INITIAL STUDY OF STRUCTURE OF NANOFIBER TEXTILES AND THE CREATION OF ITS MODEL

HAVRLÍK Michal[1], SVESHNIKOV Alexey[1,2]

[1]*CTU - Czech Technical University in Prague, Prague, Czech Republic, EU*
[2]*Institute of Physics, CAS, Prague, Czech Republic, EU*

Abstract

Today, many scientists study properties of nanofiber textiles. These properties are determined by the unique structure of nanotextiles and, therefore, it is necessary to know exactly how the structure of the fabric looks like. Nowadays, a few models are used, but they are inaccurate. The lack of an appropriate model of nanofiber textile was the main motivation of this research.

For our study we have chosen nanotextiles made of two polymers: PVDF (polyvinylidene fluoride) and PUR (polyurethane). The nanotextiles were produced at Czech Technical University in Liberec by NS 4S1000U device using Nanospider technology.

In this research, the structure of the fabrics was analyzed using an electron scanning microscope Tescan Maia 3. Two sets of the experiments have been carried out. In the first experiment the surface structure of the samples was studied. Photos created by SEM were analyzed using program Atlas and image editor GIMP. In this set of the experiments the initial parameters for the creation of a digital 2D model of a single layer have been determined (fiber size distribution, pore size and curvature of the fibers). In the second set of the experiments cross sections of nanofiber textiles were made in order to study the inner structure of the fabric. This information allows evaluation of the total number of 2D layers in the model and, thus, is very important for future creation of a 3D model of the fabric.

Keywords: Polymer, SEM photography

1. INTRODUCTION

In today's world, new composite materials with unique properties find a constantly growing range of applications. Nanotextiles are one of the relatively young materials. They are nonwoven fabrics which are usually manufactured using electrospinning method [1]. Recently, a great interest for the integration of nanofiber textiles in many branches of industry and scientific disciplines has been shown. For example, nanotextiles have found an application in medicine or engineering. In some cases, they are used as protection against biological pests [2]. Applications of a fabric mainly depend on its properties and properties greatly depend on the nanotextile structure. Today, the structure of the fabric is mainly studied by electron scanning microscope (SEM) because the fabric is composed from very fine fibers. Their diameter lies between 50 and 1000 nm [3]. There are numerous publications which describe the basic parameters of the surface of the fabric, such as the radii of the fibers, their orientation or size of the pores between the fibers [1]. In order to predict the properties of the textile, it is necessary to know the structure of the surface, but the inner structure of the textile is even more important. There exist a few studies that try to describe the inner structure or to construct its numerical model [4,5]. However, these studies are still at the beginning and therefore they are not sufficient. Another issue not addressed by existing models is the interconnection of individual layers in the 3D model.

The main goal of this paper is an analysis of the structure of nanofiber textiles, especially the comparison of the inner structure with the surface structure. In this study the basic parameters of the fabric are determined and on the basis of this information the exact number of layers in the fabric is calculated. This information is crucial for the future establishment of an accurate digital 3D model of the nanotextile.

2. MATERIALS AND METHODS

In this work we used nanofiber textiles produced at Czech Technical University in Liberec on NS 4S1000U device using Nanospider technology. We have chosen two types of polymers for the production of textiles. The first one was PVDF (polyvinylidene fluoride) and the second one was PUR (polyurethane). These polymers have been chosen based on their properties and applicability for civil engineering. PVDF shows good resistance to acids and halogens. PUR is commonly used in constructions, mainly as insulating foams and sealants gels. Parameters of the technological process of the fabrics production are shown in **Table 1**.

Table 1 Parameters of the fabrics production

Polymer	Speed of motion [mm · min^{-1}]	The distance between the electrodes [mm]	Voltage [kV]	Width of electrodes [mm]	Ambient temperature [°C]	Ambient humidity[%]
PVDF	10, 50	177	35	0.6	24	55
PUR	10, 50	175	40	0.6	23	40

3. RESULTS

In the first phase of the experiment we have determined the weight per square meter, so called grammage of the fabrics. Individual samples were cut into rectangular shapes with approximate size of 10 x 10 cm. These samples were weighted with accuracy of tenth of milligrams. Afterwards the samples were scanned and their area was measured using an image editor GIMP 2. For each fabric several samples have been analyzed by this method in order to get higher statistical accuracy. The weight per square meter was determined by a gravimetric method using the formula

$$m_s = \frac{m}{s}, \tag{1}$$

where *m* stands for the mass of sample and *s* is the area of the sample. The obtained results are summarized in **Table 2**.

Table 2 Weight per square meter of the used nanotextiles

Polymer	Weight of the sample* [g]	Area of the sample* [m^2]	Weight per square meter* [g · m^{-2}]
PVDF 10	0.227	0.00702	32.34
PVDF 50	0.065	0.00877	7.45
PUR 10	0.096	0.00775	12.39
PUR 50	0.007	0.00734	0.97

*Average value

In the next phase of our research, the surface of fabrics was analyzed using SEM. We have determined fiber diameters, their orientation with respect to the direction of movement of the substrate, and the size of the pores between the fibers. Subsequently, we studied the inner structure of the textiles. In order to do this we made a cut through the fabric and analyzed it in microscope. Several methods of producing a cut have been tried, including scissors and breaking the sample in liquid nitrogen. The best results were achieved with a simple razor blade. Razor blade created a precise edge through the fabric which enabled clear observation of the inner structure. We measured the thickness of the textile and analyzed its inner morphology. Comparison of the photographs of the surface structure of a sample with the structure of its cut shows, that these structures are very similar (see **Fig. 1).** This is a key information for the preparation of a numerical model for simulations.

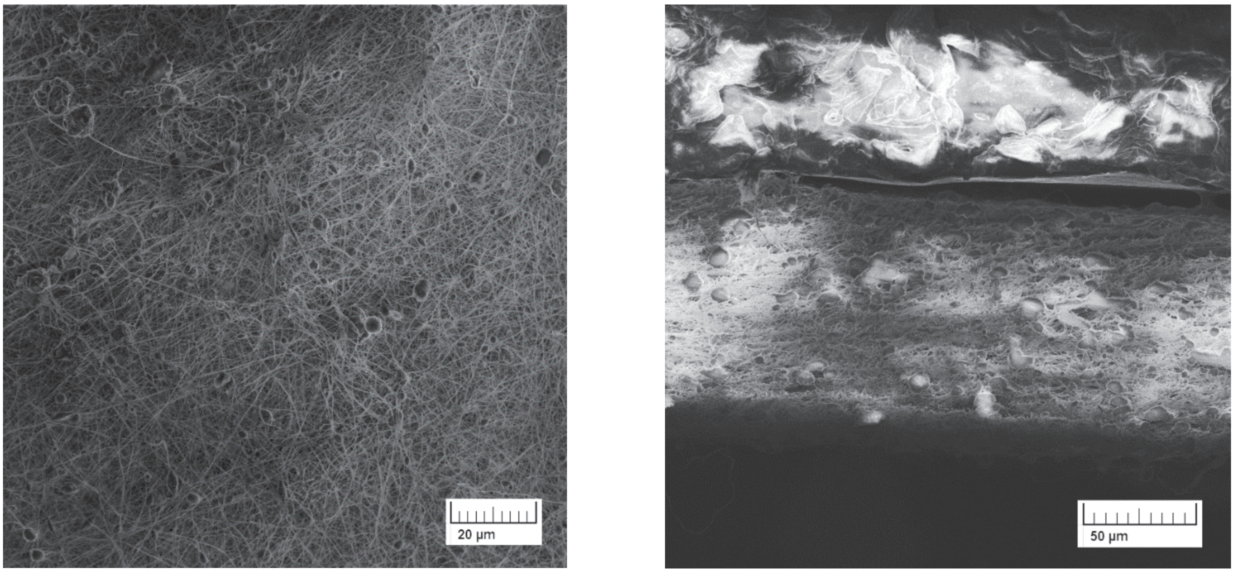

Fig. 1 Comparison of surface structure (left) with cross-cut structure (right) for PVDF 10 sample

The usually used model of nanotextile is a multilayer structure, where 2D-layers are separated by gaps [4, 5] (see **Fig. 2**). Consequently, it is important to determine the structure of each layer and the thickness of the gap. Unfortunately, because SEM pictures are not clear enough it is difficult to determine which fibers lie in the first layer, closest to the viewer. This fact significantly complicates the reconstruction of the morphology of the first layer of the textile. However, as mentioned above, the surface structure of the nanotextile is very similar to the structure of the cross-cut. Using this fact we derived a formula, which expresses the area *S* occupied by each layer:

$$S = S_{tot}\sqrt{\frac{G}{\rho * D}}, \tag{2}$$

here Stot stands for the total surface area of the sample, G is the weight per square meter (grammage), ρ is the density of polymer, and D is the thickness of the cut. This information is very useful in determination of the structure of 2D-layers. One can take a SEM photo of the nanotextile and start to emphasize fibers with red color until he reaches the area predicted by formula (2) (see **Fig. 3**). It is also possible to calculate the number of layers:

$$n = \frac{G}{\frac{S}{S_{tot}} * d * \rho}, \tag{3}$$

where *d* is the thickness of the layer without the imaginary gap (see **Fig. 2**).

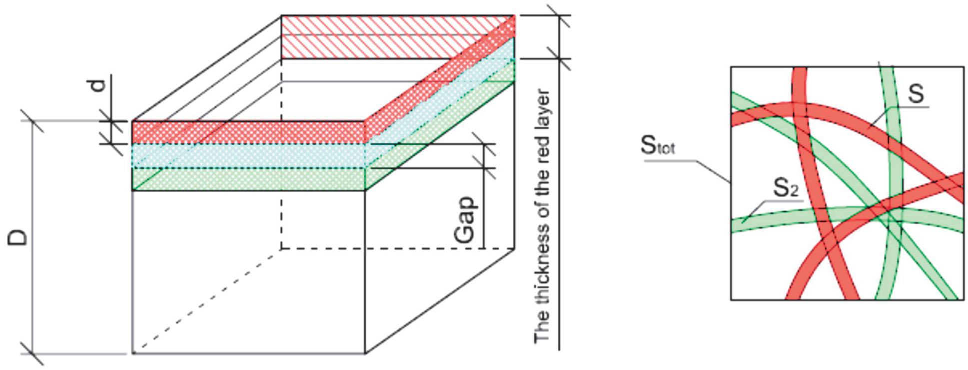

Fig. 2 On the left side: the multi-layered structure of the nanotextile. On the right side: graphical separation of the first layer (red) from the surface structure visible on SEM photographs. Green fibers belong to underlying layers

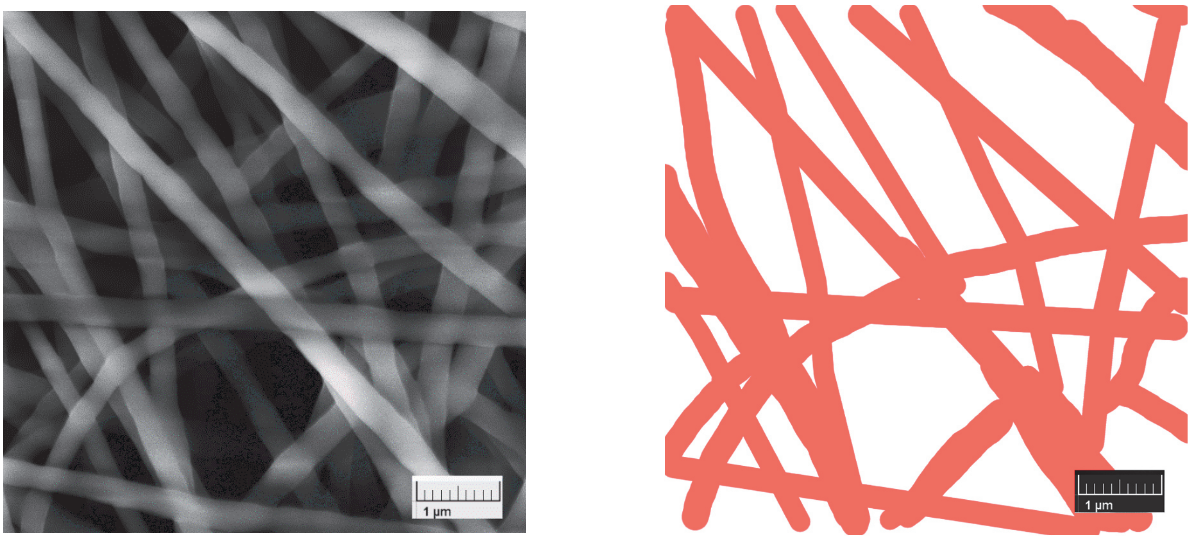

Fig. 3 The colored first layer of nanofiber textile PUR 10

This calculation was performed for all four types of fabrics and the results are presented in **Table 3**.

Table 3 Structural parameters of nanotextiles.

Sample	Thickness of the cut [um]	Diameter of fibers [um]	Number of layers	Thickness of each layer [um]
PUR 10	47.425	0.442	49	0.970
PUR 50	8.047	0.325	8	1.050
PVDF 10	136.900	0.197	252	0.542
PVDF 50	84.28	0.325	69	1.985

4. CONCLUSION

Properties of nanotextiles depend significantly on their structure. In this work we take the first steps to construction of numerical model of this structure. We compare the surface morphology with the inner structure and find them very similar. Using this information we develop a method allowing to calculate the number of layers in the textile. We also derive a formula, which is very important for determination of the structure of each layer - it shows how many fibers should be included into the first layer. Without this information it is not clear which fibers correspond to the first layer, because SEM photos do not provide information about the depth of visible elements and the fibers are intertwined in a very complex way. In the future, this information will be used to create a complete 3D model of the nanotextile structure. Such model is crucial for any successful simulation of its physical, chemical and biological properties.

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REFERENCES

[1] ANDRADY A. L. Science and Technology of Polymer Nanofibers. John Wiley & Sons, New Jersey, 2008.

[2] HAVRLIK M., RYPAROVÁ P. Protection of Wooden Materials Against Biological attack by Using Nanotechnology, Acta Polytech., Vol. 55, No. 2, 2015, pp. 101-108.

[3] HUANG Z.-M., ZHANG Y.-Z., KOTAKI M., RAMAKRISHNA S. A Review on Polymer Nanofibers by Electrospinning and their Applications in Nanocomposites. Compos. Sci. Technol., Vol. 63, No. 15, 2003, pp. 2223-2253.

[4] SAMBAER W., ZATLOUKAL M., KIMMER D. 3D Modeling of Filtration Process via Polyurethane Nanofiber Based Nonwoven Filters Prepared by Electrospinning Process. Chem. Eng. Sci., Vol. 66, No. 4, 2011, pp. 613-623.

[5] SAMBAER W., ZATLOUKAL M., KIMMER D. “The Use of Novel Digital Image Analysis Technique and Rheological Tools to Characterize Nanofiber Nonwovens. Polym. Test., Vol. 29, No. 1, 2010, pp. 82-94.

[6] HASTRUP A. C. S., GREEN III F., CLAUSEN C. A., JENSEN B. Tolerance of Serpula Lacrymans to Copper-based Wood Preservatives. Int. Biodeterior. Biodegrad, Vol. 56, No. 3, 2005, pp. 173-177.