9.36	269	0.69
4.	plain	100	31.4	7.32	242	0.71
5.	twill 3/1 S	100	31.5	7.36	241	0.80
6.	twill 3/1 S	100	31.8	9.4	266	0.79
7.	twill 3/1 S	100	31.7	11.6	292	0.78

8.	twill 3/1 S	60	31.7	11.7	238	0.74
9.	twill 3/1 S	50	31.7	11.6	225	0.67
10.	twill 3/1 S	50	32	11.8	228	0.71
11.	twill 3/1 S	40	32	11.8	215	0.65
12.	twill 3/1 S	30	31.8	11.8	198	0.61
13.	twill 3/1 S	30	31.6	11.6	187	0.57
14.	twill 2/2 S	100	31.9	11.6	287	0.79
15.	twill 2/2 S	60	31.9	11.8	238	0.76
16.	rep 1/1 (010)	100	31.1	11.5	284	0.83
17.	rep 1/1 (010)	60	31.7	11.8	237	0.78
18.	rep 2/2 (2)	100	31.7	11.9	293	0.65
19.	rep 2/2 (2)	60	32.0	11.8	242	0.60
20.	hopsack 2/2 (020)	100	31.6	11.7	287	0.79
21.	hopsack 2/2 (020)	60	31.6	11.7	234	0.76

The measurement of basic structural parameters was done using the standardised methods:

- mass per square meter – according to the PN-EN 29073-1:1994,
- warp and weft density – according to the PN-EN 1049-2:2000,
- fabric thickness – according to the PN-EN ISO 5084:1999.

The measurement of the parameters characterizing the surface geometry of the investigated woven fabric was performed by means of the contactless method using the MicroSpy® Profile profilometer (Fig. 1) by the FRT® the art of metrology™ [12 – 14].

Fig. 1. MicroSpy® Profile profilometer

It is the optical method for the precise measurement of the surface characteristic using the principle of chromatic distance measurement. The instrument uses a non-contact optical scanning method to generate 3D images of surface topography with submicron resolution. The instrument is equipped with a confocal microscope that focuses a beam of white light on the sample surface and measures the reflected light to determine the height and shape of surface features. The profilometer is equipped with a CWL sensor, which is based on a patented method using chromatic aberration of optical lenses. The profilometer cooperates with the FRT Mark III software for calculation of numerous surface parameters according to standards [7, 8, 15]. The scan of fabric sample was done for the square area with a side of 49 mm. For each fabric variants ten repetition of measurement was performed for samples taken from different area of the fabric. The exemplary scan of fabric surface obtained from the profilometer is presented in Fig. 2.

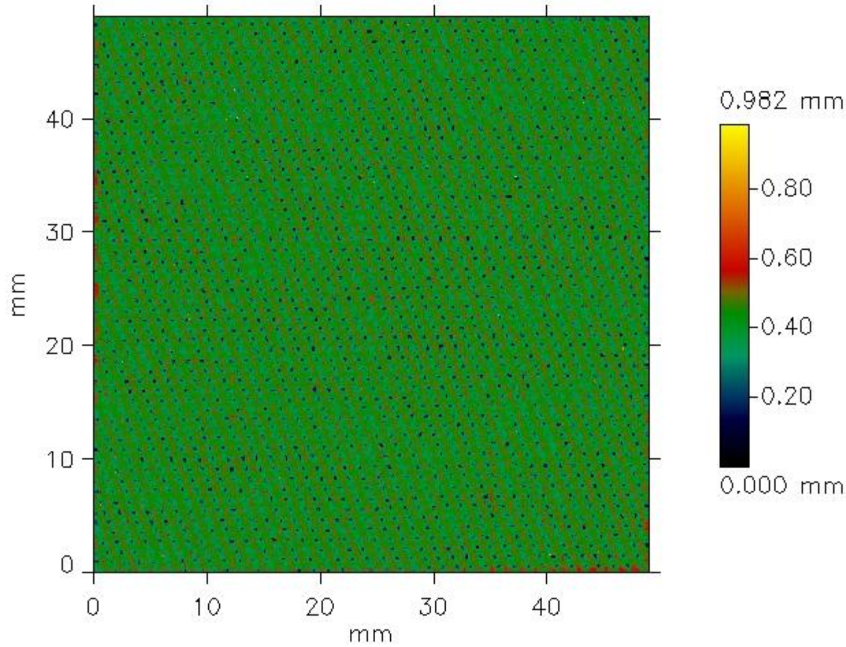

Fig. 2. The exemplary scan of the woven fabric obtained from the profilometer

In the presented work, on the basis of the data from the profilometer processed by the Mark III software the parameters and functions characterizing the surface geometry of fabrics were calculated according to the ISO 4287:1996 standard [7].

Next, the correlation analysis was performed using the TIBCO Statistica software. The correlation relationships between the parameters of surface geometry of the investigated woven fabrics and their structural parameters were analysed.

3. Results and Discussion

The values of the correlation coefficients between the parameters characterising the surface geometry of the investigated cotton woven fabrics and their structural parameters are presented in Table 2. In the table the statistically significant relationships at the significance level 0.05 are marked by red.

Tab. 2. The values of the correlation coefficients between the surface geometry parameters of the woven fabrics and their structural parameters

Surface parameter	**The value of correlation coefficient**					
	m	**g_1**	**g_2**	**W_1**	**W_2**	**h**
Ra	-0.0919	-0.0842	-0.3053	-0.2530	-0.5930	0.7778
Rq	-0.0759	0.0004	-0.3018	-0.2774	-0.5350	0.7804
Rz	-0.1229	0.0893	-0.3047	-0.0459	-0.0874	0.1770
Rp	0.1223	0.1074	-0.3107	-0.0001	-0.1152	0.2978
Rv	-0.1891	-0.1439	-0.4101	-0.2166	-0.1193	0.1450
Rt	-0.1859	0.0068	-0.3855	0.1715	-0.1011	0.3275
Rsk	0.4536	-0.3847	0.1286	0.2606	-0.0259	-0.4234
Rku	0.0326	0.3351	0.2085	0.1891	0.6467	-0.4821
Rk	0.1954	-0.5089	-0.2183	0.3360	-0.5744	0.5197
Rpk	0.3982	-0.4022	-0.1418	0.1212	-0.6819	0.6490
Rvk	-0.1741	0.0993	-0.4988	-0.3811	-0.1155	0.4336
Mr1	-0.0359	0.2916	0.0245	-0.1563	0.3676	-0.3942
Mr2	0.3371	-0.4747	-0.0460	0.6673	-0.1050	-0.0287
Rmr(c)	-0.0946	-0.1287	0.2693	0.0494	0.0586	-0.2650

In the Table 2 the following symbols of fabrics' structural parameters are applied:

m – mass per square meter.

g_1 – density of warp,

g_2 – density of weft,

W_1 – take-up of warp,

W_2 – take-up of weft.

h – fabric thickness.

Based on the correlation analysis, it was found that there is statistically significant correlation between some basic parameters of fabric structure and individual roughness parameters determined using a profilometer. The R_a and R_q parameters are considered as the basic surface roughness parameters (Fig. 3 and Fig. 4). They are the most commonly determined and analysed. The R_a parameter is defined as an arithmetic mean of the absolute height (ordinate z) within the sampling length or area. The R_q parameter represents the root mean square for z-value (height of particular points on the measured surface) within the sampling length or area. It was stated that the statistically significant correlation exists between both mentioned surface parameters R_a and R_q and fabric thickness – values of correlation coefficients are respectively: 0.7778 and 0.7804.

Fabric thickness is also correlated with other parameters characterizing the geometry of the fabric surface: R_{ku}, R_k, R_{pk} and R_{vk}. R_{ku} - kurtosis is a parameter, which relates to the tip geometry of peaks and valleys and is suitable for analysing the degree of contact between two objects. R_{ku} = 3 means a normal distribution of height on the measured surface, R_{ku} greater than 3 means that the height distribution is sharp whereas, R_{ku} lower than 3 informs that the height distribution is even. The relationship between the fabric thickness and kurtosis is negative. It means that the greater thickness is the lower value of the kurtosis. It should be mentioned that for all investigated fabrics the value of kurtosis is greater than 3 (Fig. 5). It means that the height distribution on fabrics' surface is sharp.

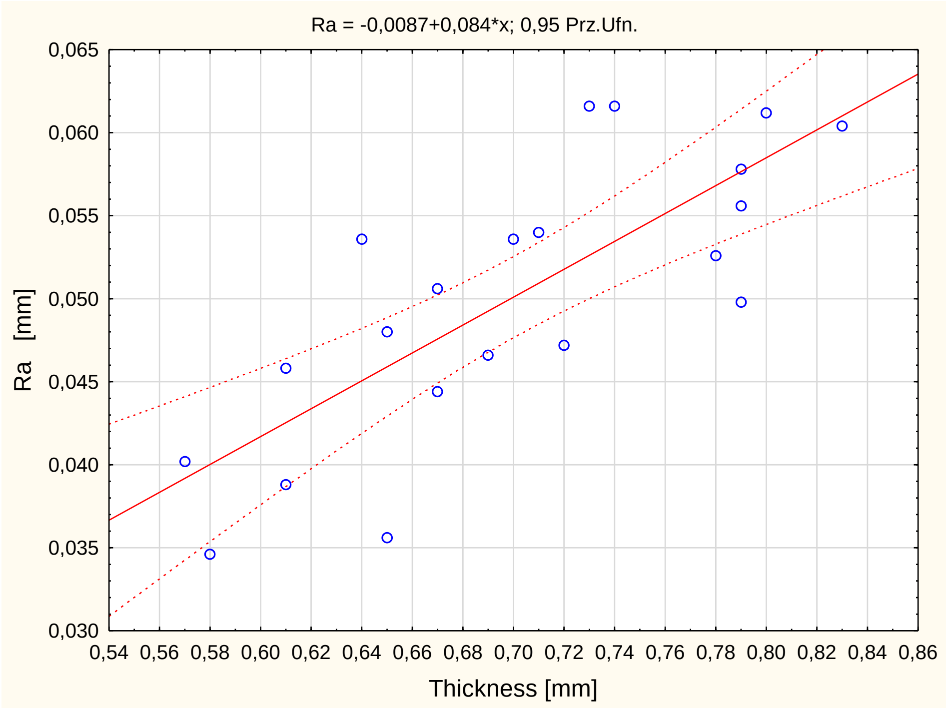

Fig. 3. Relationship between the R_a parameter and fabric thickness

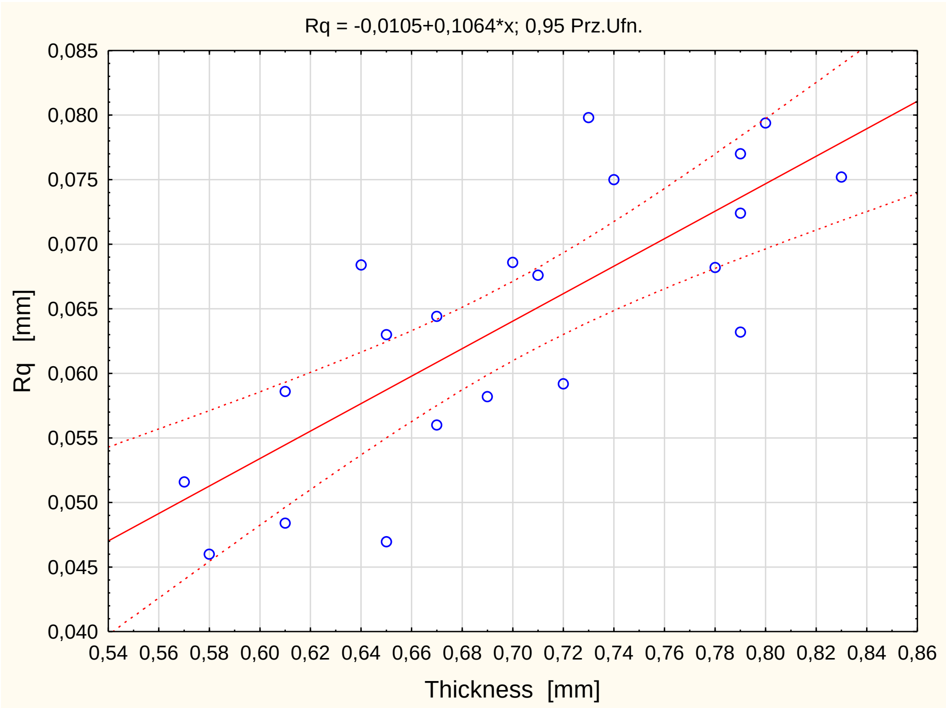

Fig. 4. Relationship between the R_q parameter and fabric thickness

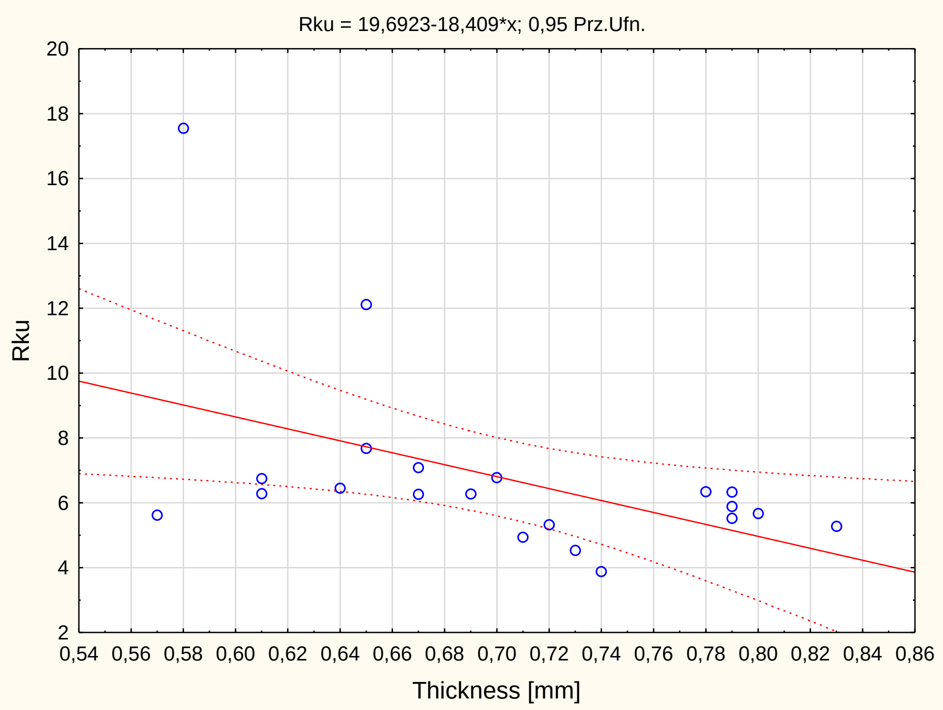

Fig. 5. Relationship between the R_{ku} parameter – kurtosis and fabric thickness

Also in the case of the W_2 structural parameter – take-up of weft yarn there are some relationships with the surface geometry parameters. The positive and statistically significant relationship occurs between the weft take-up and kurtosis, the negative relationships are observed between the weft work-up and R_{pk} (Fig. 6), R_k, R_a and R_q surface parameters. The R_{pk} means the reduced peak height on the measured surface whereas, the R_k is a core roughness depth. Both parameters are derived from the material ratio curve.

It was also stated that there is statistically significant correlation between the take-up of warp yarn and the M_{r2} surface parameter (Table 2). The M_{r2} is also derived from the material ration curve. Above results indicate that the material ratio curve can be of significant importance in the analysis of the geometric structure of fabric surfaces. It shows that it is advisable to analyse deeply the material ratio curve and the parameters derived from it in the analysis of fabric surface geometry and an assessment of the relationship between surface geometry and fabric properties.

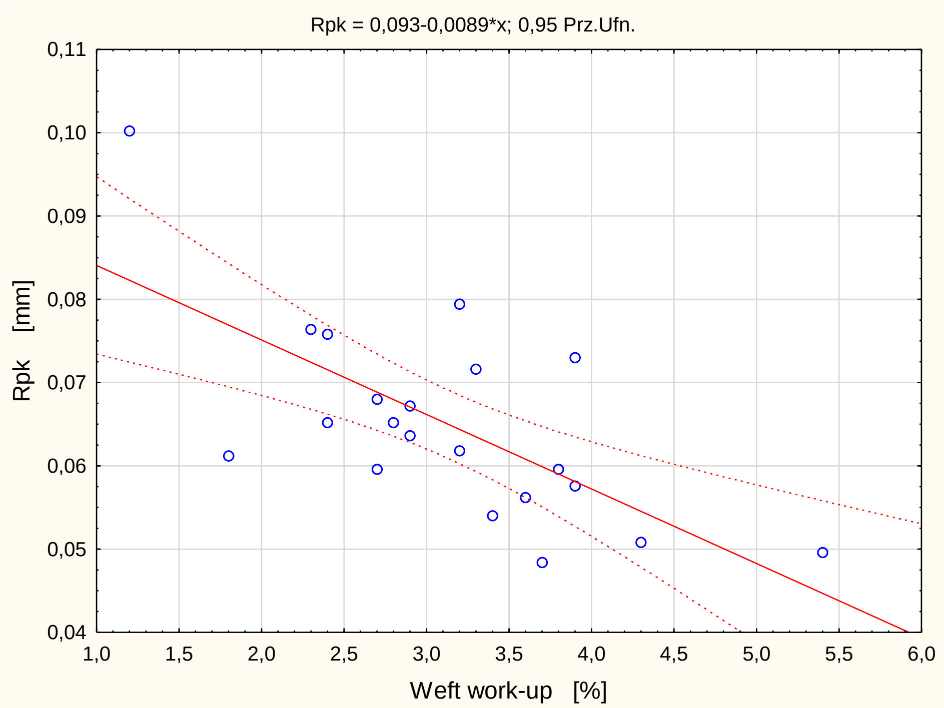

Fig. 6. Relationship between the R_{pk} parameter and work – up the weft yarn

It should be mentioned here that the values of correlation coefficients presented in the Table 2 are note very high. The results are surprising because it was expected that the relationships between the structural parameters of the woven fabrics and surface geometry parameters are stronger. It was not confirmed. Low values of correlation coefficients between fabric structure parameters and parameters characterizing the geometric structure of fabrics' surface result from the fact that the geometry of fabric surface is shaped by many factors connected with the fabrics structure. None of these factors is dominant. There is also an interaction between the fabric structural parameters, which affects their influence on the geometric structure of fabric surface.

4. Conclusions

On the basis of the performed investigations it was stated that it is possible to characterize the surface geometry of the woven fabrics in a complex way using contactless optical method. The MicroSpy® Profile profilometer cooperating with the Mark III software provides a wide range of parameters which can be connected with structural and functional properties of the woven fabrics. Obtained results showed that there is correlation between some structural parameters of the cotton woven fabrics, especially thickness and weft take-up and parameters characterising the geometry of surface of the fabrics. However, the correlation is not very strong. It can be due to the fact that the surface of the woven fabrics is shaped by several structural factors which interact between each other.

It is necessary to continue the investigation, for instance in direction of better understanding the material ratio curve and parameters derived from it in order to better characterisation of surface of textile materials as well as to analyse the relationships between the surface geometry of fabrics and their performance.

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