Mirosław Polipowski[1*], Piotr Więcek[2], Bogusław Więcek[3], Anna Pinar[1]

Influence of Selected Parameters of the Channels between Threads on the Air Permeability of Flat Textile Products with Known Characteristics

DOI: 10.5604/12303666.1228172

[1] **Textile Research Institute,**
ul. Brzezińska 5/15
92-103 Łódź, Poland
* E-mail: polipowski@iw.lodz.pl

[2] **Texo Systems,**
ul. Gorkiego 24/44
92-524 Łódź, Poland

[3] **Lodz University of Technology,**
ul. Wólczańska 211/215
90-924 Łódź, Poland

Abstract
A more detailed understanding of flat textile products' internal structure opens up new possibilities for research on the application use of voids in the structure of flat textile products, i.e. the arrangement and structure of the channels between threads and voids between fibres. The work presented is a continuation of research on the channels between threads performed by research teams from Textile Research Institute (IW), Lodz University of Technology (TUL) and Texo Systems. It refers to the study on the structural segmental models of woven fabrics conducted by the late. Prof. J. Szosland. In further works, a product micro-scanning method using structured light was applied, focusing on the study of the inlet diameter of the channels between threads. Analysis of the air permeability test results showed an influence of the size of the channels between threads (approximate volume of the channel, spacing surface area, coefficient of spacings, angle of channel inclination) and parameters of woven fabrics (type of weave, sett of warp and weft or tightness) on this parameter. Creating a spatial model of the channel between threads would enable to estimate the media flows through these materials (air and water vapour permeability, heat resistance) and electromagnetic radiation, e.g. IR, UV. The directions for further research were defined.

Key words: *inter-yarn channels, fabrics, knitted, textile materials, air permeability.*

Introduction

The spatial structure of flat textile products significantly affects their applicability and barrier properties for different media, as shown by J. Szosland [1]. Studies on the structure of woven fabrics have shown channel spacings between the threads of various and complex shapes. The analysis of solids formed in the channels between threads proves big differences in such objects, which is important not only for air, water vapor and heat flow but also for examining and attaining the barrier effect against various types of electromagnetic radiation, e.g. IR and UV [1-4]. The relation of the configuration of the woven fabric structure (resulting from the voids between threads) to the barrier effect coefficient UPF, characterising the value of UV transmittance, was found [2-3]. Between the analytical descriptions of the model configurations and the real woven fabrics, there are significant differences. While utilising a woven fabric, it goes through stretching and shrinking phases, obtaining different shapes of spatial channels, which noticeably change the actual conditions of usage resulting from the predetermined structure of a woven fabric [1]. A structural model of a flat textile product is based on the ideal model of yarn with a circular cross-section and homogeneous compact structure [1].

In fact, yarn, in particular that made of staple fibers, is characterised by a variability in linear density, while of the cross section textured yarns significantly differs from a circular cross-section. For this reason, in the further stages of the research on the virtual modeling of a flat textile product, a geometric model of yarn is adopted based on the spatial scanning of long sections of yarn.

The presence of narrowings in a channel leads to changes in the course of velocity of the air stream, fluid transported through the woven fabric, or the electromagnetic radiation used [1].

A complex spatial configuration in the structure of the product in the form of large quantities of channels of different size and distribution in textile and between-thread arrangements makes it difficult to describe the transport of air, moisture and heat. Due to the nature of its application, a flat textile material must fulfill a number of functions, in which the most important are protection against adverse climatic conditions and assurance of physiological and hygienic comfort.

The development of computer technology has led to a great development of image analysis methods, including 3D configurations, which enable to obtain in-depth information about the different types of materials [5].

Some authors [6-7] have rightly noticed that the internal structure of woven fabrics is the basis of information about their properties. Yarn parameters such as unevenness, the direction and amount of twist as well as the arrangement of fibers, are no less important than the parameters

Table 1. Characteristics of selected flat textile products.

Series No	Name of product	Raw material composition	Yarn density, tex	Yarn diameter, mm	Weave	Surface mass of product, g/m^2	Thickness of product * G, mm	Sett of warp/weft\ course/ wale, 1/dm
1	Gustaw 6/150	CO72 PES28	18	**0.165**	plain	100	0.27	385/260
2	Kornel 150K	CO100	18	**0.170**	twill (course) 2/1 Z	120	0.33	500/260
3	Andromeda 150	CO65 PES35	25	**0.20**	twill (course) 2/1 S	180	0.39	480/205
4	KM 1/150	CO100	25	**0.20**	angled twill 2/2 Y_{12}	160	0.45	340/190
5	91/2009	CO50 PES50	16.9	**0.16**	plain	125	0.28	425/280
6	LJ 1/05	PES 100	18.3 warp 38.0 weft	**–**	sateen 1 (3) 7	278	0.52	630/340
7	LJ 4/06	PES 100	18.3 warp 38.0 weft	**–**	combined	359	0.74	990/348
8	No. 1	PES 95,4 CV 4,6	11 f**24 40.0	**–**	wale, RL, weft	86	0.53	129c/70w
9	No. 2	PES 96,5 CV 3,5	11 f24 40.0	**–**	wale, RL, weft	119	0.59	171c/69w
10	No. 3	PES 97,0 CV 3,0	11 f24 40.0	**–**	wale, RL weft	145	0.63	176c/69w

** Tests of the product's thickness were conducted at IW using a digital thickness gauge – MO34A by Atlas – load 1000 Pa, foot surface 20 cm^2.*
*** f – number of filaments.*

of the weaving process. The parameters of the internal structure can be identified on the basis of a computer image of the woven fabric and influence, among others, filterability and the propagation of multidirectional internal stress, as well as display the ability of spatial formation under the influence of a load. A stand for measuring multidirectional stresses in the structure of woven fabric was used in the research applying computer image analysis. The structural parameters of woven fabrics, including yarn spacing as well as the size, shape and position of spacings between the threads were identified. These studies allow us to evaluate the behaviour of the woven fabric's structure in relation to a spherical load in a multidirectional arrangement of the distribution of internal stress and enable to determine the size and shape of the deformations [7].

The porosity of textile products in a 2D configuration in the context of yarn properties was also discussed and the significant influence of yarn properties, especially its hairiness, on the porosity of the textile products tested was stated [8].

Some research works on the influence of the structure of knitted products on their biophysical properties were limited to the correlation between known parameters of the knitted fabric structure (tightness, thickness, filling coefficient) and biophysical properties [8]. The relationship between the parameters characterising the spatial structure of a knitted fabric and biophysical properties was not determined despite conditioning the phenomena of air and heat flow within the system of channels and spacings between threads. In these studies the application of digital 2D image processing of a knitted fabric and computer registration of the results were taken into account. The number and dimensional value of porosity between the threads and their arrangement in a knitted fabric were determined. In studies on the structure of knitted fabrics, the need for more research in the direction of three-dimensional image analysis to evaluate the spatial structure of knitted textiles was indicated [9].

The need to extend studies on the structure of flat textile products in the field of image processing techniques in a 3D configuration has also been discussed in recent literature reports [6-7, 10].

The recognition and identification of spatial objects which form channels between threads in woven fabric are important not only for air flow and humidity transfer, but they can also be used for in-depth structural analysis such as the creation of a barrier effect with the use of woven products for various kinds of adverse electromagnetic radiation, or when determining different properties of woven fabrics. Currently, IW (Textile Institute) in cooperation with Lodz University of Technology (TUL) and Texo Systems is conducting research works on the application use of knowledge gained and on the structure of woven fabrics in a 3D configuration taking into account the in-depth identification of channels between threads. It is a new unique approach to the practical use of assessing a woven fabric's structure [11-16]. The methods of channel analysis developed allow to refer to a greater diversity of the structure of flat textile products and to make more efficient use of their properties, such as for optimisation of the flow of various media (air, moisture, heat and various types of electromagnetic radiation such as IR or UV), as well as to investigate the barrier properties of these products.

Materials

Aim and scope of the research

The aim of the study was to determine the relationship arising from the influence of the size and arrangement of the channels between threads in flat textile products and already-known parameters of the products on their air permeability.

The characteristics of flat textile products and relevant parameters of the channels between threads were used to achieve the aim of the research.

The range of the research material consisted of polyester-cotton woven fabrics with different percentages of polyester and cotton fibers as well as warp and single-jersey polyester weft knitted fabrics. Materials of different weaves, surface weight, thickness, sett of warp and weft or tightness and different approximate volume of the channel, surface area of spacing and angle of channel inclination were used, see ***Table 1***.

Study on the physical – mechanical parameters of flat textile products and their characteristics

For the studies, knitted fabrics marked as No.1, 2 & 3 and woven fabrics marked as Gustaw, Kornel, Andromeda, KM, 91/2009, LJ 1/05 and LJ 4/06 were selected according to the established criteria (***Table 1***). The knitted fabrics presented were the subject of previous research works conducted at IW [14], where they were produced on a Raschel knitting machine by Mayer – type RM6 and needle cut 32/2 S. The background of the knitted fabrics was made of polyester yarns with a linear density of 110 dtex f24. A two-component yarn – VSc Lenzing of 75% / 25% PES with a linear density of 40 tex was inserted in the structure of a knitted fabric along the wales in the form of a vertical weft thread at a distance between successive weft threads of not more than 10 mm.

The three variants of knitted fabrics introduced differed in the filling coefficient of the background with polyester yarn. These knitted fabrics were characterised by the greatest sizes of through-channels among the flat textile products investigated according to the microscopic observations performed.

The woven fabrics selected for testing had a sateen weave, which completed the woven fabrics with plain weave and twill previously tested, together giving a group of three essential weaves whose structure significantly vary.

Woven fabrics marked as LJ 1/05 and LJ 4/06 do not have through-channels between threads and, when using a microscope and light transmitted from below, you can see only weak spacings of light. At IW, investigations on the relevant physical and mechanical parameters were made for knitted and woven fabrics, and the collective characteristics of the products were established on the basis of previous research results and those currently conducted, see ***Table 1***.

Research methodology

Research methodology was based on:

1. Investigation of selected physical and mechanical properties of woven and knitted fabrics and their analysis, see ***Table 1***.
2. Investigation of the channels between threads in woven fabrics using the stereovision method [12-13].
3. Preliminary investigations on flow through flat textile products, including air permeability and their analysis.
4. Reconstruction analysis of the diameter of the channel's inlet in woven fabric using micro scanning with structured light [15-16].
5. Statistical analysis of investigations on the air permeability of textile products with known characteristics in the context of the parameters of channels between threads.

Study on the channels between threads according to the stereovision method developed for selected flat textile products

The following parameters of the channels between threads were determined in previous works using [12-13] a method developed for testing the channels between threads for flat textile products: channel length D, μm, surface area of spacing P, μm^2, and angle of channel deviation from the vertical position α, °. This research was carried out for woven fabrics of plain and twill weave. For a single channel and for the entire image of the woven fabric viewed, the approximate volume of the channel V_p, μm^3 was calculated on the basis of the surface area of the spacing and the angle of channel deviation from the vertical position, according to which the channel length was determined. A new coefficient of surface spacings of the woven fabric ξ (1) was introduced, determining the relation of the surface area of the spacing and the total surface area of the woven fabric in a 3D configuration [12-13].

For the flat textile products tested there was no correlation stated between the size of the surface area of the channel and its angle of inclination. Values of the standard deviation and coefficient of variation for selected parameters of the channels between threads: surface area of spacing and angle of channel deviation from the vertical position, prove highly dispersed results. The average area of spacing for a 3D configuration is comparable to the porosity parameter for a 2D configuration, while the method determining the surface area of the spacing is more precise for a 3D configuration. Values of the surface area of spacings obtained for the same products differed significantly. The median value of the angle of the channel inclination for the woven fabrics tested was within the range α = 19.30°-36.51°. The lengths of the channels were greater than the thickness of the woven fabric due to the inclination of the channel, where the approximate value of the channel volume depends more on the size of the surface area of spacing and, to a lesser degree, on the channel length [13].

It was assumed that for selected parameters of the channels between threads in the woven fabrics, the following values might be significant for the flow, including air permeability: the approximate volume of the channel, surface area of spacing as well as the angle of channel inclination. Due to the great sizes of the through-channels between threads in knitted fabrics, in comparison to the woven fabrics tested (from microscopic observations), the parameters of the channels between threads in knitted fabrics were not determined, while the analysis was based on known characteristics of flat textile products, see ***Table 1.***

Table 2 presents characteristics of the channels between threads for selected woven fabrics and the basic relationships determined resulting from the parameters of the channels.

For the calculations, a new coefficient of surface gaps of the woven fabric (ksi) was introduced:

$$\xi = \frac{P_p}{P_c} \text{ x } 100, \% \qquad (1)$$

where: P_p – summary surface area of channel gaps for a series of woven fabrics, P_c – total surface area for a series of woven fabrics

Study on the air permeability of flat textile products and analysis of test results

Studies of air permeability were carried out at IW on the woven fabrics and knitted fabrics (***Table 1***), showing a decrease in pressure of 100 Pa, and surface area tested of 20 cm^2 [17]. The uncertainty of the measurement was determined according to document [17], being an expanded uncertainty at a 95% confidence level and coverage factor of k = 2 [18].

The results of air permeability measurements of woven and knitted fabrics and values of statistical parameters are presented in ***Table 3***.

The value of air permeability of woven fabrics when compared to knitted fabrics shows a large difference resulting from the different structure of these products and the type of yarn used. The knitted fabrics tested, when compared to woven fabrics, have much bigger channels between threads and voids, which is associated with the weave and more relaxed structure of knitting yarn. Knitting yarn has a smaller twist in comparison to warp and weft weaving yarn. For example, for Andromeda woven fabric of compact structure, with few and small channels between threads, the median of air permeability was R = 80.08, mm/s, while for knitted fabric No.1, with considerably bigger through-channels between threads and voids in the yarn (microscopic images), the median of air permeability was R = 5380, mm/s, being 67 times bigger for this knitted fabric in comparison to Andromeda woven fabric.

Table 2. *Characteristics of the channels between threads for woven fabrics used in the tests [13].*

No.	Name of woven fabric	Woven fabric thickness* G, μm	Porosity 2D** P, %	Coefficient of spaces of woven fabric surface, ξ P_p/P_c x100, %	Average angle of channel deviation from vertical position α, °	Average surface area of channel space P_p, μm^2	Average length of channel*** D, μm	Approximate average volume of channel **** V_p, μm^3
1	Gustaw 6/150	270	14.10	7.05	24.77	20800	297.358	0.0062
2	Kornel 150K	330	0.80	1.36	36.51	6937	410.574	0.0028
3	Andromeda 150	390	1.80	0.65	27.28	2838	438.805	0.0012
4	KM 1/150	450	19.90	15.30	22.21	25560	486.064	0.0124
5	91/2009	280	17.70	10.62	19.30	10770	296.673	0.0032
6	III 79/2009	280	9.50	5.55	24.49	5066	307.681	0.0016

** The test on the thickness of the woven fabrics was conducted at IW using a digital thickness gauge – MO34A by Atlas, load 1000 Pa, foot surface 20 cm^2.*
*** Tests were conducted at IW on a measuring stand for computer analysis of 2D images, equipped with, among others, a camera – CCTV Panasonic, as well as Textil3d and Loo3D applications.*
**** Calculation of the channel length D was based on the trigonometric function: D = G / cosα, where: G – thickness of woven fabric, and α – angle of channel deviation from the vertical position resulting from the measurement.*
***** Approximate average volume of the channel $V_p = P_p$ x D, where P_p was taken from **Table 2** as the average value of the surface area of the space.*

Table 3. *Results of air permeability measurements R of selected woven and knitted fabrics and statistical parameters.*

No.	Products statistical parameters	Gustaw 6/150	Kornel 150K	Andromeda 150	KM 1/150	91/2009	LJ 1/05	LJ 4/06	No 1	No 2	No 3
1	R, mm/s	591	175	74.2	812	317	45.0	26.8	5400	2850	2090
2		618	181	78.9	841	325	45.3	25.7	5380	2860	2080
3		657	172	76.5	810	320	46.3	26.1	5350	2810	2030
4		658	178	79.4	809	301	45.8	25.4	5400	2840	2050
5		664	187	79.4	796	303	46.3	26.0	5350	2760	2110
6		648	185	81.3	794	–	–	25.3	–	–	2150
7		631	180	83.0	789	–	–	26.3	–	–	1990
8		636	181	84.2	765	–	–	25.8	–	–	2160
9		659	178	82.2	804	–	–	27.6	–	–	2100
10		661	177	81.7	809	–	–	27.2	–	–	2060
	Minimum value	591.0	172.0	74.2	765.0	301.0	45.0	25.3	5350.0	2760.0	1990.0
	Maximum value	664	187	84.2	841	325	46.3	27.6	5400	2860	2160
	Mean value	642.3	179.4	80.08	802.9	313.2	45.7	26.2	5376.0	2824.0	2082.0
	Median	652.5	179.0	80.4	806.5	317.0	45.8	26.1	5380.0	2840.0	2085.0
	Range	73	15	10	76	24	1.3	2.3	50	100	170
	Standard deviation	23.53	4.45	3.05	19.49	10.65	0.59	0.76	25.10	31.20	52.24
	Coefficient of variation	3.7	2.5	3.8	2.4	3.4	1.3	2.9	0.47	1.43	2.51
	Skewness	1.30	178.00	-0.69	-0.02	-0.30	-0.29	0.69	-0.20	-1.2	-0.142
	Kurtosis	1.23	-0.04	0.07	2.06	-2.66	-2.33	-0.51	-3.03	0.95	-0.26
	Variance	553.80	19.82	9.31	379.66	113.20	0.34	0.58	630.00	1630.00	2728.90

The median values and mean value of air permeability for each flat textile product are at a similar level; standard deviation is a measure of the uncertainty of measurement of the values analysed. Statistical distributions of air permeability values for the woven and knitted fabrics were directly proportional to the size of the channels between threads.

Results

Reconstruction analysis of the diameter of the channel between the thread inlet in structured light for selected flat textile products

Research teams of TUL and IW working on flat textile products developed a method for measuring the diameter of the inlet to the channel between threads with the use of structured light micro scanning [15-16].

For woven fabrics (***Table 1***) the appropriate cross-sections were made by cutting through with many parallel "cutting" planes, and their degree 3 polynomial approximation was performed, on the basis of which, histograms of the diameters of channel inlets for a particular woven fabric were determined (***Figure 1-7***).

A method developed for the reconstruction of the diameter of the channels between the thread inlet and the many cross-sections of the product, as well as the polynomial approximation of these cross-sections performed, enabled to indicate the size and distribution of these diameters in the through- and blind-channels (***Table 4***), and also to specify the approximate shape of the channel inlet, which, in most cases of woven fabrics, is an irregular cone, as confirmed by microscopic images.

The empirical distribution of the diameter size of the channel inlet for most of the woven fabrics (***Figure 1-7***) shows the largest grouping within the range of 0.15-0.25 mm and 0.15-0.40 mm. An exception is KM 1/150 woven fabric, being of large groupings within the range of 0.40-0.60 mm. KM 1/150 woven fabric within the field of a microscopic view has the largest size of through-channels, whose number is small when compared to other woven fabrics tested. The histograms of diameters are largely clustered around the mean or median value.

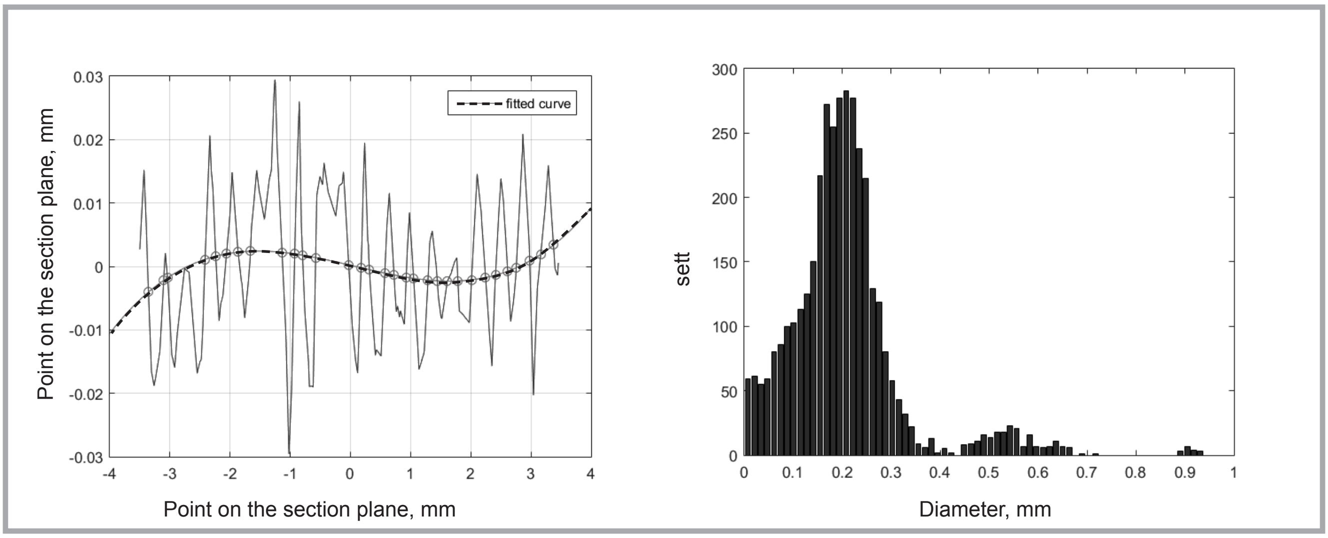

Figure 1. *Cross-section of diameters and its degree 3 polynomial approximation, and histogram of diameters of channel inlets for 91/2009 woven fabric [15-16].*

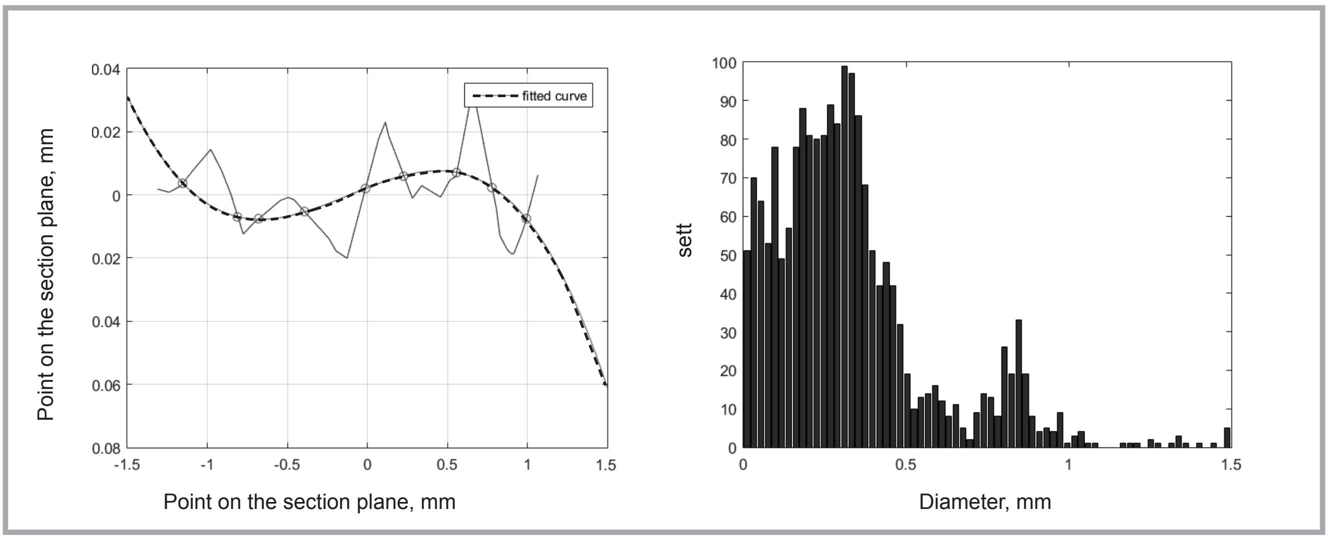

Figure 2. *Cross-section of diameters and its degree 3 polynomial approximation, and histogram of diameters of channel inlets for Andromeda 150 woven fabric [15-16].*

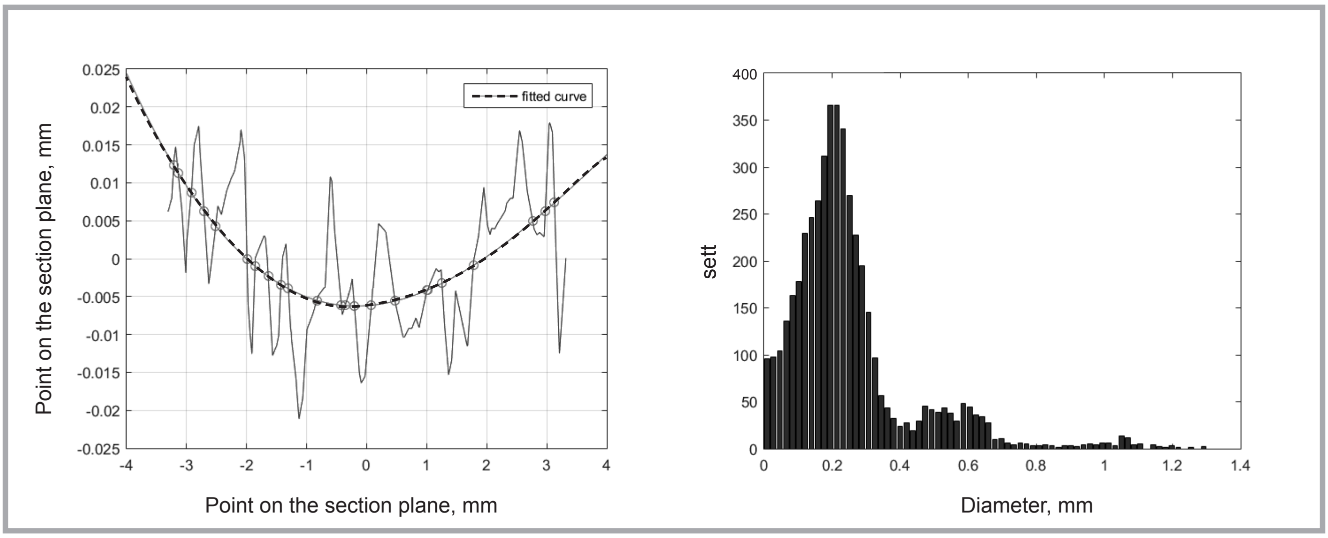

Figure 3. *Cross-section of diameters and its degree 3 polynomial approximation, and histogram of diameters of channel inlets for Gustav 6/150 woven fabric [15-16].*

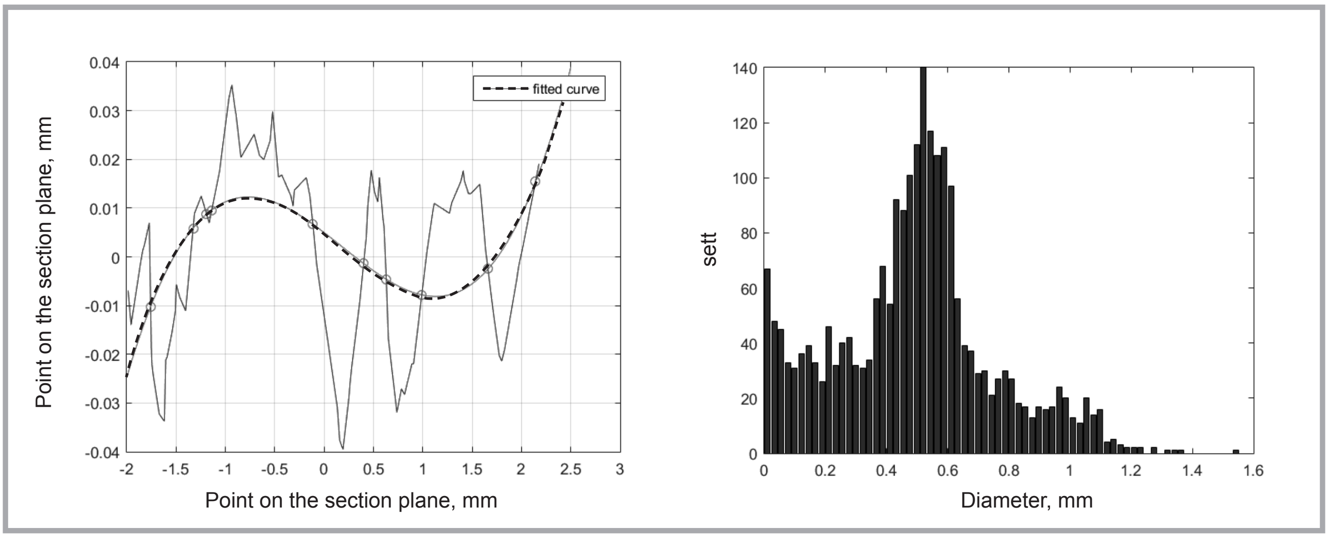

Figure 4. *Cross-section of diameters and its degree 3 polynomial approximation, and histogram of diameters of channel inlets for KM 1/150 woven fabric [15-16].*

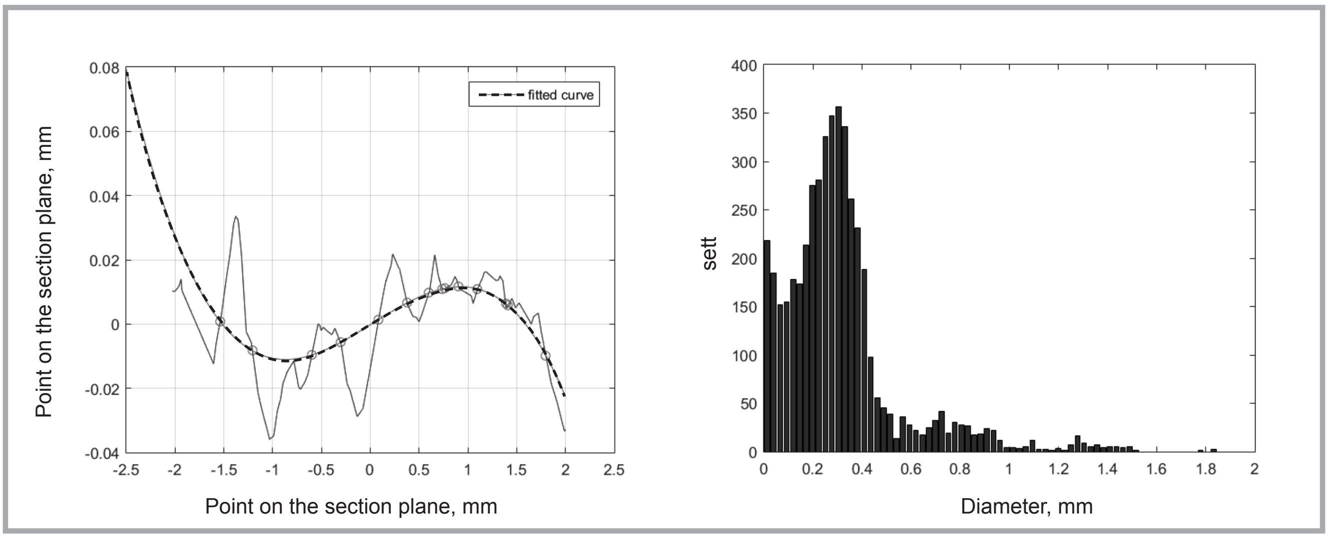

Figure 5. *Cross-section of diameters and its degree 3 polynomial approximation, and histogram of diameters of channel inlets for Kornel 150 K woven fabric [15-16].*

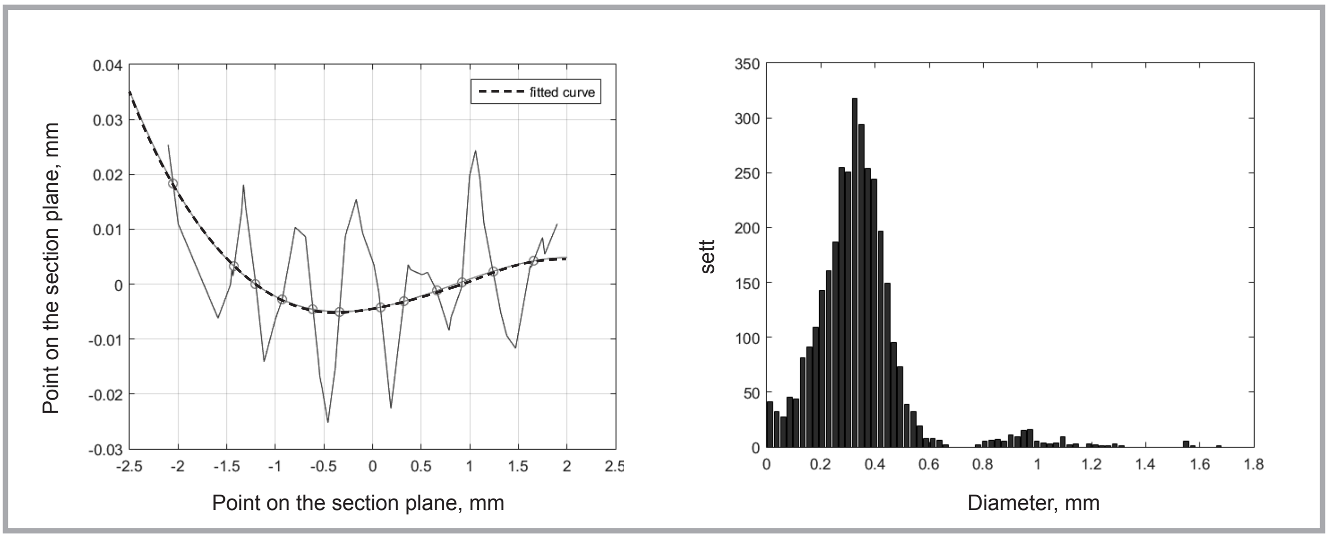

Figure 6. *Cross-section of diameters and its degree 3 polynomial approximation, and histogram of diameters of channel inlets for LJ 1/05 woven fabric [15-16].*

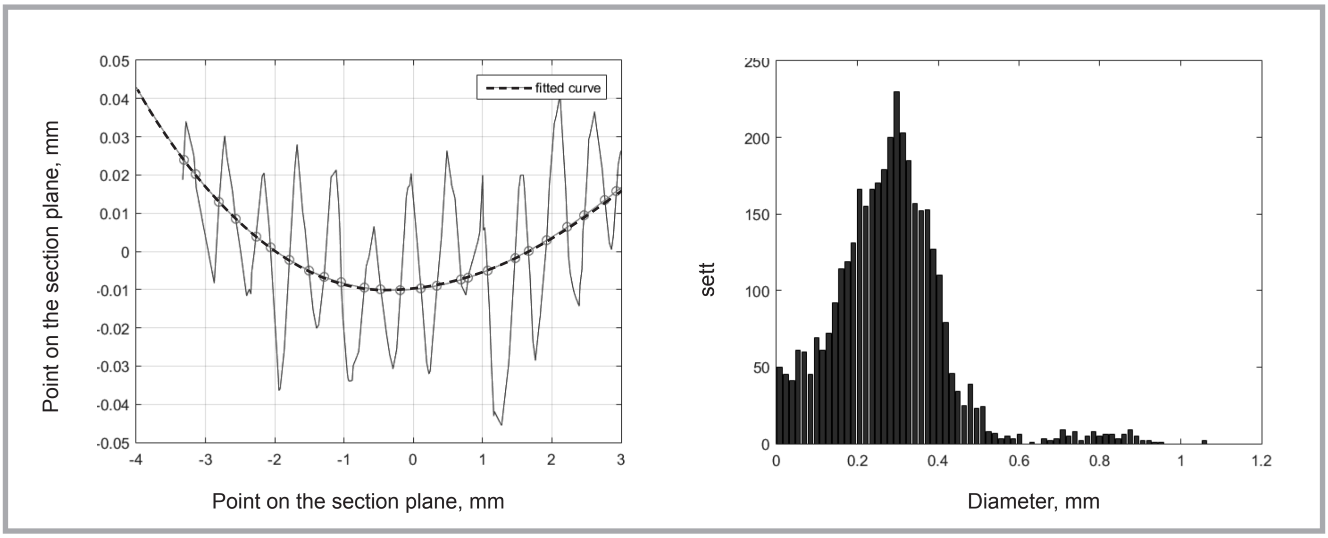

Figure 7. *Cross-section of diameters and its degree 3 polynomial approximation, and histogram of diameters of channel inlets for LJ 4/06 woven fabric [15-16].*

Determination of the correlation and regression of the channels between selected thread parameters and the air permeability of the products

For the woven fabrics given in ***Figures 8-13***, the regression of the following parameters of channels between threads was determined: surface area of spacing, approximate average volume of the channel, average length of the channel, coefficient of channel spacing, and the thickness and porosity of woven fabric in regard to air permeability.

Correlation results for all parameters of the flat textile products tested are summarised in ***Table 5***. ***Figures 8-13*** illustrate a strong and very strong correlation for the relevant parameters of the channels between threads (|R| < 1).

A very strong correlation of air permeability shows the spacing surface area (|R| = 0.99) and approximate volume of the channel (|R| = 0.94). A strong correlation of air permeability also shows the coefficient of spacings (|R| = 0.83), porosity of the product (|R| = 0.81), and sett of the warp and weft (|R| =0.70).

A very strong correlation was obtained for the spacing coefficient of the product's surface and porosity of the product (|R| = 0.96) – ***Table 5***. A strong correlation of the sett of warp and weft was observed for the surface mass and thickness of the product (|R| = 0.85-0.89).

A poor correlation relates to the slight impact of the average length of the channel on the air permeability of the product (|R| = 0.4). The correlation of the diameter of the channel inlet and air permeability is also poor (|R| = 0.4). It is known that the air permeability of a flat textile product does not only depend on the diameter of the channel inlet but also on many technological parameters of the woven fabric: product's thickness, sett of warp and weft, and particularly the size of the channel between threads and voids.

There is no correlation, for example, for, the spacing coefficient of the woven fabric surface and average length of the channel (|R| = 0.013). A negative high correlation means, for example, that with a decrease in the angle of channel inclination, the spacing coefficient of the channel's surface and the porosity of the product increase (R = – 0.85).

Table 4. Dameters of the channel between the thread inlet and its statistical parameters for the woven fabrics tested.

Woven fabric	91/2009	Andromeda 150	Gustaw 6/150	KM 1/150	Kornel 150K	LJ 1/05	LJ 4/06
Mean diameter value, mm	0.206256	0.327847	0.249897	0.489261	0.311149	0.339691	0.279123
Standard deviation	0.121146	0.245557	0.184197	0.260377	0.239557	0.177113	0.140824
Kurtosis	9.803456	5.64128	8.713794	3.090246	8.862777	13.03786	6.720174
Skewness	1.956271	1.448254	2.062936	0.260756	2.0299	2.298245	1.11911
Variance	0.014676	0.060298	0.033928	0.067796	0.057387	0.031369	0.019831
Coefficient of variation, %	58.7359	74.8997	73.7091	53.2186	76.9909	52.1395	50.4523
Median, mm	0.195657	0.283784	0.211014	0.502971	0.277583	0.327106	0.277763
Max, mm	0.937916	1.498919	1.300746	1.552455	1.844464	1.683001	1.065683
Min, mm	0.000568	0.000101	4.2E-05	0.000356	2.87E-06	0.000257	7.18E-05

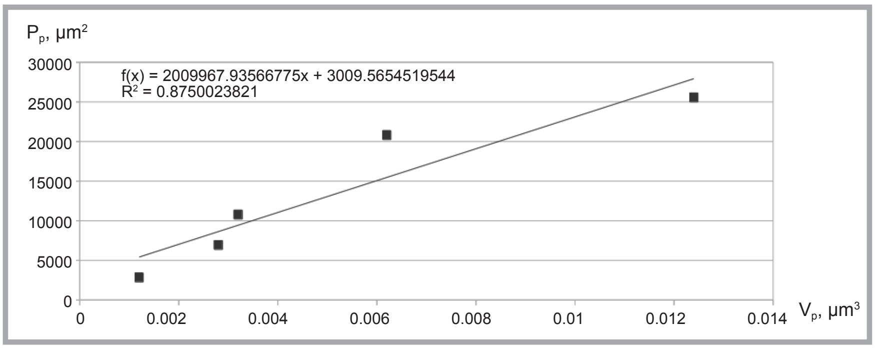

Figure 8. Linear regression of the surface area of spacing and approximate average volume of the channel between threads for woven fabrics tested.

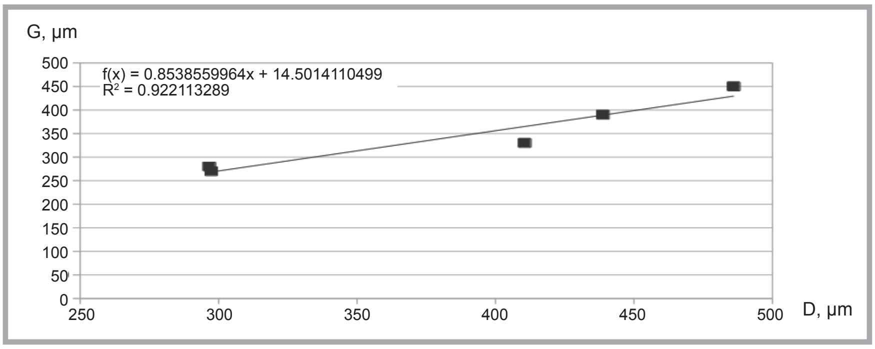

Figure 9. Linear regression of woven fabric thickness and average length of the channel between threads for woven fabrics tested.

Table 5. Correlation of the parameters of channels between threads and air permeability of flat textile products [18].

	Air permeability	Porosity 2D	Spacing coefficient of woven fabric's surface	Average angle of channel deviation from vertical position	Average surface area of channel	Average length of channel	Approximate average volume of channel
Air permeability	1.0000	0.8094	0.8260	-0.4904	0.9992	0.0406	0.9387
Porosity 2D		1.0000	0.9612	-0.8533	0.8089	0.2343	0.7228
Spacing coefficient of woven fabric's surface			1.0000	-0.8533	0.8258	0.0136	0.8314
Average angle of channel deviation from vertical position				1.0000	0.6086	0.5402	0.3781
Average surface area of spacing					1.0000	0.0243	0.9354
Average length of channel						1.0000	0.3564
Approximate average volume of channel							1.0000

Conclusions

Significant differences in the structure of the flat textile products tested were empirically proved. Analysis of the measurement results for different flat textile products shows differences in the arrangement and size of channels between the threads and voids in yarn, mainly associated with the following parameters of the product: type of weave, sett of warp and weft, and the thickness of the product. An influence on the structure of the product is also shown by the yarn structure.

Defined values of channel parameters between filaments according to the method presented, together with the basic parameters of the fabric, showed a mutual correlation and significant influence on the value of the air permeability index.

Statistical analysis of the research results showed the complex nature of many factors on the air permeability of products with specific thickness, of which the important are the size and arrangement of the channels between threads i.e. the approximate volume of the channel (spacing surface area of the product or coefficient of spacings, the angle of channel inclination) as well as the type of weave and sett of warp and weft.

The works presented are a part of a larger research program on the identification of the channels between threads in flat textile products, which deserve special attention due to the fact that voids resulting from the channels are within 0.8-19.9% of the surface mass of woven fabrics.

In the fabric structure analysis, previously used basic structure parameters were taken into consideration, applied in combination with the proposed parameters of the channel between hairs, which allows a more complete picture of the structure of the fabric. It is an innovative proposition compared to existing solutions in this area.

The research proposed and the characteristics of flat textile products and channels between threads initially determined enable to compare various flat textile products and also to predict the parameters which affect their structural properties in a way not previously used. Ongoing research works are also a statement of the possibility of appropriate programming of the voids in flat textile products in order to optimise the flow of air, moisture, various types of electromagnetic radiation such as IR and UV, and thermal resistance, to improve the barrier properties of such products.

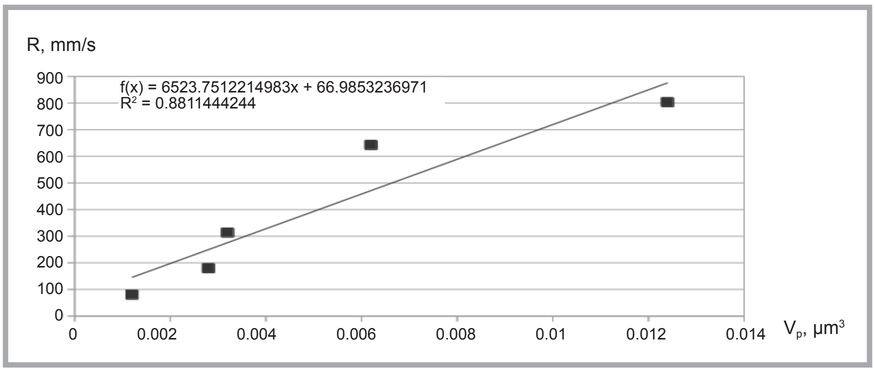

***Figure 10.** Linear regression of air permeability and approximate average volume of the channel between threads for the woven fabrics tested.*

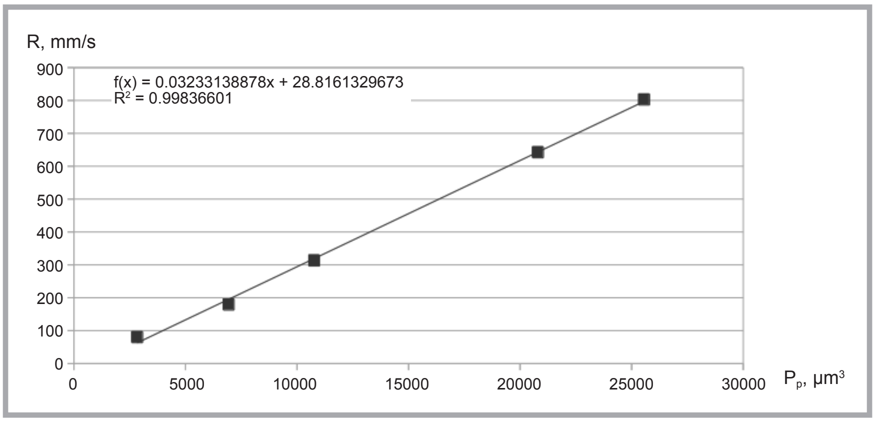

***Figure 11.** Linear regression of air permeability and average surface area of spacing for woven fabrics tested.*

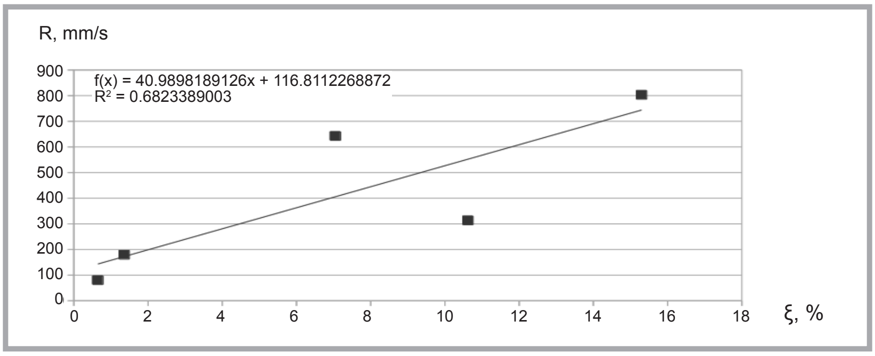

***Figure 12.** Linear regression of air permeability and coefficient of spacings of the channel surface for woven fabrics tested.*

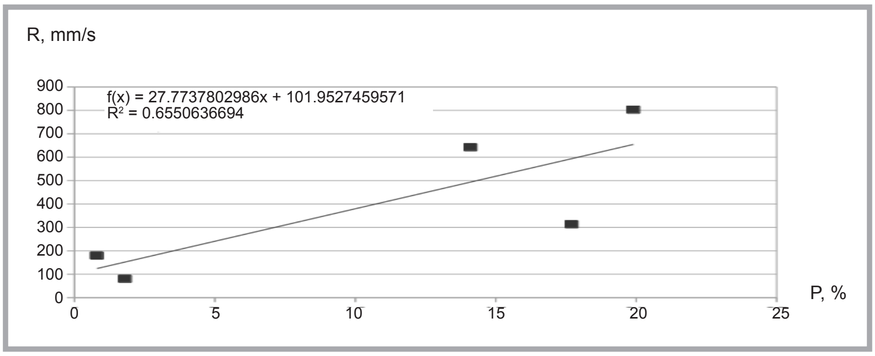

***Figure 13.** Linear regression of air permeability and porosity of the product.*

Funding

The results presented in this publication were obtained as part of the statutory research work of the Textile Research Institute, financed by the Polish Ministry of Science and Higher Education during 2015.

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❑ ***Received 19.01.2016 Reviewed 21.03.2017***