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The Modelling of Porous Properties Regarding PES/CV-blended Nonwoven Wipes

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Abstract: This paper reports the results from the modelling of porous properties of raw polyester/viscose nonwoven wipes. This was carried out on the basis of nonwoven construction parameters (fibre fineness, web mass per unit area, web thickness), mercury intrusion porosimetry, and a non-deterministic modelling method, e.g. genetic algorithms. Despite the fact that the nonwoven fibre webs had different porous structures as a result of varying their construction parameters, it was possible to very precisely develop predictive models of the porous parameters (pore volume, volume porosity, pore surface area, pore diameter). The results show that the genetic algorithm is a successful modelling tool in those cases where the testing population is limited but still different. The proposed models provide guidelines for the engineering of nonwoven wipes in order to fit the desired porosity properties.

Keywords: Nonwoven fibre web, Porosity, Porosity properties modelling, Genetic algorithm

Introduction

Fabrics are porous materials used for different applications. Nonwoven fabric, as a porous material, allows for the transmission of energy (UV, IR, X-ray, visible radiation, etc.) and substances (particles, liquid, gas) and is, therefore, a suitable material for a wide-range of technical applications, as well as for garments and interiors. The porous structure of nonwoven fabrics is a result of the nonwoven construction (the type and properties of fibres or yarns as input material, fabric mass, fabric thickness, etc.), as well as the technological phases, e.g. the type of web production, bonding-methods, and finishing treatments, which all give them unique appearances and end-use properties. The porous structure affects several of the important end-use properties of nonwovens, such as wettability, moisture-uptake, thermal conductivity, filtering efficiency, air permeability, UV transmission, anti-microbial effect, softness, durability, mechanical strength, noise absorption, and other properties [1-7]. Knowledge about the material's pore structure is, therefore, an important step when characterizing materials, in order to predict their behaviour under different end-use conditions regarding a product. Hence, if porosity is estimated or predicted then: 1. when developing a new product the desired porous parameters can be set in advance on the basis of selecting those factors that have an effect on porosity and, in this way, sample production trials could be reduced, 2. its influence on some end-use properties can be further defined.

In order to characterize the porosity-structure of the material, the following porosity parameters are commonly defined: pore size, pore size distribution, specific pore volume, volume porosity, specific surface area, bulk density, apparent density, etc. [8-10], and refer to an inner geometrical model of porous structure. The unit of a web porous structure is a void space called a "pore" or "cappilar", which can be situated between the fibres and within the fibres. Pores are classified into the following groups regarding their size or width: macropores that are larger than 50 μm, mesopores within a width-range of between 2 and 50 μm, micropores that have a width of less than 2 μm, and nanopores with the sizes as low as 100 nm. Nonwovens have, with regard to woven and knitted fabrics, less similar and an exactly-determined inner geometrical model of their porous structures in the form of a tube-like system where each pore has a cylindrical shape with a permanent cross-section along its full length [11]. The geometrical model of three-dimensional needle-punched fabrics, as proposed by Mao and Rusell [12], is constructed based on a two-dimensional fibre orientation within the fabric plane, with interconnecting fibres oriented in the Z-direction. Pores can also be classified regarding their fluid accessibility, firstly as closed pores, being inaccessible, blind pores that terminate inside the material and prevent fluid flow, and secondly as through pores that are open to external surfaces and permit fluid flow. Through pores are of primary interest for many applications regarding nonwovens and are also known as open-pores. The porous structure of needle-punched fabrics is affected by fibre diameter and interrelated physical parameters, such as fabric mass, thickness, and density. The latter-mentioned parameters are also affected by the needle-punching parameters, such as the densities of the needles on the needle board, the frequency and depth of needle penetration and feed-rate, as well as by the calendaring parameters, such as pressure and temperature.

Several methods (optical, geometrical, fluid flow, sorption, filtration) are applicable for quantifying the porous structures of nonwovens, and are commonly divided into "direct" and "indirect" and are differentiated according to their porous parameters, which can be measured [11,13]. The more often used methods for analysing open and blind pores in nonwovens are porosimetry (liquid intrusion/extrusion techniques)

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and capillary flow porometry (liquid extrusion technique) [9]. In this study, the porous parameters of needle-punched nonwoven fabrics were studied using the mercury intrusion method, as an indirect method.

From the literature, it can be seen that there have been a lot of studies dealing with gas/liquid permeability or transmissivity as a measure of fabric porosity, which is critical for the many end-uses dedicated to the absorbtion, desorption, filtration, drainage, vapour transmission, compression behaviour, etc. of needle-punched nonwovens, and their comparison with pore-size and pore-size distribution [3,14-16]. There is, however, a lack of research work dealing with the prediction of needle-punched nonwovens porosity properties. White [3] proposed a theoretical calculation of mean capillary radius, which is deduced from the fibre radius and theoretical porosity. The latter is calculated from fabric characteristics such as thickness, mass per unit area, and fibre material density.

As there has been a dearth of published work on this important aspect, this study attempted for the first time to link changes in fabric constructional parameters with the measured porous properties of those needle-punched nonwoven fabrics used for cleaning wipes. Predictive models of nonwoven wipe porous parameters, based on the fabric's primary construction parameters, such as fibre fineness, web mass and web thickness (which are all parameters that must be set in advance during the phase of fabric engineering), and genetic algorithms, were developed. Such models can serve as guidelines for a fabric engineer when developing nonwoven wipes with the desired porous properties. There are essentially two kinds of modelling tools: deterministic (mathematical models, empirical models, computer-simulation models), and the non-deterministic (models based on genetic methods, neural-network models, models based on the chaos and soft-logic theories), each having its own advantages and disadvantages [17,18]. In this work, genetic algorithms were used as a non-deterministic method for modelling porous parameters for a limited group of nonwoven fabrics, e.g. raw webs for cleaning wipes. We intended to show that genetic algorithms are useful and effective modelling tools for nonwoven porous properties' engineering.

Experimental

Materials

This research focused on dry-laid nonwovens for cleaning wipes, made from a mixture of polyester and viscose fibres. Bearing in mind the fact that nonwovens have very different structures and, thus, also porous parameters, due to their sequences when web-forming, bonding, as well as finishing methods, the tested samples were limited to one type of nonwoven structure-those needle-punched fibre webs used for cleaning wipes. Nonwoven multi-layered webs were obtained from the same manufacturing process by subjecting the fibre mixtures to carding and then orienting the carded webs in a cross-direction by using a cross lapper to achieve web weight ranges of 100-150, 150-200, 250-300, and 300-350 g/m^2, and a web density range of 0.019-0.035 g/cm^3. The webs were made from a mixture of polyester (PES) and viscose (CV) fibres of different content, fineness, and lengths, as follows: samples 1-3 from a mixture of 87 % CV fibres (1.7 dtex linear density, 38 mm length) and 12.5 % of PES fibres (4.4 dtex linear density, 50 mm length), samples 4-7 from a mixture of 60 % CV fibres (1.7 dtex linear density, 38 mm length) and 40 % PES fibres (3.3 dtex linear density, 60 mm length), samples 8-11 from a mixture of 30 % CV fibres (3.3 dtex linear density, 50 mm length), 40 % PES fibres type 1 (6.7 dtex linear density, 60 mm length) and 30 % of PES fibres type 2 (4.4 dtex linear density, 50 mm length), samples 12-15 from a mixture of 70 % PES fibres type 1 and 30 % PES type 2. Here fibre fineness is expressed in dtex, which is a unit of measure for the linear mass-densities of fibres and is defined as the mass in grams per 10,000 meters. Multi-layered carded webs were further subjecting to pre-needling using Dilo needle-punching machine, under the following processing parameters of one-sided pre-needle punching: stroke frequency 250/min; delivery speed 1.5 m/min; needling density 30/cm, depth of needle penetration 15 mm, and felting needles of 15×18×38×3 M222 G3017. The processing parameters of further two-sided needle-punching were as follows: stroke frequency 900/min; delivery speed 5.5 m/min; needling density 60/cm (30/cm upper and 30/cm lower), depth of upper and lower needle penetrations 12 mm, and felting needles of 15×18×32×3 M222 G3017. The webs were further processed through a pair of heated Comerio calendars at under 180 ^{o}C with different gaps between the rollers, in order to achieve further changes in fabric density and, consequently, in the volume porosity within the range of 80-92 %. The construction parameters of the nonwoven samples are collected in Table 1. All the tested samples were in a grey state, while our purpose at the first stage of the study was to investigate the influence of nonwoven construction on the porous properties without the influence of finishing treatments, which also have a great effect on porous structure.

Methods

Porosity Measurements

The porous parameters of the nonwoven samples were measured using the Pascal 140 computer aided mercury intrusion porosimeter (Thermo Fisher Scientific Inc.), which measures pores' diameters between 3.8-120 μm, and operates under low pressure. The mercury intrusion technique is based on the principle that non-wetting liquid (mercury) coming in contact with a solid porous material can not be spontaneously absorbed by the pores of the solid itself because of the surface tension, but can be forced by applying external pressure. The required pressure depends on the pore-size and

Table 1. The construction parameters of the nonwoven samples

No. sample	Average fibre fineness (dtex)	Web mass (g/m^2)	Web thickness (mm)	Web volume fraction	Web volume porosity (%)
1	2.0	143	1.202	0.086	91.4
2	2.0	142	0.941	0.109	89.1
3	2.0	142	0.576	0.178	82.2
4	2.3	173	1.509	0.080	92.0
5	2.3	201	1.558	0.090	91.0
6	2.3	171	0.941	0.127	87.3
7	2.3	200	1.071	0.131	86.9
8	5.0	259	1.360	0.129	87.1
9	5.0	259	1.261	0.140	86.0
10	5.0	279	1.182	0.160	84.0
11	5.0	274	1.112	0.162	83.8
12	6.0	298	1.400	0.140	86.0
13	6.0	304	1.266	0.158	84.2
14	6.0	352	1.347	0.172	82.8
15	6.0	343	1.235	0.183	81.7

this relationship is commonly known as the Washburn equation [8]:

$$P = \frac{-2 \cdot \gamma \cdot \cos\theta}{r} \tag{1}$$

where P is the applied pressure, γ is the surface tension of mercury, θ is the contact-angle and r is the capillary radius. The distribution of pore size, as well as the total porosity and the specific pore volume can be obtained from the relationship between the pressure necessary for penetration (the pore dimension) and the volume of the penetrated mercury (pore volume). There are certain main assumptions necessary when applying the Washburn equation: the pores are assumed to be of cylindrical shape and the sample is pressure stable.

Each nonwoven sample of known weight was placed in the dilatometer (part of the porosimeter), then the air around the sample was evacuated and finally the dilatometer was filled with mercury by increasing the pressure up to the reference level. The volume and pressure measurements' data were transferred into the computer programme and the following data were detectable or calculated: the specific pore volume (mm^3/g), the specific surface area (m^2/g), the average pore diameter (μm) and the volume porosity (%). The volume of penetrated mercury is directly the measure of the sample's pore volume expressed as a specific pore volume in mm^3/g, and is obtained by means of a capacitive reading system. The calculation of specific surface area is based on the cylindrical shapes of pores. The side surface of the cylinder is calculated knowing the values for the pore volume and the pore radius. The calculation is repeated for each experimental point. The average pore diameter is evaluated at 50 % of the cumulative volume of mercury.

The theoretical volume porosity, P_V, is calculated from the fabric volume fraction, and the fabric volume fraction from the fabric's constructional parameters, such as the fabric's mass per unit area, thickness, and fibre density [5,10]:

$$P_V = (1 - V_F) \cdot 100\% \tag{2}$$

$$V_F = \frac{V_{fib}}{V_{fab}} = \frac{\rho_{fab}}{\rho_{fib}} = \frac{m_{fab}}{D_{fab} \cdot \rho_{fab} \cdot 1000} \tag{3}$$

where P_V is volume porosity as a %, V_F is the volume fraction, $V_{fib/fab}$ is the volume of fibres/fabric in cm^3, ρ_{fab} is the fabric volume mass in g/cm^3, ρ_{fib} is the fibres' average volume mass in g/cm^3, m_{fabc} is the fabric mass per unit area in g/m^2, and D_{fab} is the fabric thickness in mm. For the average fibre density calculations, the following densities of fibres were taken into account: ρ_{PES}=1.37 g/cm^3 and ρ_{CV}=1.52 g/cm^3.

Web-Construction Parameters Measurements

The construction parameters of the nonwoven samples, e.g. the web mass per unit area and thickness were measured according to ISO 9073-1 (Textiles – Test Methods for nonwovens – Part 1: Determination of mass per unit area) and ISO 9073-2 (Textiles – Test Methods for nonwovens – Part 2: Determination of thickness).

Predictive Modelling

In this work the genetic algorithm (GA) was used for defining the predictive models of porous parameters. Since the basic steps in evolutionary computation are well-known, only a brief description follows. Firstly, the initial population $P(t)$ of random organisms (solutions) is generated. The variable t represents the generation time. The next step is the evaluation of population $P(t)$ according to fitness measure.

Altering the population $P(t)$ by genetic operations follows. The genetic operations alter one or more parental organism(s); thus, creating their offspring(s). The evaluation and alteration of population takes place until the termination criterion has been fulfilled. This can be the specified maximum number of generations or a sufficient quality of solutions [19]. More comprehensive information on evolutionary computation can be found in [18].

Coding of organisms: In this research, the independent input variables were fibre fineness – T (dtex), web mass per unit area – m (g/m^2), and web thickness – D (mm). The dependent output variables were of specific pore volume V_p (mm^3/g), specific surface area A_p (m^2/g), average pore diameter d_p (μm) and volume porosity P_V (%). Since the GA approach is unsuitable for the evolution of prediction models (organisms) in their symbolic form, it is necessary to define them in advance [19]. In this study, a quadratic polynomial equation with three variables is used as a prespecified model for the prediction of porous parameters:

$$c_1 + c_2 m + c_3 D + c_4 T + c_5 m^2 + c_6 D^2 + c_7 T^2 + c_8 mD + c_9 mT + c_{10} DT + c_{11} mDT \quad (4)$$

where m is the web mass per unit area in g/m^2, D is the web thickness in mm, T is the fibre fineness in dtex, and $c_{1...11}$ is the constant. The main reasons for this selection were as follows: (1) a polynomial model is relatively simple, (2) for the problem studied we did not expect, e.g., harmonic dependence of the output variables, (3) some preliminary modeling-runs with different types of prespecified models showed that the quadratic polynomial model provides very good selection in terms of prediction quality. However, in general, any other types of polynomial, exponential or other equations could be used. In our research, the population $P(t)$ consisted of N prespecified models (see equation (4)) where N is the population size, i.e., the number of organisms (models) within the population. Of course, in our computer implementation of the genetic algorithm, the population $P(t)$ consisted only of the N sets of the real–valued vectors of model constants. The individual vector is equal to:

$$c = (c_1, c_2, \cdots, c_{11}) \quad (5)$$

Fitness measure: The absolute deviation $D(i, t)$ of individual model i (organism) in generation time t was introduced as a fitness measure. It was defined as:

$$D(i,t) = \sum_{j=1}^{n} |E(j) - P(i,j)| \quad (6)$$

where $E(j)$ is the experimental value for measurement j, $P(i, j)$ is the predicted value returned by the individual model i for measurement j, and n is the maximum number of measurements. Note, that equation (6) has to be evaluated over each generation time t for each model i within the population of N-models, for each measurement j. The goal of the optimisation task was to find such a predictive model (defined by equation (4)), that equation (6) would give as low an absolute deviation as possible. Therefore, the aim was to find out the appropriate real-valued constants in equation (5). However, since it was unnecessary that the smallest values of the above equation also meant the smallest percentage deviation of this model, the average absolute percentage deviation of all measurements for individual model I was defined as:

$$\Delta(i) = \frac{D(i,t)}{|E(j)|n} \cdot 100\% \quad (7)$$

The equation (6) was not used as a fitness measure for evaluating population, but only for finding the best organism within the population, after completing the run [19].

Genetic operations: The altering of population $P(t)$ was effected by reproduction, crossover, and mutation. For the crossover operation, two parental vectors, e.g., c_1 and c_2 were randomly selected. Then the crossover took place between two randomly-selected parental genes having the same index. Two offspring genes were created according to the extended intermediate crossover, as considered by Mühlenbeim and Schlierkamp-Voosen [20]. During the mutation operation, one parental vector c was randomly selected. Then, the mutation took place in one randomly selected parental gene. During both the crossover and mutation processes, the numbers of crossover and mutational operations performed on parental vector(s), were randomly selected.

Assessment of the Developed Models

Correlation analysis between the predicted and experimental results was used to judge the prediction performance of the developed models. Statistical parameters were used such as mean prediction error and correlation coefficient. Prediction error was calculated by using the following expression.

$$\text{prediction error (\%)} = \frac{\text{predicted value} - \text{experimental value}}{\text{experimental value}} \times 100\,\% \quad (8)$$

Results and Discussion

The results of the measured fabric mass per unit area and thickness are collected in Table 1. Table 2 shows the results from the porosity parameters' measurements (experimental values), as well as those porosity parameters calculated using equations (9), (10), (11) and (12) (predicted values) according to the developed predictive models for the specific pore volume V_p in mm^3/g, the volume porosity P_V as a %, the average pore diameter d_p in μm, and the specific surface area

A_p in m^2/g, respectively. Here T is the fibre fineness in dtex, m fabric mass per unit area in g/m^2, and D fabric thickness in mm.

$$V_p=-1607.26+0.240896m+8012.37D-2323.05T+2.27985\cdot 10^{-5}m^2 -3325.34D^2+164.605T^2+0.900355mD+4.63963\cdot 10^{-2}mT +828.328DT-1.12485mDT \quad (9)$$

$$P_V=150.1-8.60497\cdot 10^{-2}m+3.20866\cdot 10^{-2}D-66.0399T-1.08974 \cdot 10^{-3}m^2-28.7365D^2+0.887001T^2+0.241635mD +0.1994mT+32.1638DT-0.101239mDT \quad (10)$$

$$d_p=103.119-0.387186m+6.00845D-0.733258T-2.11795\cdot 10^{-3}m^{-2} -30.7736D^2-3.79198T^2+0.455376mD+0.163758mT +1.13306DT-3.79197\cdot 10^{-3}mDT \quad (11)$$

$$A_p=0.920081-1.07922\cdot 10^{-2}m+9.19297\cdot 10^{-2}D+4.34826\cdot 10^{-2}T +3.23294\cdot 10^{-6}m^2-0.46912D^2-5.22964\cdot 10^{-3}T^2+7.60477 \cdot 10^{-3}mD+8.516\cdot 10^{-4}mT+9.3904\cdot 10^{-3}DT-7.65507\cdot 10^{-4}mDT \quad (12)$$

Table 2 also shows the prediction errors (e), the theoretical values for volume porosity (T) calculated by equation (2), and the experimental errors (e*) between the experimental and theoretical values of volume porosity in regard to the theoretical ones.

Whilst the basic construction parameters such are web mass per unit area, web thickness, and fibre density (which must be set in advance by a new fabric's development), have an influence on the porous structures of nonwovens through the web volume fraction (equations (2) and (3)), it was decided to show the influences of the web volume fraction on the individual porous parameters (Figures 1-4). At the same figures also predicted porous properties calculated upon equations (9)-(12) are presented. In Figure 2, theoretical values of pore volume have been added for the comparison with the experimental and predicted ones.

Web Volume Fraction vs. Porous Properties

The volume fraction, which represents the share of textile material within the volume unit of the nonwoven fabric, had an influence on pore volume and volume porosity (Figures 1-2). As the volume fraction increased, the pore volume and volume porosity decreased due to an increased consolidation of the fibres in the web. The R-squared value for the experimental values of pore volume was 0.70, and for the predicted values of pore volume 0.91. These results clearly indicate that a correlation exists between the volume fraction of nonwoven fabrics and the pore volume. Sample 4 had the biggest prediction error of pore volume (29.7 %). If we compare samples 1, 4, and 5 which all had the lowest web volume fractions (0.086, 0.080 and 0.090, respectively) or the highest volume porosity (91.4 %, 92.0 %, and 91.0 %, respectively), the predicted pore volume of sample 4 fits the dependence between the volume fraction and pore volume quit well (4245 mm^3/g, 4149 mm^3/g, and 4057 mm^3/g, respectively). The problem is the experimental value for pore volume, which at 3198 mm^3/g is too low for sample 4 in

Table 2. Results of experimental (E) and predicted (P) values for nonwoven porous parameters, the prediction errors (e), and the experimental errors (e*) for volume porosity

No. sample	Specific pore volume V_p (mm^3/g)			Volume porosity P_V (%)					Average pore diameter d_p (μm)			Specific surface area A_p (m^2/g)		
	E	P	e	E	P	e	T	e*	E	P	e	E	P	e
1	4278	4254	-0.6	87.5	86.6	-1.1	91.4	-4.3	76.7	77.1	0.5	0.254	0.252	-0.9
2	4118	3641	-11.6	85.5	84.4	-1.3	89.1	-4.0	75.5	75.7	0.2	0.249	0.261	4.8
3	2006	2023	0.9	74.5	74.7	0.3	74.7	-0.3	66.5	66.5	0.0	0.166	0.166	-0.2
4	3198	4149	29.7	79.8	83.3	4.4	92.0	-13.3	76.2	75.7	-0.7	0.190	0.190	-0.1
5	4056	4057	0.0	82.0	82.1	0.1	91.0	-9.9	71.8	72.3	0.7	0.314	0.216	-31.3
6	3413	3312	-3.0	79.1	80.4	1.6	87.3	-9.4	80.3	70.4	-12.4	0.193	0.208	7.9
7	3353	3652	8.9	82.6	82.0	-0.7	86.9	-4.9	65.0	64.1	-1.3	0.253	0.190	-24.8
8	2995	2946	-1.6	78.1	77.3	-1.0	87.1	-10.3	86.6	87.0	0.5	0.186	0.183	-1.6
9	2465	2727	10.6	74.5	75.6	1.5	86.0	-13.4	84.1	82.7	-1.7	0.157	0.194	23.6
10	2426	2403	-0.9	74.1	74.1	0.1	84.0	-11.8	72.2	74.9	3.8	0.182	0.190	4.3
11	2171	2202	1.4	73.4	72.6	-1.1	83.8	-12.4	68.7	71.8	4.5	0.188	0.184	-1.9
12	2971	2969	-0.1	81.2	81.2	0.0	86.0	-5.6	90.9	89.6	-1.4	0.157	0.131	-16.5
13	2615	2610	-0.2	79.9	80.2	0.3	84.2	-5.1	80.8	80.9	0.1	0.158	0.159	0.6
14	2424	2461	1.5	75.5	76.0	0.7	82.8	-8.8	75.9	75.9	0.0	0.163	0.170	4.1
15	2714	2259	-16.8	80.4	78.0	-2.9	81.7	-1.6	70.1	69.4	-1.0	0.168	0.167	-0.4
Mean error (%)			**5.9**			**1.1**		**7.7**			**1.9**			**8.2**

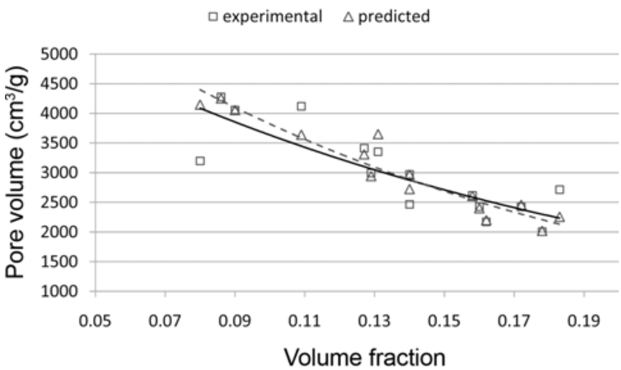

Figure 1. Comparison between the experimental and predicted values for pore volume vs volume fraction.

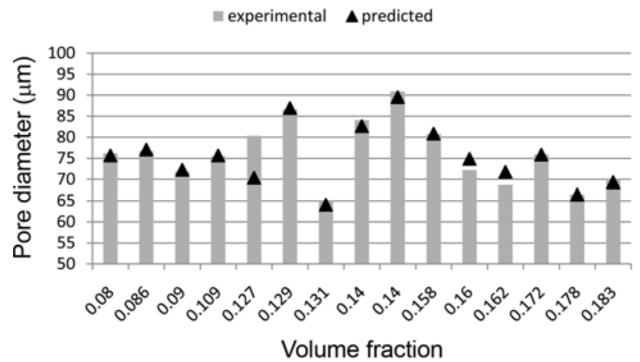

Figure 3. Comparison between the experimental and predicted values for pore diameter.

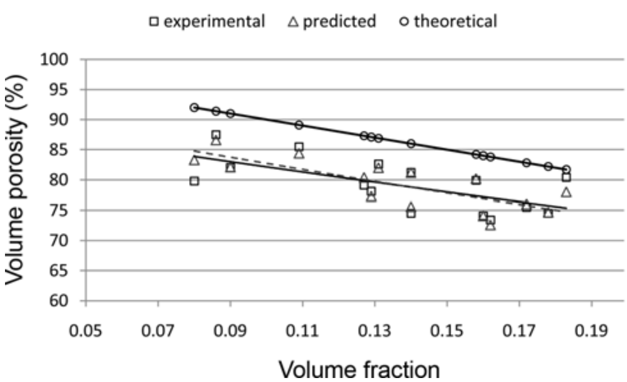

Figure 2. Comparison between the experimental, predicted, and theoretical values for volume porosity vs volume fraction.

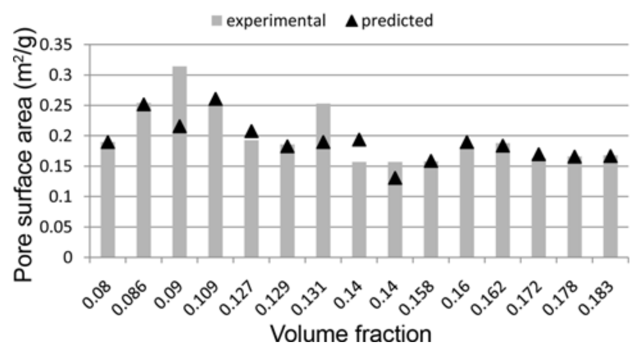

Figure 4. Comparison between the experimental and predicted values for pore surface area.

regard to sample 5 (4056 mm^3/g) or sample 1 (4278 mm^3/g). Obviously the structure of sample 4, which had the lowest volume fraction of all the samples, was too loose to stand against the deformation during low pressure intrusion porosimetry.

From Figure 2 it can be seen that the experimental values for volume porosity (as well as the predicted ones) are, for all the samples, lower than the theoretical ones. This was expected because with the mercury intrusion porosimetry, only the open and blind pores are detectable. Closed pores, which might also occur in nonwoven fabric, and which increase the volume porosity, were undetectable. The mean error of the experimental values for volume porosity regarding the theoretical ones was small and came to 7.7 % (Table 2, e*). This fact confirms the conclusion that mercury intrusion porosimetry is a suitable method for porous properties' measurements of a textile material, if its structure is tight enough.

The results from Figures 3-4 show that there is no correlation between volume fraction and pore surface area or pore diameter, whilst fabrics with different volume fractions have similar pore diameters or surface areas. This is in accordance with the fact that nonwoven fabrics could have the same volume porosity at higher number of small pores or lower number of bigger pores. The nonwoven samples were prepared with different fibre fineness and, consequently, with different pore-sizes. If we compare samples at the same fibre fineness, a relationship between web volume fraction and pore size is clear – the higher the web volume fraction means the lower the average pore diameter, due to the higher fibres consolidating in the web-volume unit. The relationship between web volume fraction and pore surface area is unclear. The reason may lie in the different pore-sizes and numbers of pores within the nonwoven samples, made from finer fibres than the coarser ones. By a comparison of nonwoven fabrics with similar web volume fractions and different fibres finenesses, it can be concluded that nonwoven fabrics made from finer fibres have lower average pore diameters and higher pore surface areas. With similar web volume fractions, several finer fibres were present in the volume unit of the web, resulting in lower distances between them and a higher number of pores, consequently, the pore diameter was lower whilst the specific surface area was bigger.

Fibre Fineness, Web Mass Per Unit Area and Thickness vs. Porous Properties

By a developing a web construction plan, an engineer should set the basic web construction parameters in advance. These include the fibre type, fineness, length, mixture content; web mass per unit area and thickness, as well as certain technological parameters, depending on the web-forming, bonding and finishing. In our case the technological parameters were taken as constant, because the samples went through the same technological phases and conditions. When the fibre fineness, web mass per unit area and thickness are defined, the porous structure was defined as well, and this is the reason why the mentioned construction parameters for the nonwoven fabric were taken as input parameters for predictive modelling.

It can be concluded from the predictive models, that a higher fabric mass per unit area means lower pore volume, volume porosity, mean pore diameter, as well as a lower pore surface area at the same web thickness and fibre fineness, due to more textile material being in the web volume unit, thus reducing the void space as well as the pore size within the web. Pores with lower average diameters also have lower pore surface areas. Higher fabric thickness means higher pore volume, volume porosity, average pore diameter and pore surface area at the same fabric mass per unit area and fibre fineness, due to a higher web bulk, e.g. the web volume unit contains less textile material and more pores. The comparison between nonwovens having the same mass per unit area and thickness (e.g. the same web density) but are differentiated regarding fibre fineness is nonsense whilst, in practice, coarser fibres are used for nonwovens with higher mass per unit area, as well as higher thickness, and finer fibres are used for lower mass per unit area and thickness. In other words, it is impossible to achieve the same mass per unit area and thickness with 2 dtex or 6 dtex of fibre fineness.

Porous Properties Predictive Modelling

Instead of knowing the individual influences of construction parameters on nonwoven porous properties, the most valuable information regarding a new product's development is how to combine basic construction parameters, such as fibre fineness, web mass per unit area and web thickness, in order to reach the desired porous properties. The proposed predictive models provide nonwoven fabric constructors with guidelines when developing nonwoven fabrics with the desired porous properties. The results show that the predicted values for porous properties, calculated using equations (9)-(12), are in good agreement with the experimental ones. The mean predicted error is: 5.9 % (from 0.0 % to 29.7 %) for the specific pore volume, 1.1 % (from 0.0 % to 4.4 %) for the volume porosity, 1.9 % (from 0.0 % to 12.4 %) for the average pore diameter, and 8.2% (from 0.1 % to 31.3 %) for the specific surface area. The correlation coefficients between the predicted and experimental values are 0.90, 0.95, 0.92, and 0.71 for pore volume, volume porosity, pore diameter, and pore surface area, respectively. Scatter plots of the experimental and predicted values for porous properties, are depicted in Figure 5. Using genetic algorithms, we were able to predict the porous properties of nonwoven fabrics precisely enough.

The models are based on an intrusion porosimetry technique and the following assumptions were considered: 1. nonwoven samples are pressure stable, 2. webs are considered to have no blind pores, 3. pores are circular cylinders. The boundary limits for the validity of the models are as follows: 1. the minimal values for fibre fineness and web density are

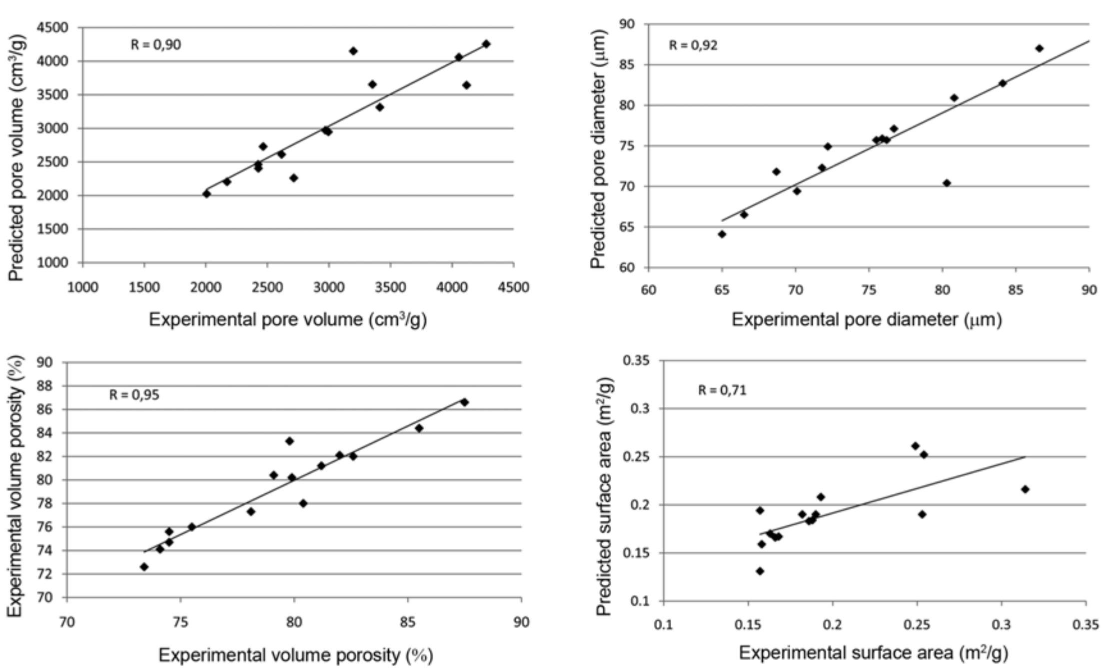

Figure 5. Scatter plots of experimental and predicted porous properties using GA models.

2 dtex and 0.119 g/cm^3, respectively, 2. the maximal values for fibre fineness and web density are 6 dtex and 0.278 g/cm^3, respectively.

We are aware of that the proposed models refer to selected nonwoven samples and the method of porosity measurements, but we believe that, due to several factors having an effect on porous structure, it is impossible to develop common models that would be valid for all types of nonwoven fabrics and all types of measurement techniques. The purpose of this study was to show that, for a textile engineer, the non-deterministic modelling tool is a useful tool, and that each nonwoven producer can create their own data base of different kinds of nonwovens using genetic algorithms.

The benefit of the proposed models is also the possibility of further investigating the influence of porous structure on some end-use properties for cleaning wipes, and to optimize porous structure to fit the desired end-use property. In this way, knowledge about the relationship between porous structure and some of the important end-use properties of wipes like water absorption, velocity of the soaking water, abrasion resistance etc. could be extended, and will be the subject of further research.

Conclusion

Nonwoven fabrics have very different porous structures as a result of their construction parameters' combinations, as well as the types of web-forming, bonding, and finishing methods. Nonwovens made from staple fibres have, in regard to woven and knitted fabrics, a lesser exactly determined inner geometrical model of a porous structure, in the form of a tube-like system. Besides the open pores, they also contain blind and closed pores. Therefore, it is inappropriate to predict their porous parameters on the basis of a geometrical model, as this is suitable for woven fabrics. Whilst porous structure has a great effect on several end-use properties, knowledge is needed as to how to combine construction parameters in order to reach the desired porosity. This research focused on the prediction of porous properties regarding nonwoven wipes, on the basis of construction parameters (fibre fineness, fabric mass per unit area and thickness) and mercury intrusion porosimetry, by using a genetic algorithm. The predictive models of the pore volume, volume porosity, pore surface area, and pore average diameter for one type of nonwoven fabrics, e.g. a raw nonwoven web made from polyester/viscose staple fibres, were created. The proposed models were created very precisely and could serve as guidelines for nonwoven fabric engineering in order to develop wipes with the desired porous properties.

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