KAUNAS UNIVERSITY OF TECHNOLOGY

INSTITUTE OF PHYSICAL ELECTRONICS OF
KAUNAS UNIVERSITY OF TECHNOLOGY

Asta Olšauskienė

RESEARCH AND DESIGN OF STRUCTURE AND AIR PERMEABILITY OF FABRICS WOVEN OF POLYESTER MULTIFILAMENT YARNS

Summary of the Doctoral Dissertation
Technological Sciences, Materials Engineering (08 T)

Kaunas, 2005

The Dissertation was carried out in 1999-2004 at Kaunas University of Technology, Faculty of Design and Technologies.

Scientific Supervisor:

Assoc. Prof. Dr. Rimvydas MILAŠIUS (Kaunas University of Technology, Technological Sciences, Materials Engineering – 08T).

Counsil of Materials Engineering science trend:

Prof. Dr. Habil. Arvydas Juozas VITKAUSKAS (Kaunas University of Technology, Technological Sciences, Materials Engineering – 08T) - chairman,
Prof. Dr. Habil. Rimgaudas ABRAITIS (Institute of Architecture and Construction of Kaunas University of Technology, Technological Sciences, Materials Engineering – 08T),
Prof. Dr. Habil. Matas Vytautas GUTAUSKAS (Kaunas University of Technology, Technological Sciences, Materials Engineering – 08T),
Dr. Habil. Audronis Jonas KVIKLYS (Lithuanian Energy Institute, Technological Sciences, Materials Engineering – 08T),
Prof. Dr. Habil. Jonas VOBOLIS (Kaunas University of Technology, Technological Sciences, Materials Engineering – 08T).

Official opponents:

Dr. Marina MICHALAK (Technical University of Lodz, Technological Sciences, Materials Engineering – 08T),
Assoc. Prof. Dr. Eugenija STRAZDIENĖ (Kaunas University of Technology, Technological Sciences, Materials Engineering – 08T).

Public defence of the Dissertation will take place at the open meeting of the Council of Materials Engineering trend at 14 p. m. on 31 March, 2005 in Dissertation Defence Hall at the Central Building of Kaunas University of Technology.

Address: K. Donelaičio g. 73-403, 44029 Kaunas, Lithuania.
Phone:(370)37300042. Fax: (370) 37 324144. E-mail: mok.skyrius@ktu.lt

The summary of the Dissertation is sent on 28 February, 2005.

The Dissertation is available at the Libraries of Kaunas University of Technology (K. Donelaičio g. 20, Kaunas) and Institute of Physical Electronics of Kaunas University of Technology (Savanorių pr. 271, Kaunas).

KAUNO TECHNOLOGIJOS UNIVERSITETAS

KTU FIZIKINĖS ELEKTRONIKOS INSTITUTAS

Asta Olšauskienė

AUDINIŲ IŠ POLIESTERINIŲ DAUGIAGIJŲ SIŪLŲ SANDAROS BEI LAIDUMO ORUI TYRIMAS IR PROJEKTAVIMAS

Daktaro disertacijos santrauka
Technologijos mokslai, medžiagų inžinerija (08 T)

Kaunas, 2005

Disertacija rengta 1999-2004 metais Kauno technologijos universitete, Dizaino ir technologijų fakultete.

Mokslinis vadovas:

Doc. dr. Rimvydas MILAŠIUS (Kauno technologijos universitetas, technologijos mokslai, medžiagų inžinerija – 08T).

Medžiagų inžinerijos mokslo krypties taryba:

Prof. habil. dr. Arvydas Juozas VITKAUSKAS (Kauno technologijos universitetas, technologijos mokslai, medžiagų inžinerija – 08T) – **pirmininkas,**
Prof. habil. dr. Rimgaudas ABRAITIS (KTU Architektūros ir statybos institutas, technologijos mokslai, medžiagų inžinerija – 08T),
Prof. habil. dr. Matas Vytautas GUTAUSKAS (Kauno technologijos universitetas, technologijos mokslai, medžiagų inžinerija – 08T),
Habil. dr. Audronis Jonas KVIKLYS (Lietuvos energetikos institutas, technologijos mokslai, medžiagų inžinerija – 08T),
Prof. habil. dr. Jonas VOBOLIS (Kauno technologijos universitetas, technologijos mokslai, medžiagų inžinerija – 08T).

Oficialieji oponentai:

Dr. Marina MICHALAK (Lodzės technikos universitetas, technologijos mokslai, medžiagų inžinerija – 08T),
Doc. dr. Eugenija STRAZDIENĖ (Kauno technologijos universitetas, technologijos mokslai, medžiagų inžinerija – 08T).

Disertacija bus ginama viešame Medžiagų inžinerijos mokslo krypties tarybos posėdyje 2005 m. kovo 31 d. 14 val. Kauno technologijos universiteto centrinių rūmų Disertacijų gynimo salėje (K. Donelaičio 73, 403 a).

Adresas: K. Donelaičio g. 73, 44029 Kaunas, Lietuva.
Tel.: (370) 37 300042. Fax: (370) 37 324144. El. paštas: mok.skyrius@ktu.lt

Disertacijos santrauka išsiuntinėta 2005 m. vasario 28 d.

Disertaciją galima peržiūrėti Kauno technologijos universiteto (K. Donelaičio g. 20, Kaunas) ir KTU Fizikinės elektronikos instituto (Savanorių pr. 271, Kaunas) bibliotekose.

Introduction

Reasoning of the analyzed subject and relevance of the dissertation. Technical fabrics form a rather large share of all woven fabrics (expressed in financial terms they made up 40% of all woven fabrics in 2001). Technical fabrics should be designed according to their properties whereas their appearance is not so important. The properties of a new fabric should be considered before the launch of its manufacture as it is important to design a material that would initially have high performance properties. For this reason, studies about the influence of different parameters on the fabric properties and creation of a method for designing a fabric according to the intended characteristics bear considerable relevance. Due to relatively high strength (up to 60 cN/tex) and relatively low stretch (up to 10%) as compared to other synthetic yarn, multifilament polyester yarn is often used in manufacture of filter cloths.

A very important characteristic for the filtering properties of filter cloths is the diameter of a cloth pore which determines the size of suspended particles. It is a significant characteristic of filtering properties for if the diameter of pores is too large, the filter cloth will not serve its function to suspend a filtered substance; however, if the diameter of pores is too small, the intended yield of a filtered substance will not permeate through the cloth. Porosity of a fabric depends on its structure. The structure of a fabric can be defined by seven major technological parameters. These include raw material of yarn, linear densities, warp and weft sets and a fabric weave type. It is comparatively easy to evaluate all the above-mentioned fabric parameters except weave, as they can be expressed in specific numbers, whereas weave is a graphic image of a fabric structure. Different weave factors are applied when making a proper evaluation of a fabric weave. When designing fabrics and their technological parameters and when analyzing their properties, the problem of how to generalize the properties of a fabric by one generalizing factor is encountered. This problem is complicated as woven fabrics possess a multi-stage structure, therefore, the factors of different levels, such as raw material of fiber, linear density of yarn, fabric sets and a weave type must be considered. All the above-mentioned parameters are evaluated by the integrated factors of a fabric structure. The currently known integrating fabric structure factors were distributed into two groups by Newton. The first group is based on Peirce's theory of surface coverage and the second one on Brierly's theory of maximum density. In the first case, there is the ratio of the area covered with one or two systems of threads to the total area of the fabric. In the second case, there is the ratio of density of the given fabric to the maximum density of the standard plain weave fabric. The two groups of fabric structure factors differ in how they evaluate the fabric weave type. There have been found no studies in which the influence of integrated factors on air permeability is analyzed; for this reason, it is important not only to examine the influence of the integrated factors on air permeability but also to determine which of the given integrated fabric structure factors produces the best evaluation of all weaves and which of the factors should be used when designing a fabric by required fabric air permeability.

The Aim of the dissertation is to investigate the dependencies of the structure of polyester multifilament yarn fabrics and their permeability to air on the fabric structure factors and to develop methods for designing air permeable fabrics.

Objectives of the dissertation: 1) to determine the influence of the fabric porosity on fabric air permeability; 2) to determine the dependence of fabric air permeability on different fabric structure factors; 3) to analyze and select integrated fabric structure factor that evaluates the structure of a fabric best; 4) to develop methods for designing fabrics with identical air permeability properties throughout; 5) to determine the influence of an integrated fabric structure factor on air permeability of fabrics woven from yarn of different structure.

Scientific novelty of the dissertation. This study determines the dependence of fabric porosity on various parameters of fabric structure. It also identifies the dependence of a pore area of fabrics woven in different weaves on fabric air permeability. While designing the air permeability of the fabric, attention should be paid to the fabric structure factors such as linear density of yarn, yarn sets, a weave type that are related to fabric porosity. The influence of the fabric structure factors of various weaves on air permeability was determined. There were 15 frequently used weave types selected for the research. It is suggested that in this study a fabric weave should be evaluated according to the weave factors P and P_1 proposed by Milašius. The influence of these fabric weave factors on the fabric air permeability had not been investigated before. In this study the influence of the above-mentioned fabric weave factors on air permeability of different weave type fabrics was determined. The integrated fabric structure factor φ which was proposed by Milašius and which reflects the influence of a fabric weave well was examined. The influence of integrated factors on fabric air permeability had not been investigated in previous studies. Furthermore, the results of the fabric structure factor φ analysis were compared to the results of investigations carried out according to fabric structure factors proposed by other researchers. The influence of fabric structure factor φ on air permeability of fabrics woven from different structure yarn was determined. The method to design fabrics with equal air permeability according to the integrated fabric structure factors was created. It is proposed to evaluate the fabric structure of different weaves (with the exception of the rib weaves) by the fabric structure factor φ. It is also proposed to evaluate the rib weave by the fabric structure factor *MS/MD*. By using this method, it is possible to design a fabric of higher thread density and greater firmness and yet the same rate of air permeability. What is more, it is possible to predict in advance the air permeability of a designed fabric.

Defensive propositions: 1) Dependence of fabric air permeability on relative area of fabric pores is equal in fabrics of different structure but with multifilament yarn with close linear density; 2) A fabric of appropriate air permeability can be design according to the integrated fabric structure factor; 3) It is best to use the integrated fabric structure factor φ, proposed by Milašius, when designing a fabric with the required air permeability; 4) Brierley's integrated fabric structure factor *MS/MD* should be used when designing air permeability of weft rib fabrics; 5) Integrated fabric structure factors can be used only when designing fabrics that are made from yarn of identical structure.

Content of the dissertation

Introduction presents the reasoning of the analyzed subject and relevance of the research, definition of the research aim and objectives, survey of the scientific novelty and practical value of the dissertation.

In Chapter 1 relevance of the study and reasoning of the investigated problem are described. The goal and aims of the study as well as its originality and thesis statements are presented in the chapter.

In Chapter 2 the overview of researches on the same issue is presented. The analysis of fabric structure factors as well as yarn cross-section modeling principles and analysis of cross-section models are introduced. Moreover, the overview of fabric air permeability dependence on fabric structure is made, while the influence of fabric porosity on air permeability is also introduced. Finally, the analysis of fabric weave evaluation factors and integrated fabric structure factors is presented in this chapter.

In Chapter 3 the research object is described. There are also thread density measurement method, fabric permeability to air measurement method and fabric porosity measurement method introduced. Moreover, a method to determine integrated fabric structure factors is presented.

More than 100 various polyester fabrics of different weaves made of yarn with different linear density formed the research object. The above-mentioned fabrics were woven with projectile (STB-180), air-jet (PN-130 ir PN-170) or water-jet (H-125) weaving looms. The first group of fabrics (57 fabrics) that were researched were plain weave fabrics woven from different linear density yarn (S_1=160÷310 dm^{-1}, S_2=110÷216 dm^{-1}). Their warps and wefts were woven from multifilament 29.4 tex twisted (180 m^{-1}) and 27.7 tex twistless yarn. Plain weave fabrics with folded 15,6*2 tex warps and 29,4 tex ir 27,7 tex wefts were also investigated. The second group of the investigated fabrics (45 fabrics) included cloths woven in different weaves (Fig. 1) from 29.4 tex yarn by. Warps of the same density (S_1=284 dm^{-1}) were used throughout the research, whereas density of wefts varied.

For the measurement of permeability to air the VPTM-2M device was used. Air permeability of fabrics was measured according to the standard LST EN ISO 9237:1997. When measuring porosity of the fabrics, the value of the transversal dimension of a thread to the plane was measured. The number of fabric pores was counted according to this value. Microscopes MIKKO and ASKANIA which were connected to a digital camera and a computer were used to measure the value of the transversal dimension of a thread (Fig. 2).

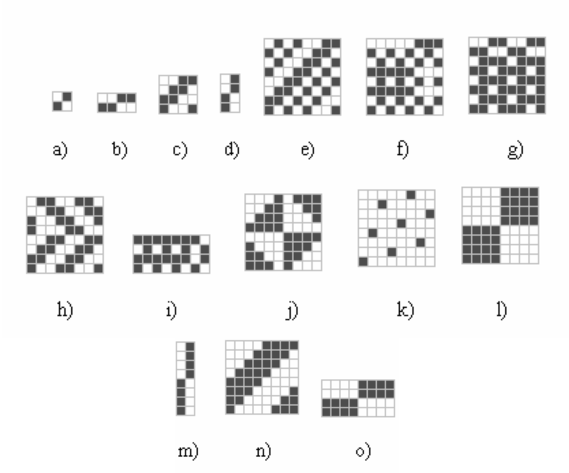


Fig. 1. Weaves used for experiment

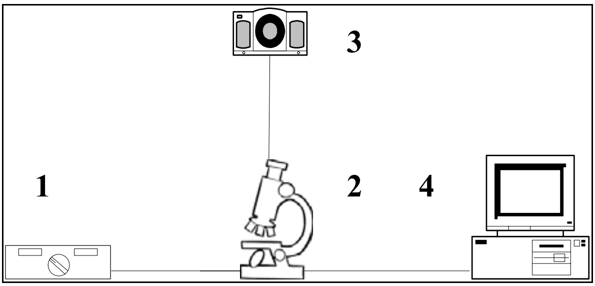


Fig. 2. Connection scheme of the devices: 1 – lighting device, 2 – microscope, 3 – digital camera, 4 – personal computer.

All the seven technological parameters of a fabric are evaluated by integrated fabric structure factors. These factors are distributed into two groups: one group refers to the Peirce theory and another to the theory of Brierley. There are several integrating structure factors corresponding to Peirce theory, namely: Galceran, Seyam and El-Shiekh, Newton. However, here we are going to analyse more widely only Galceran factor because it evaluates the fabric structure from this group of factors best. Galceran's fabric structure factor is calculated as a ratio of the sum of the coefficients of the setting of the given fabric with the sum of the coefficients of the maximum warp and weft settings.

Having denominated the coefficients of maximal setting and that of given fabric, this fabric structure factor is calculated according to the formula:

$$O = \frac{\dfrac{S_1\sqrt{T_1}}{\sqrt{1000}} + \dfrac{S_2\sqrt{T_2}}{\sqrt{1000}}}{\dfrac{5\sqrt{\pi\rho_1}}{1+0.73Kl_1} + \dfrac{5\sqrt{\pi\rho_2}}{1+0.73Kl_2}} 100, \quad (1)$$

where $T_{1/2}$ are warp and weft linear densities, respectively, $\rho_{1/2}$ are warp and weft raw material densities, respectively, $Kl_{1/2}$ are warp and weft weave factors by Galceran, respectively.

In the Brierley's case fabric structure factor is the ratio of set of the given fabric "square" structure analogue with the set of the standard "wire" plain weave fabric. The original Breirley's factor called him as *Maximum Setting/Maximum Density* can be calculated by following equation:

$$[MS/MD] = \sqrt{\frac{12}{\pi}} \frac{1}{F^m} \sqrt{\frac{T_{average}}{\rho}} S_2^{\frac{1}{1+g\sqrt{T_1/T_2}}} S_1^{\frac{g\sqrt{T_1/T_2}}{1+g\sqrt{T_1/T_2}}} \quad (2)$$

Galuszynski analysing weaving resistance found that Brierley's formula "requires some modification of certain values of the coefficients *m* and *g* for some weft and warp faced ribs" and proposed the coefficient of fabric tightness $T_{\text{Galuszynski}}$. For the weft-faced ribs value *F* is taken as an average for the weave with *g*=2/3. For warp-faced ribs Galuszynski proposed the value of *m*=0.35 instead of 0.42 given by Brierley.

Milašius proposed new integrating fabric firmness factor that can be calculated by equation:

$$\varphi = \sqrt{\frac{12}{\pi}} \frac{1}{P_1} \sqrt{\frac{T_{average}}{\rho}} S_2^{\frac{1}{1+2/3\sqrt{T_1/T_2}}} S_1^{\frac{2/3\sqrt{T_1/T_2}}{1+2/3\sqrt{T_1/T_2}}}, \quad (3)$$

where P_1 is weave factor.

The firmness factor φ also can be used for fabric properties prediction, for example, air permeability of fabric depends on threads set as well as on weave.

<u>In Chapter 4</u> the dependence of fabric porosity on various fabric structure parameters as well as the dependence of fabric air permeability on the area of fabric pores and the area occupied by yarn is analyzed. Dependence of fabric air permeability on cloth density as well as the influence of weave factor on fabric air permeability are also presented in this chapter. Moreover, the comparison of various integrated fabric structure factors and peculiarities of different rib weaves are introduced there. In this chapter the method of designing fabric permeability to air according to the integrated fabric structure factors is introduced and the influence of yarn structure on fabric air permeability is described. While analyzing the fabric structure one can distinguish between places without yarns and places in which yarns block up air. The latter ones could be further divided into areas covered by the warp, areas covered by the weft, and areas covered by both the warp and the weft.

Consequently, the whole area of fabric:

$$S=S_p+S_a+S_m+S_{sp}, \quad (4)$$

here: S_p – area of fabric pores; S_{sp} – area in which the warp and the weft yarns interlace; S_a – area only by the weft; S_m – area covered by the warp

$$S=S_p+S_s+S_{sp}. \quad (5)$$

The relative area of fabric pores S_p can be calculated according to the equation:

$$S_p=l_a l_m P_m P_a; \quad (6)$$

It is possible to note, that S_p is the reverse value of well-known fabric surface cover factor e_s, i.e.:

$$S_p=1- e_s; \quad (7)$$

During the experiment it was established that while testing fabrics according to the standard EN ISO 9237, the air yield that gets through a perforation in a non-permeability material could be calculated according to the equation:

$$Q_K = 62S_K; \quad (8)$$

here: S_K - value for the relative area of the perforation in respect of the whole area.

The assumption made in this study is as follows – the air flow volume permeating through fabric pores is equal to the air flow volume permeating through holes of an air-impermeable cloth (Q_p=Q_K).

During the present experiment fabrics woven in plain weave from polyester multifilament yarns with different densities of the warp and the weft were checked. Fifteen different fabrics have been investigated. There were checked fabrics woven in plain weave from polyester multifilament twisted 29,4 tex yarns (first group of fabrics) with various set of the warp and the weft (S_1=160÷310 dm^{-1}, S_2=110÷210 dm^{-1}). We presume that the air yield permeating through fabric pores equals the air yield getting through the perforations (Q_p=Q_K). Figure 3 presents the relationship between plain weave fabric Q and the area of fabric pores S_p. Reliability of the results of air permeability measurements was verified by the coefficient of variation which did not exceed 10% (v=1÷10%). The dispersion of results was not high, therefore there were not many tests carry out (n=3÷6).

If air permeated only through fabric pores, Q could be related to S_p as is displayed in Fig.3 as linear dependency, i.e. $Q=Q_p=Q_K=62S_p$. However, air permeates not only fabric pores, but also yarns and their intersection-points. In order to get the air yield that permeates through yarns and their intersections, we subtract the air yield getting only through fabric pores from the air yield permeating the whole fabric. In this way we establish the air current that permeates through yarns and their intersections Q_1 (Q_1=Q-Q_p). Since yarns clean air better than pores, the air yield Q_1 will be filtered more properly than the air yield Q_p. It is evident that the air yield in fabrics of high density (S_p<6%) approximates 0, which means that air gets mainly through fabric pores.

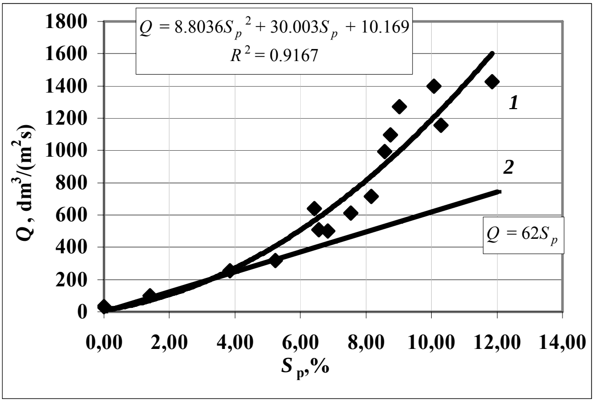


Fig. 3. Dependence of air permeability Q on relative area of fabric pores S_p of the fabrics of first group

The greater relative part of the area in fabrics of high density is occupied by yarn intersections, not by yarns of different systems. As the density of yarns decreases, the relative area of yarns S_p enlarges, and at the same time the air yield which permeates through yarns increases. This proves the statement that air permeates through separate yarn systems easier than through yarn intersection-points.

During experiment it was also established dependence of air permeability Q on relative area of pores of fabric S_p of the plain weave fabrics, woven from multifilament polyester yarns - the warp is 29,4 tex and the weft is 27,7 tex (second group of fabrics). The dependence of Q on relative area of pores of the fabric of the second group is presented in Figure 4. The third group of fabrics checked in this investigation was woven also in plain weave from polyester multifilament yarns. In these two different fabrics were used folded 15,6tex×2 warp and 29,4 tex or 27,7 tex weft yarns. The dependence of air permeability Q from relative area of fabric pores S_p of the all groups of fabrics (the total 33 different fabrics) is presented in Figure 5. As it is observed though folded warp (15,6tex×2) were used in a fabric, but the yield of Q dependently from S_p of the fabric changes like in previous two cases, when were used not folded 29,4 tex warp. In this case is received the equation of the second order with quite a high correlation (R^2=0,9363) as well. It means that dependence of Q on S_p is similar to the all polyester fabrics that have similar linear densities yarns (not taking into account the structure of these yarns).

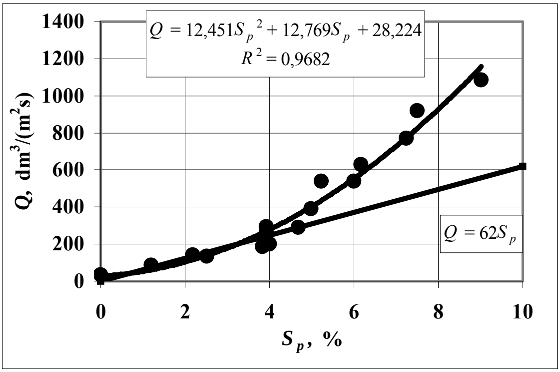


Fig. 4. Dependence of air permeability Q on relative area of fabric pores S_p of the fabrics of second group

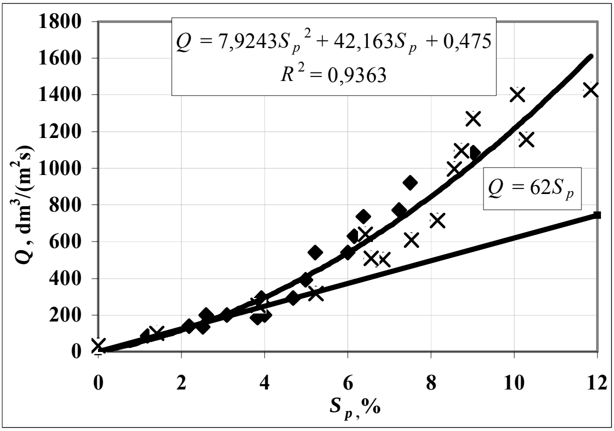


Fig. 5. Dependence of air permeability Q from relative area of fabric pores S_p of all groups of the fabrics

In order to determine how the change of air permeability of fabrics with different weaves depends on fabric porosity, fabrics of 9 different weave types were examined. Fabrics with different weave types (plain, twill 2/2, warp rib 2/2, weft rib 2/2, 8 healds sateen, basket weave 4/4, twill 4/4, rib-basket weave 2/4 and weave type imitating leno weave) were woven from multifilament polyester 29,4 tex yarn in different weft densities (S_2=140÷706 dm^{-1}), when S_1=284 dm^{-1}. 37 fabrics with different weaves and 18 fabrics with the plain weave pattern were tested. Fabrics with the plain weave had been woven with different yarn densities (S_2=112÷230 dm^{-1}, S_1=166÷284 dm^{-1}). Figure 6 illustrates the dependence of Q on S_p of fabrics with different weave types (curve 1) as well as fabrics with the plain weaves (curve 2–marked with crosses). Provided that air would permeate only through fabric pores, Q dependence on S_p would be the same as the dependence 3 shown in Figure 6, $Q=Q_p=Q_K=62S_p$. It may be concluded that the Q of fabrics with different weaves changes equally throughout according to fabric porosity. In Figure 7 the general dependence of air permeability of different weave patterns on the size of fabric pores S_p.

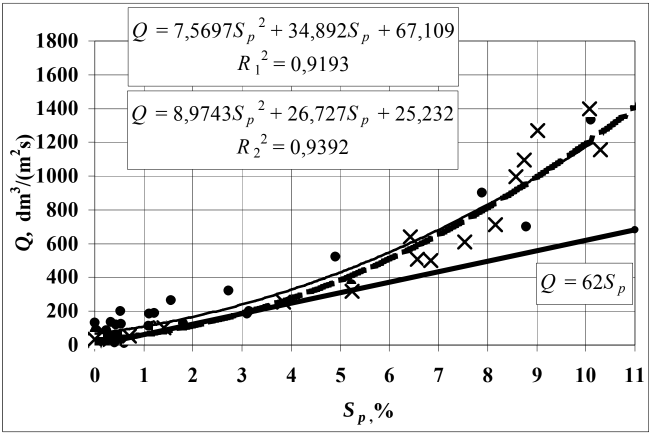


Fig. 6. Dependence of air permeability of different weave patterns with different densities on the relative area of pores where **x -** stands for the plain weave type, ● - different weave patterns.

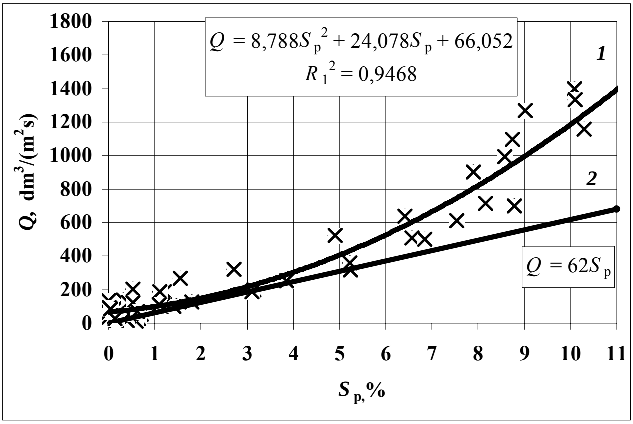


Fig. 7. Dependence of air permeability of the relative area of pores

Q of different weave patterns with higher density is closer to the air permeability which occurs when air permeates only through pores of the fabric (curve 2). When density is lower, Q increases considerably and air flow permeates not only through pores but also through threads and their floats.

Therefore, it is possible to make a conclusion that dependence of Q on S_p of different weave patterns is almost equal. Air flow permeates through pores of fabrics at the same rate in spite of weave pattern.

Q dependencies of air permeability of plain weave fabrics on yarn densities were determined. 20 fabrics woven in different yarn densities (S_1=160÷284 dm^{-1}, S_2=120÷200 dm^{-1}) were selected for the experiment. The results showed that when density of the weft increases, Q decreases independently of the warp density. It was also found how Q of fabrics with plain weave changes according to S_1. It was determined that when S_1 is increasing, Q decreases considerably. However, it is not convenient to use the dependencies of air permeability on yarn density for examining properties of fabrics, as many graphs have to be considered. In such cases the dependence of a property on several factors is frequently determined. In Figure 8 the dependence of fabric permeability to air on S_1 and S_2 is presented. However, in this case it is also not convenient to examine Q dependencies as well as to design a fabric according to the set air permeability value as a complex dimensional shape is obtained. When designing a fabric according to a property, it is more convenient to use dependence on one factor incorporating all the factors that influence fabric properties. The fabric structure factor proposed by Milašius could be used as such factor for it gives the best evaluation of fabric structure.

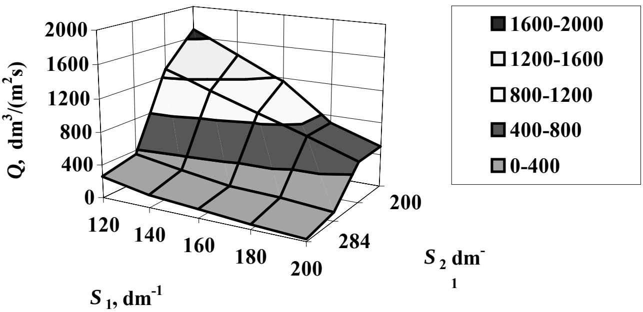


Fig. 8. Dependence of plain weave fabric air permeability on warp and weft densities.

Experimental investigations establishing the dependence of fabric air permeability on weft density were carried out with 8 fabrics of different weaves, namely: plain, twill 2/2, warp rib 2/2, weft rib 2/2, 8 healds sateen, basket weave 4/4, twill 4/4 and rib-basket weave 2/4. Figure 9 presents 8 different weavings having the same factor φ (φ =71.5%), and Q dependence on weft set (series 1). The constant φ is hold by changing weft set S_2 when warp set S_1 = 284dm^{-1}. So we see that fabric air permeability of different weavings changes slightly. The other curves present Q dependences of individual weaves on weft set S_2. From these curves we can see that when weft set increases provided warp set is constant, fabric Q decreases but if we choose S_2 for each weaving securing φ stability, Q changes slightly (series 1).

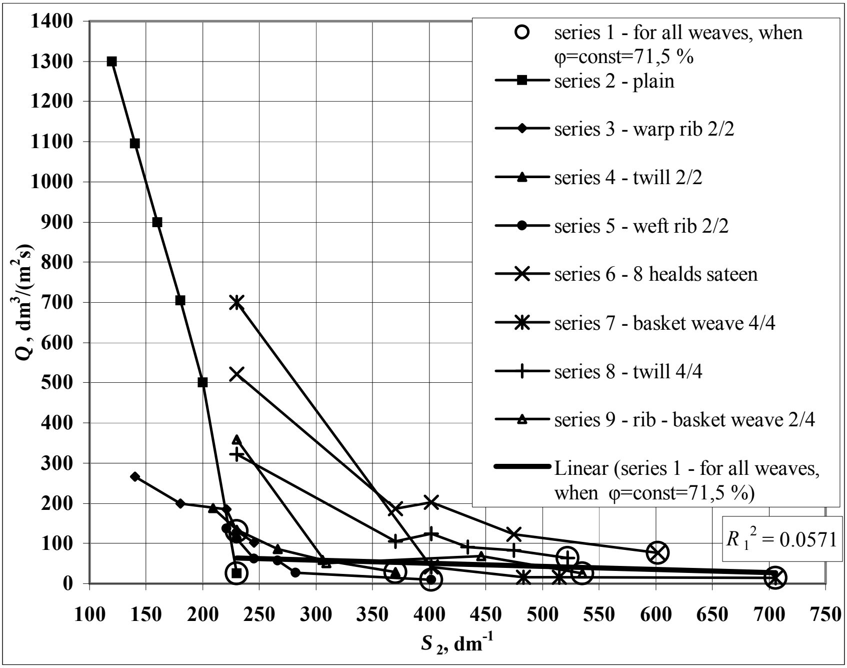


Fig. 9. Dependence of fabric air permeability Q on weft set S_2

So we can state that according to the formula having calculated S_2 for each weaves it is possible to achieve the same air permeability for different weaving fabrics. While keeping the same rate of air permeability, it is possible to increase weft density and to strengthen a fabric at the same time. Durability of such a fabric would increase whereas its properties of air permeability would not be affected.

Influence of weave pattern on air permeability was investigated. Fig. 10 presents Q dependences on the P_1 for fabrics made of multifilament 29,4 tex polyester threads both in warp and in weft. So we may state that Q does not depend on the P_1, if the factor φ is constant. Althoug air permeability strongly depends on both thread density and weave, however, Q dependences from S_2 and P_1 on fabrics woven by these different parameters but having the same φ are negligible. It means that it is possible to design a fabric of suitable Q according to the factor φ. When preserving the same fabric structure factor and designing a fabric according to the preferred rate of air permeability, a weave pattern can be selected as, in this case, Q does not depend on the weave pattern. Although Q has strong dependence on both yarn density and a weave pattern, its dependencies on S_2 and P_1 are very low for the fabrics which had been woven in different density and weave pattern parameters but according to the same value of the factor φ. This means that it is possible to design a fabric with appropriate air permeability value according to the fabric structure factor.

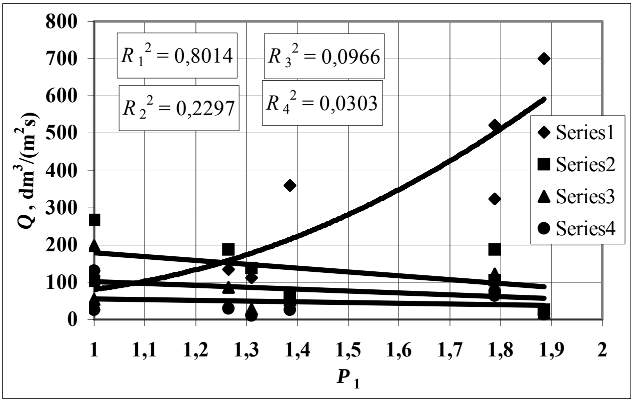
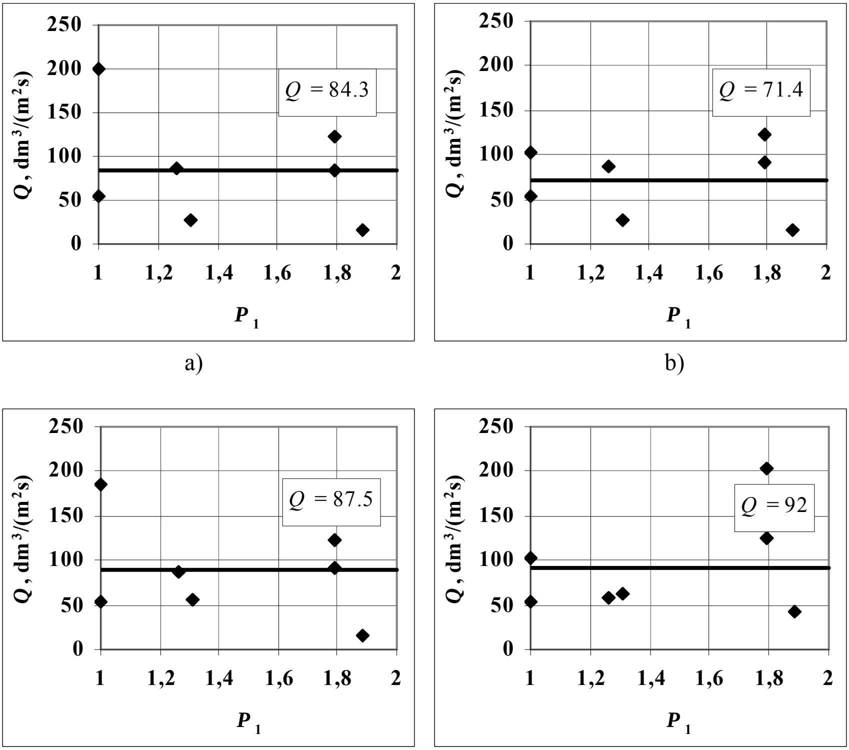


Fig. 10. Dependence of fabric air permeability Q on weave factor P_1: 1– S_1 = const (284 dm^{-1}), S_2=const (230 dm^{-1}), 2, 3 and 4 - φ= const (2– 53.1%, 3– 61.5 % and 4– 71.5 %).

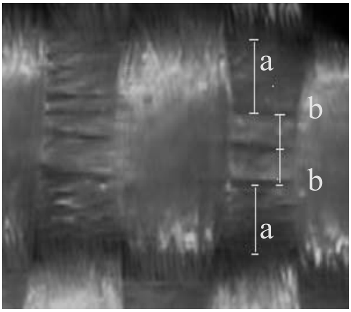
Fabrics with 7 different weave patterns were analyzed in order to determine which of the examined fabric structure factors provides the best evaluation of the fabric structure. The above-mentioned fabrics had been woven with weft set according to the factor φ, which is normally calculated for the plain weave pattern, when S_1=284 dm^{-1} (Fig. 11). A plain fabric was chosen as an indication point calculating various fabric structure factors (Milašius, Brierley, Galuszynski and Galceran) provided S_1=284dm^{-1} and S_2=180dm^{-1}. The smallest Q dispersal is in the case of Brierley, however, according to Brierley and Galuszynski proposed structure factors we cannot evaluate those weaves as the empirical factor m is unknown. The fabric structure factor suggested by Milašius can evaluate all weaves, however, in the case of weft ribs 2/2 the value of Q in this point differed distinctly from the mean air permeability value of all weaves. This cannot be noticed both in the case of Galceran and Brierley. If in Milašius and Galuszynski cases the greatest noncorrespondence to the mean value is obtained in the case of weft rib 2/2, that in the case of Galceran the greatest noncorrespondence to the mean value is obtained to the weaves the both systems of which are woven by long floats and the weave factor of which is P_1 =1.7 ÷1.9. So, it is possible to affirm that the structure factor φ proposed by Milašius evaluates all the analyzed factors best except weft ribs 2/2. So, while designing a fabric according to a necessary Q it should be used this criterion best except the weft rib 2/2 case when it is expedient to use Brierley or Galceran criterion.

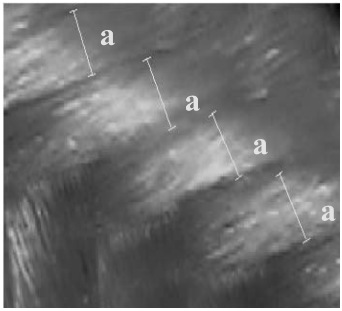


a) b) c) d)

Fig. 11. Dependence of fabric air permeability Q on weave factor P_1 at constant fabric structure factors: a) φ=61.6; b) *MS/MD*= 61.6; c) $T_{\text{Galuszynski}}$ =61.6; d) O_{Galceran} =66.1.

It should be noted that the rib weaves are special weaves and it is difficult to evaluate them in the general context of the remaining weaves. The research showed that when using the maximum thread density in warp rib 4/4 it can be noticed that the inner threads are squeezed by those on the sides; thus, the transversal dimension to the plane of the inner threads is considerably lower than that of the outer ones. This, however, is not the case with the twill weave 4/4 that had also been woven with maximum weft density (Fig. 12). Figure 12 illustrates that the outer threads squeeze the central threads of the rib weave when S_2 has the maximum value. This property influences fabric air permeability as the air flow will permeate through inner threads with more difficulty. Other weave patterns were not noticed to possess such qualities.





a) b)

Fig. 12. Weave pattern: a) warp rib 4/4; b) twill 4/4.

What is more, it is specific to the rib weaves that at high yarn density the inner threads may go one under the other (Fig. 13). This factor influences certain properties of a fabric, for example, its air permeability. When a thread goes under the other thread, the fabric becomes thicker and its air permeability decreases; however, at the same time, the porosity of the fabric and, consequently, its air permeability increase. Thus, a special design method is needed when designing a rib weave. For this reason it can be stated that from all the fabric structure factors that are analyzed, the factor φ gives the best evaluation of all weaves with the exception of the rib weave. Therefore, it is best to use the factor φ when designing a fabric according to the required air permeability (when designing a rib weave, it is advisable to use Brierley's or Galceran's factors).

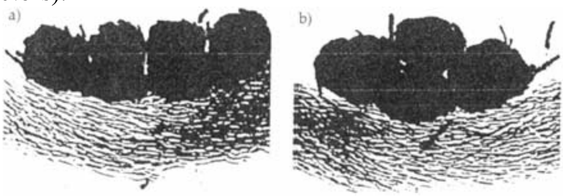


Fig. 13. Cross-section of rib weave fabrics.

As it has already been mentioned, it is advised that the fabric structure of various weaves should be evaluated by the factor φ, while that of the rib weave should be evaluated by the *MS/MD* factor. Value φ was set for the plain weave, when S_1=284 dm^{-1}, S_2=140 dm^{-1}; this value remained the same for all weave types. The factor *MS/MD* was used to evaluate the rib weave. Using the set value, S_2 when S_1=284 dm^{-1} was calculated for the rib weave. The *MS/MD* factor was calculated accordingly in the second group of fabrics, when S_2=180 dm^{-1}. In the third case the maximum value of the *MS/MD* factor was calculated; S_2 (S_2=230 dm^{-1}) for the rib weave fabric was calculated according to *MS/MD* value. The received value S_2 was very high (S_2=350 dm^{-1}). It is not possible to weave a fabric if using such a value. The maximum value S_2 with which it is possible to weave a rib weave fabric was equal to 245 dm^{-1}. For this reason it was assumed that this value is the maximum possible S_2 when the given factor *MS/MD* is used. Figure 14 shows the dependence of Q of all fabrics on P_1 when fabric structure of all weaves (with the exception of the rib weave) is evaluated by the factor φ and the fabric structure of the rib weave is evaluated by the factor *MS/MD*.

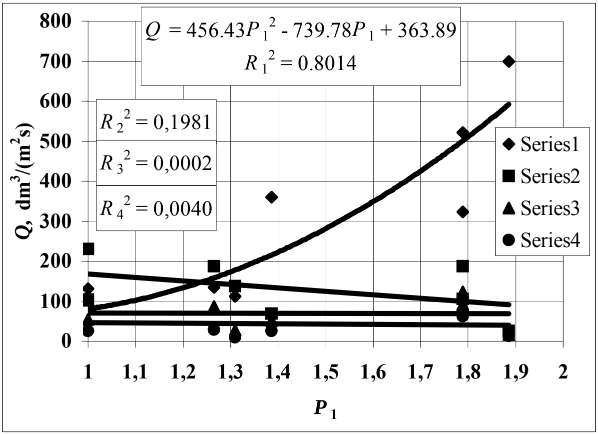


Fig. 14. Dependence of fabric air permeability on weave factor: 1–S_1=const (284dm^{-1}), S_2=const (230dm^{-1}), 2, 3, 4- φ=const (2–53.1%, 3–61.5%, 4–71.5%).

When factors φ and *MS/MD* have constant values, dependence of Q of different fabrics on P_1 is low, R^2=0.0002÷0.1981. It can be said that the structure of fabrics of all weaves (with the exception of the rib weave) can be best evaluated by the factor φ, while it is best to apply the factor *MS/MD* when evaluating the structure of the rib weave; however, it should be indicated that the latter factor can not be used when S_2 calculated according to the *MS/MD* factor exceeds the maximum possible value of the weft density.

The dependence of fabric air permeability on the porosity of a fabric is the same to all polyester fabrics made from threads of similar linear density irrespective of their structure. However, the integrated factors do not evaluate the structure of the threads used. As all the weaves except the weft rib 2/2 can be best evaluated by the factor φ which will be used in further research. The dependence of Q on factor φ of the fabrics, woven in plain weave from polyester multifilament 29,4 tex yarns (S_1=166÷280 dm^{-1}, S_2=112÷216 dm^{-1}), is presented in Fig. 15a. It is seen that as higher is φ as less yield of air permeates through the experimental fabric. Very similar dependence is received from the second group of fabrics where linear density of warp is 29,4 tex, and weft - 27,7 tex (S_1=160÷310 dm^{-1}, S_2=110÷210 dm^{-1}) (Fig. 15b). This dependence is expressed by the equation of the second order with high coefficient of correlation (R^2=0,8877) as and in the first case when were checked filter fabrics

(R^2=0,8873). The results were verified when using the third group of fabrics which were woven from folded (15,6 tex*2) weft as well as 29.4 and 27.2 tex weaves of different densities (S_1=165÷200 dm^{-1} ir S_2=140÷175 dm^{-1}). The dependence of Q on φ of the all three groups of fabrics is presented in the Fig. 15c. Also the equation of the second order is received, but in this case R^2=0,6264. Thus we cannot prove that dependence of Q on factor φ is equal to all polyester-fibre fabrics, despite the structure of its yarns.

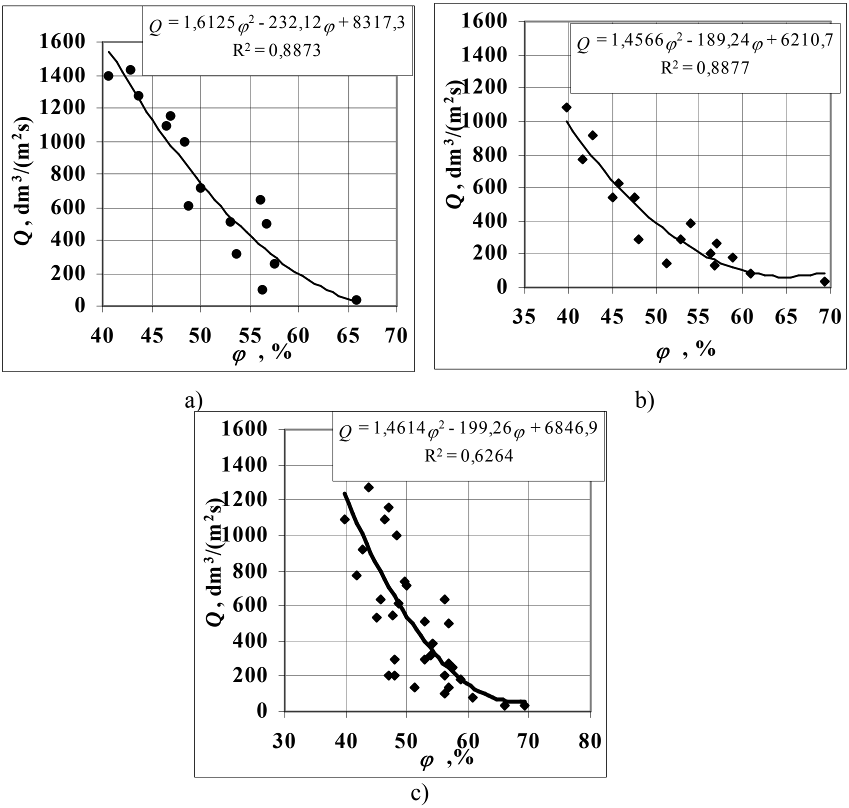


Fig. 15. Dependence of air permeability on fabric firmness factor: a - of the fabric of first group; b - of the fabric of second group; c - of the fabric of all three groups.

Fabrics woven in identical yarn densities but from different type of yarn have different projections to the plane. Thus, Q dependence on the factor φ is not equal to all polyester fabrics irrespective of their yarn structure, as the factor φ does not evaluate this structure. The results showed that a small flow Q permeates through fabrics which have greater yarn density and a high value of the factor φ. As regards fabrics woven from threads of different structure, their Q dependence on fabric porosity is identical while Q dependence on φ is different. This is due to the fact that projections of threads of different structure vary while none of the structure factors can evaluate such variation. It can be stated that by using the factor φ it is possible to predict air permeability of the designed fabric on condition that the threads of the same structure are used.

Conclusions

1. Dependence of fabric air permeability on the relative size of fabric pores is equal for all polyester fabrics that are woven from threads with very similar linear density with no regard to the structure of the threads (it is not important whether twisted or not, folded or not yarn is used).
2. When the density of a plain ewave fabric is high, the air flow permeates mainly through the pores of the fabric, however, as the thread density of these fabrics decreases, the air flow permeates not only through the pores but also through individual yarn systems.
3. Dependence of air permeability to fabrics of different weaves on the relative size of pores is almost identical. The air flow permeates through fabric pores at the same rate irrespective of the weave type.
4. It was determined that the fabric air permeability Q depende on weft and warp densities and fabric weaves. However, the dependencies of air permeability of fabrics on weft density and weave factor are insignificant when fabrics had been woven using different warp and weft densities as well as different fabric weaves and at least one equal integrated fabric structure factor. This means that a fabric of a suitable air permeability can be designed using an integrated fabric structure factor.
5. It was established that from all the integrated fabric structure factors that had been investigated, the φ factor, proposed by Milašius, is best when evaluating all weave types (with the exception of the weft rib 2/2). For this reason, it is suggested that when a fabric is being designed according to its permeability to air, it is best to consider the factor φ.
6. When designing a fabric by the integrated fabric structure factor φ, major inaccuracies appear in fabrics woven in weft rib weave. Those inaccuracies result from the particular character of the weft rib weave.
7. The research has shown that cross-sections of weft rib fabrics as well as threads of weft rib fabrics differ considerably – their yarn projection to the plane differs up to 2 times.
8. It is suggested to use Brierley's integrated fabric structure factor when designing air permeability of weft ribs. In cases when it is not possible technologically to reach the density of fabrics S_2 that is calculated according to the *MS/MD* factor, it is suggested that the maximum possible weft density of the rib weave should be used.
9. By using the integrated fabric structure factors φ and *MS/MD* it is possible to design a fabric with higher thread density (which, at the same time,

increases the durability of a fabric) yet with the same rate of permeability to air.

10. Dependence of fabric air permeability Q on the integrated fabric structure factor φ is not equal to all polyester fabrics irrespective of the structure of their threads (irrespective of whether twisted or not, folded or not yarn is used). Therefore, this integrated fabric structure factor can be used only when a fabric is made from threads with identical structure.

List of Publications and Proceedings

PUBLICATIONS

Scientific Materials of the Institute of Scientific Information (ISI)

1. R. Milašius, V. Milašius, E. Kumpikaitė, A. Olšauskienė. Influence of Fabric Structure on Some Technological and End-use Properties Fabrics // Fibres & Textiles in Eastern Europe, ISSN 1230-3666 Vol. 11, 2003, No. 2, p. 49-52.
2. A. Olšauskienė, R. Milašius. Dependence of Air Permeability on Parameters of Fabric Geometry // Tekstil, ISSN 0492-5882 Vol. 52, 2003, No. 6, p. 278-281.

PUBLICATIONS

Review Periodicals in Lithuania

3. A. Olšauskienė, R. Milašius. Dependence of Air Permeability on Fabric Porosity and Integrated Fabric Firmness Factor φ // Materials Science (Medžiagotyra). ISSN 1392-1320 Vol. 9, No. 1, 2003, p. 124-127.
4. A. Olšauskienė, R. Milašius. Dependence of Air Permeability on Various Integrated Fabric Firmness Factors // Materials Science (Medžiagotyra). ISSN 1392-1320 Vol. 9, No. 4, 2003, p. 401-404.

PUBLICATIONS

Materials of International Conferences

5. A. Olšauskienė, R. Milašius. Integrated Fabric Firmness Factor as a Criterion of Air Permeability Designing // Proceedings of International Conference "Magic World of Textiles", Dubrovnik, 2004, p. 246-250.
6. A. Olšauskienė, R. Milašius. Influence of Fabric Structure Parameters on Air Permeability // Proceedings of International Conference "The Textiles: Research in Design and Technology", Kaunas, 2000, p.201-206.
7. R. Milašius, V. Milašius, E. Kumpikaitė, A. Olšauskienė. Development of Employment of Fabric Firmness Factor φ // Transactions of Conference "ArchTex-2002", Lodz, 2003, p. 31-39.

PUBLICATIONS

Others in Lithuania

8. A. Olšauskienė, R. Milašius. Struktūros parametrų įtaka audinio oro laidumui // Gaminių technologijos ir dizainas. Konferencijos pranešimų medžiaga.- Kaunas: Technologija, 2000, p. 234 – 238.

Information about the Author of the Dissertation

Asta Olšauskienė was born on December 20, 1974.
1993-1997: bachelor's degree studies at Kaunas University of Technology, Faculty of Ligft Industry; Bachelor of Science in Industrial Engineering.
1997-1999: master's degree studies at Kaunas University of Technology, Faculty of Design and Technologies; master of Science in Industrial Engineering.
1999-2004: doctoral's degree studies at Kaunas University of Technology, Faculty of Design and Technologies.

Acknowledgements

I would like to thank Assoc. Prof. Rimvydas Milašius, my supervisor, for valuable ideas and consultations, support and encouragement through out this work, Prof. Vytautas Mykolas Milašius for his consultations and Mr. Mindaugas Gėgžna for help during experiments.

Reziumė

Projektuojant techninius audinius, yra svarbu ne šių audinių išvaizda, o svarbu juos projektuoti pagal savybę. Projektuojant naują audinį, reikia prognozuoti jo savybes dar prieš audinio gamybą, nes svarbu iš karto pagaminti tokį audinį, kuris pasižymėtų tinkamomis eksploatacinėmis savybėmis. Todėl darbai skirti ištirti įvairių parametrų įtaką audinio savybėms bei sukurti audinio projektavimo pagal užduotą jo savybę metodą yra labai aktualūs. Filtrinių audinių savybėms svarbi charakteristika yra audinio akutės skersmuo, nuo kurio priklauso, kokio dydžio dalelės bus sulaikomos filtrinio audinio.

Audinio struktūra gali būti apibūdinama septyniais pagrindiniais technologiniais parametrais: siūlų žaliava, ilginiai tankiai, siūlų tankumai bei pynimas. Tinkamam audinio pynimo įvertinimui naudojami įvairūs pynimo rodikliai. Tačiau norint įvertinti bendrą audinio struktūrą reikalingas faktorius, kuris įvertintų visus pagrindinius audinio struktūros parametrus. Tokiu

faktoriumi gali būti naudojamas integralinis audinio struktūros rodiklis. Šiuo metu žinomi integraliniai audinio struktūros rodikliai Newton'o buvo suskirstyti į dvi grupes: pagrįsti Peirce'o paviršiaus uždengimo teorija ir pagrįsti Brierley'o maksimalaus tankumo teorija. Šios dvi audinio struktūros rodiklių grupės viena nuo kitos skiriasi audinio pynimo įvertinimo būdu. Šiame darbe audinių struktūrai įvertinti buvo parinkti 4 integraliniai audinio struktūros rodikliai (Galceran'o, Brierley'o ir Galuszynski'o ir Milašiaus).

Buvo nustatyta, kad mažėjant ataudų tankumui, santykinis audinio akučių plotas didėja, tuo pačiu didėja ir oro srautas, besiskverbiantis per tiriamą drobinį audinį. Audinio laidumo orui priklausomybė nuo audinio akučių ploto yra vienoda visiems poliesteriniams audiniams iš apytikriai vienodo ilginio tankio siūlų, neatsižvelgiant į šių siūlų sandarą. Buvo gauta, kad oro srautas per didelio tankumo drobinius audinius skverbiasi beveik tik per audinio akutes, o mažėjant šių audinių siūlų tankumui, oro srautas jau skverbiasi ne tik per audinio akutes, bet ir per atskiras siūlų sistemas. Audinių laidumas orui įvairių pynimų audiniams nuo audinių akučių ploto priklauso beveik vienodai. Oro srautas skverbiasi per audinių akutes vienodai, nepriklausomai nuo pynimo pobūdžio. Nustatyta, kad nors audinių laidumas orui priklauso tiek nuo metmenų ir ataudų tankumo, tiek nuo pynimo, tačiau audiniams, išaustiems su skirtingais šiais parametrais, tačiau vienodu kuriuo nors audinio struktūros rodikliu, audinio laidumo orui priklausomybės nuo ataudų tankumo ir pynimo rodiklio yra labai nežymios. Tai reiškia, kad galima projektuoti atitinkamo laidumo orui audinį pagal integralinį audinio struktūros rodiklį. Nustatyta, kad iš nagrinėjamų integralinių audinio struktūros rodiklių visus pynimus, išskyrus ataudų ripsą 2/2, geriausiai įvertina Milašiaus pasiūlytas audinio struktūros rodiklis, todėl projektuojant audinį pagal reikalingą laidumą orui, geriausiai naudoti būtent šį kriterijų. Didžiausi netikslumai, projektuojant audinio laidumą orui pagal rodiklį φ, gaunami audiniams išaustiems ripsiniu pynimu. Šiuos netikslumus sąlygoja išskirtinis ripsinių pynimų pobūdis. Tyrimais patvirtinta, kad ripsinių pynimų audinių siūlų skerspjūviai ypatingai nevienodi - siūlų projekcijų dydis į audinio plokštumą skiriasi net iki 2 kartų.

Projektuoti ataudų ripsų audinių laidumą orui siūloma naudoti Brierley'o integralinį audinio struktūros rodiklį *MS/MD*. Tais atvejais, kai apskaičiuotą pagal Brierley'o audinio struktūros rodiklį ataudų tankumą pasiekti nebeįmanoma technologiškai, siūloma naudoti ripsinio pynimo audinio maksimalų ataudų tankumą. Pasinaudojus audinio struktūros rodikliais φ bei *MS/MD*, galima suprojektuoti didesnio siūlų tankumo (tuo pačiu ir didesnio stiprumo), tačiau tokio pačio laidumo orui audinį. Audinio laidumo orui priklausomybė nuo integralinio audinio struktūros rodiklio φ nėra vienoda visiems poliesteriniams audiniams, nepriklausomai nuo jų siūlų sandaros, todėl šis integralinis audinio struktūros rodiklis gali būti naudojamas projektuojant audinius tik iš siūlų su tokia pačia sandara.

UDK 677.494.674+677.017](043)

SL 344. 2005-02-24. 1 leidyb. apsk. 1. Užsakymas 114. Tiražas 70 egz.
Išleido leidykla “Technologija”, K. Donelaičio g. 73, 44029 Kaunas
Spausdino leidyklos “Technologija” spaustuvė, Studentų g. 54, 51424 Kaunas