POROSITY IN TEXTILE MATERIALS

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Abstract: *This paper is focused on the flat fabric textiles (woven and nonwoven fabrics) and their porous structures and parameters as the "key" properties for their different applications. In the experimental part, the results of several researches regarding the modelling of porous parameters of woven and nonwoven fabrics are presented using different modelling tools. Results show, that modern, non-deterministic modelling tool, e.g. genetic programming, is a useful and more precise modelling tool to predict porous properties of flat textiles in comparison with deterministic ones (geometrical model, statistical model) and can serve as a useful tool by a new product development.*

Keywords: *porosity structure, fabric construction parameters, porosity parameters modelling*

1. Introduction

Fabrics are porous materials having different porous structures as the consequence of different manufacturing techniques needed to interlace the fundamental building elements, e.g. fibres, yarns or layers, into fibrous assembly. Fabric porosity is the parameter which also describes the fabric construction and has an effect on fabric performance, e.g. comfort, aesthetic appeal, care and maintenance, and health/safety/protection, as well as durability. Through the porosity structure (as well as fibrous material), fabrics namely allow the transmission of energy and substances, and are therefore interesting materials for different applications (generally for clothing, interior and wide range of technical applications). Fabric as porous barrier between the human bodies an environment should support heat and water vapour exchange between the body and environment in order to keep the body temperature within the homeostasis range. Besides thermo-physiological comfort, fabrics also play an important role by heat protection due to the flames or convection heat, contact heat, radiant heat as well as due to the sparks and drops of molten metal, hot gases and vapours [1]. Fabrics protect users against micro-organisms, pesticides, chemicals, hazardous particles and radiations (radioactive particles, micro-meteorites, X-rays, micro-waves, UV radiation, etc.). They act very important role also by environmental protection as filters for air and water filtrations, sound absorption and isolation materials against noise pollution, adsorption materials for hazardous gas pollution, etc. [2, 3, 4]. By all mentioned applications dedicated to absorption, desorption, filtration, drainage, vapours transmission, etc., the essential constructional parameter that influences fabric efficiency to protect human or environment is porosity [4, 5].

Knowledge about the fabric's porous structure is, therefore, an important step when characterising fabrics, in order to predict their behaviour under different end-usage conditions regarding a product. Hence, if porosity is estimated or predicted then when developing a new product the desired porosity parameters can be set in advance on the basis of selecting those fabric constructional factors that have an effect on porosity and, in this way sample production trials could be reduced.

2. Definition of an ideal fabric porosity structure and porosity parameters

The fabric in a dry state is a two-phase media which consists of the fibrous material – solid component and void spaces containing air – gas (void) component. The porosity of a material is one of the physical properties of the material and describes the fraction of void space in the material. Mathematically, the porosity is defined as the ratio of the total void space volume to the total (or bulk) body volume [6]:

$$\varepsilon = \frac{V_v}{V} = \frac{V - V_s}{V} = 1 - \frac{V_s}{V} = 1 - \frac{m_s \rho_b}{\rho_s m_b} = 1 - \frac{\rho_b}{\rho_s} \qquad (1)$$

where, ε is the porosity expressed as coefficient, V_v is the volume of the total void space in cm^3, V_S is the volume of solid component in cm^3, V is the total or bulk body volume in cm^3, m_s is the mass of solid component in g, m_b is the mass of the body (or bulk mass) in g, ρ_b is the bulk density in g/cm^3, and ρ_s is the density of solid component in g/cm^3.

In this way exactly defined porosity of the material is useful parameter, only, when materials with the same porous structure are compared, and gives an indication which material possesses more void space in the bulk volume. It does not give any information about the porous structure of the material, so it is an insufficient parameter for describing fibre assembly characteristics [7]. From the theoretical point of view, the porosity parameters could be easily determined on the basis of an ideal geometrical model of the material porous structure. The simpler models consider that all pores, whatever their shape, are the same and regularly arranged in a fibre assembly [7].

The fundamental building elements of the material porous structure are pores (also capillaries, channels, holes, free volume), e.g. void spaces within the material which are separated between each other and could be classified [19, 20] according to: 1. the position in the material, 2. the pore width (the shortest pore diameter, 3. the fluid accessibility, 4. the pore shape, 5. the geometry of pore-cross section, and 6. the uniformity of pore cross-section over the pore length.

2.1 Woven Fabric's Ideal Geometric Model of Porous Structure

As fibrous materials, woven fabrics have, with regard to knitted fabrics or nonwovens, the most exactly determined an ideal geometrical model of a macro-porous structure in the form of a tube-like system, where each macropore has a cylindrical shape with a permanent cross-section over all its length (Figure 1). Because the warp density is usually greater than the weft density, the elliptical shape of the pore cross-section is used to represent the situation in Figure 1. Macropores are opened to the external surface and have similar cross-section area. They are separated by warp or weft yarns, and are uniformly distributed over the woven fabric area. The following porosity parameters can be calculated on the basis of the woven fabric primary (yarn fineness / diameter, warp / weft density) and secondary (fabric mass, thicknesses) constructional parameters and the ideal model of porous structure in the form of a tube-like system: 1. total porosity, 2. area of macro pore cross-section, 3. number of macropores in the area unit (pore density), 4. open porosity (open area), 5. equivalent, maximal, and minimal macropore-diameters, and 6. macroporosity.

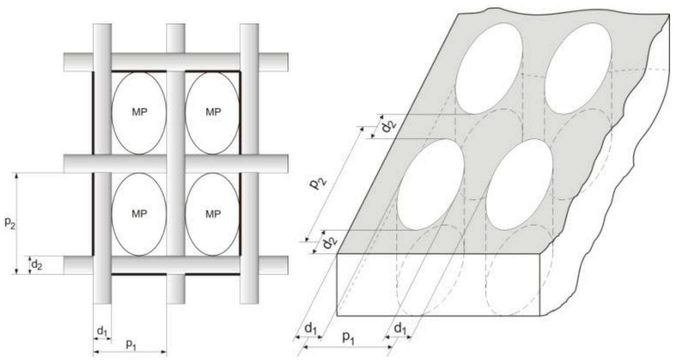

Figure 1: An ideal model of the porous structure of a woven fabric (d – yarn thickness, p – yarn spacing, MP - macropore; 1, 2 indicates warp and weft yarns, respectively)

2.2 Nonwoven Fabric's Ideal Geometric Model of Porous Structure

The ideal geometric model of porous structure in the form of tube-like system is partially acceptable only by those nonwovens which are thin and translucence, e.g. light polymer–laid nonwovens and some thin spun-laced or heat-bonded nonwovens (Figure 2). Such model is based on the assumptions that fibres having the same diameter are distributed only in the direction of fabric plane and the distance between fibres and the length of individual fibres is much greater than the fibre diameter.

The following porosity parameters can be calculated on the basis of the nonwoven fabric constructional parameters (fibre fineness, fibre density, web mass per unit area, web thickness) and the ideal model of porous structure in the form of a tube-like system: 1. total porosity, 2. opening diameter, and 3. average area of pore cross-section.

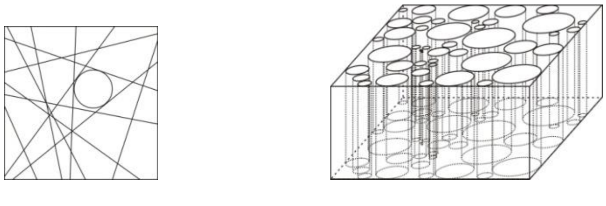

Figure 2: An ideal model of the porous structure of a nonwoven fabric (with detail to define opening diameter of pore by 2D presentation)

2.3 Modelling of Fabric's Porous Properties

Many attempts have been made to develop predictive models for fabric properties with different modelling tools. There are essentially two types of modelling tools: deterministic (mathematical models, empirical models, computer simulation models) and non-deterministic (models based on genetic methods, neural network models, models based on chaos theory and theory of soft logic), and each of them has its advantages and disadvantages [8].

3. Experimental Methods, Results and Discussion

3.1 Predictive Models of Woven Fabric Porous Parameters

Our experiment involved raw woven fabrics made from 100% cotton yarns. The cotton fabrics varied according to yarn fineness (14 tex, 25 tex, and 36 tex), weave type (plain, twill, satin), and fabric relative density (tightness) (55% - 65%, 65% - 75%, 75% - 85%). We used an optical method to measure porosity parameters of woven fabrics, since it is the most accurate technique for macro-pores with diameters of more than 10 μm. For each fabric specimen, between 50 and 100 macro-pores were observed using a Nikon SMZ-2T computer-aided stereomicroscope with special software. Following macro-porosity parameters were measured: area of macro-pore cross-section, pore density, and equivalent macro-pore diameter. To predict porous parameters two modelling tools was used, e.g. deterministic (a three-factor analysis) and non-deterministic modelling tool (genetic programming). The developed models of porous properties can be seen in references 9 and 10. Here, Figure 3 presents a comparison between experimental values, theoretical values (rectangular shape of macropores), and values, calculated on the basis of genetic programing (GP) and a three-factor analysis (FA) for equivalent macropore diameter only.

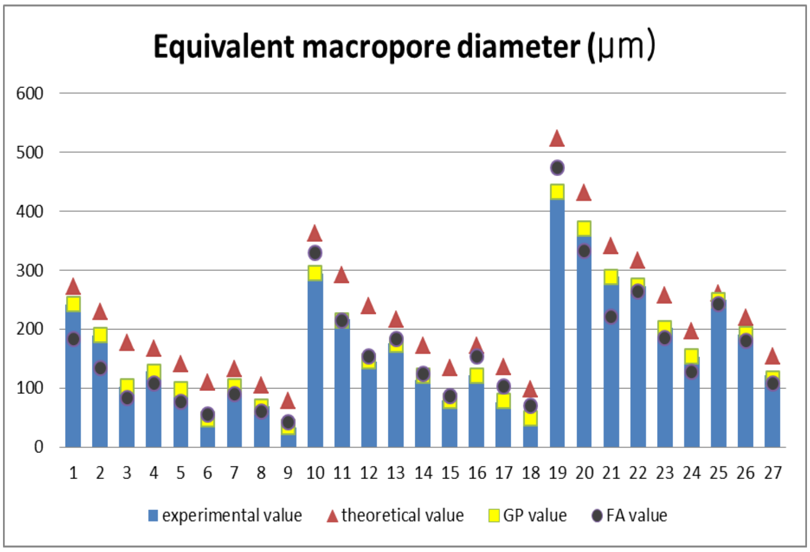

Figure 3: Comparison between experimental, theoretical, GA and FA values of the equivalent macropore diameter of tested woven fabrics

The average error was 43,7 % regarding theoretical values, 15,4 regarding the values calculated upon the models developed using a three-factor analysis, and 0,7 % regarding the values calculated upon GA predictive models.

3.2 Predictive Models of Nonwoven Fabric Porous Parameters

For the porous properties prediction models, the nonwoven fabric samples were limited to one type of nonwoven fabrics – those needle-punched nonwoven fabrics made from a mixture of polyester and viscose staple fibres having different fibre fineness (T), web mass per unit area (m) and web thickness (t). The porosity parameters of the nonwoven fabric samples were measured using the Pascal 140 computer aided mercury intrusion porosimeter, which measures pores' diameters between 3.8 - 120 µm, and operates under low pressure. Following porous parameters were measured: specific pore volume, total porosity, average pore diameter, and pore surface area. The predictive models of porous parameters were developed using non-deterministic modelling tool, e.g. genetic algorithms - GA (see reference 11). Figure 4 presents the experimental results of pore diameter measurements, predictive values calculated using GA and theoretical values of pore diameter. The average error was 19,7 regarding theoretical values of pore diameter and 1,9 % regarding GA values.

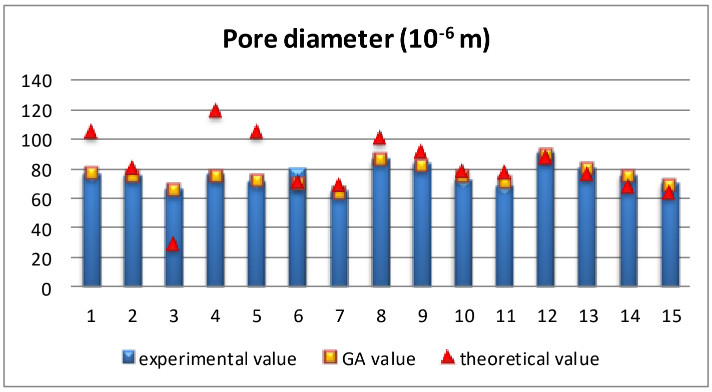

Figure 4: Comparison between experimental, theoretical, GA and FA values of the equivalent macropore diameter of tested woven fabrics

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