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

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Abstract

Today, many scientists deal with the research of properties of nanofiber textiles. Properties of textiles depend on their unique structure and therefore it is necessary to know how exactly structure of the fabric looks like. Nowadays, there are a few macroscopic models, but they are inaccurate. It 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 fabrics were mapped in two ways using an electron scanning microscope Tescan Maia 3. In the first experiment the surface structure of the samples was analysed. Photos created by SEM were analysed using program Atlas and a bitmap graphics editor GIMP 2. Here we determined the initial parameters for the creating a digital 2D model of a single layer (fibre distribution, the radius of the fibre, pore size and curvature of the fibres). In the second experiment cross sections of nanofiber textiles were made and from it the inner structure was determined. The cross section looks almost exactly like the surface of the textile. Finally, we calculated the total number of 2D layers from the whole thickness of sample and it is a key piece of information for future creating a 3D model of the fabric.

Keywords: Polymer, SEM photography.

1. INTRODUCTION

In today's world, invention of new composite materials with unique properties constantly grows. Nanotextiles are one of the relatively young materials. They are a nonwoven fabric which is manufactured using electrospinning method [1]. Recently, there is a great interest for the integration of nanofiber textiles in many branches of industry and scientific disciplines. Nanotextiles have found an application in many fields, for example, in medicine or engineering. In some cases, they are used as protection against biological pests [2]. Application of fabric mainly depends on their properties and properties greatly depend on the nanofiber 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]. In many literatures are described the basic parameters of the surface of the fabric, such as the radii of the fibres, fibres orientation or size of the pores between the fibers [1]. For a better understanding of behaviour of textiles is important to know how the structure of surface looks like, but the inner structure of the textile is even more important. Today, there exist a few studies that try to describe the inner structure or to construct a model using computer software [4, 5]. However, these studies are still at the beginning and therefore they are not sufficient. Another issue is the interconnection of individual layers or their interaction as a whole in the 3D model.

The main aim of this work is a mapping the structure of nanofiber textiles, especially compare the inner structure with 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 from which the fabric is made are calculated. This information is critical for the future establishment of an accurate digital 3D model of the general fabric.

2. MATHERIALS AND METHODOLOGY

In this work we used nanofiber textiles that were produced at Czech Technical University in Liberec. The fabrics were produced by using NS 4S1000U device using Nanospider technology. Two types of polymers were used 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 in civil engineering. PVDF shows good resistance against strong acids and halogens. PUR is a frequently occurring polymer in construction. It is used mainly as insulating foams and sealants gels. Parameters of fabrics production are shown in **Tab. 1**.

Table 1 Parameters of 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, before the fabrics were analysed by SEM, it was necessary to determine the weight per square meter. Individual samples were cut into rectangular shape with size about 10 x 10 cm. These samples were weighted with accuracy of tenth of milligrams. Afterwards the samples were scanned and the size of their area was measured using a graphics program GIMP 2. This method was repeated several times for more accurate statistical results. The weight per square meter was determined by a gravimetric method using this formula:

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

where *m* is the mass of sample and *s* is the area of the sample.

Table 2 Resulting weight per square meter

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 the research, the fabrics were mapped using SEM. Photographs of nanotextiles were analysed using software ATLAS and GIMP 2. There were determined fiber diameters, fiber orientation respect to the direction of movement of the substrate and the size of the pores between the fibres. In this phase of the experiment only the surface of the fabric was mapped. Subsequently, the cut was made through the fabric by a razor blade. Razor blade created a precise edge through fabric which enabled clear observation of the inner structure. We measured the thickness of textile and analysed its inner morphology. If we compare the photographs of the surface structure with the structure of the cut (see **Fig. 1)**, we can state that their structures are very similar. This is a key information for further preparation of model for numerical simulations.

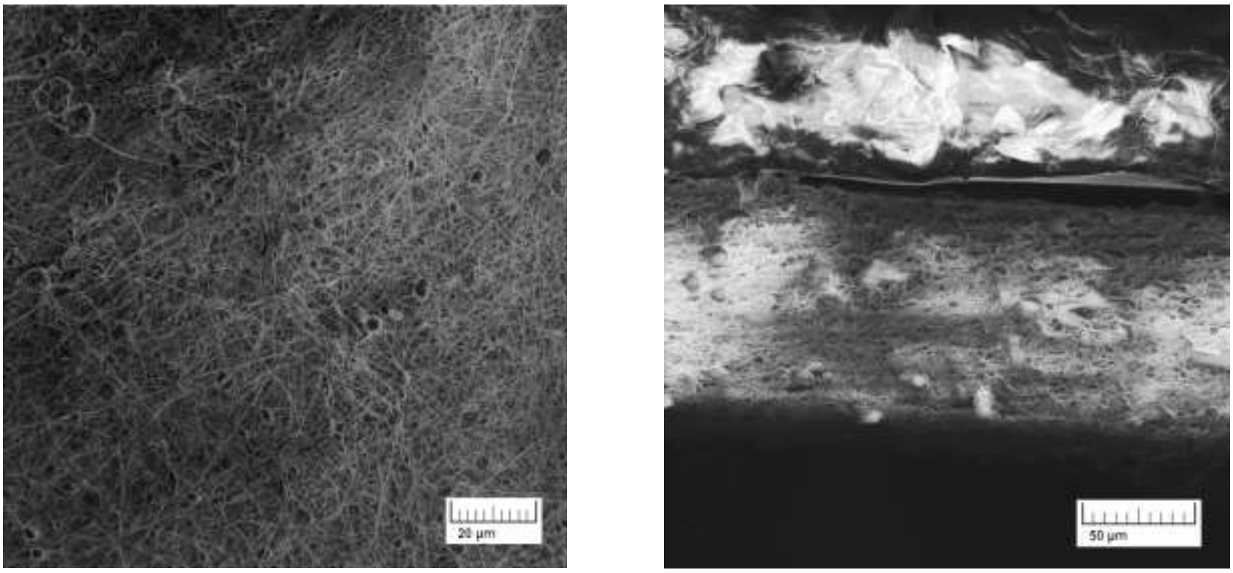

Fig. 1 Comparison of surface structure (left) with cross-cut structure (right). Sample identification is PVDF 10.

The standard 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. Because SEM pictures are not clear enough we do not know for sure which fibers lie in the first layer, closest to the viewer. As mentioned above, the planar structure of the nanotextile is very similar to the structure of a 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 S_{tot} 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. We took a SEM photo of the nanotextile and emphasized fibers with red color until we reached the area predicted by formula (2) (see **Fig. 3**).

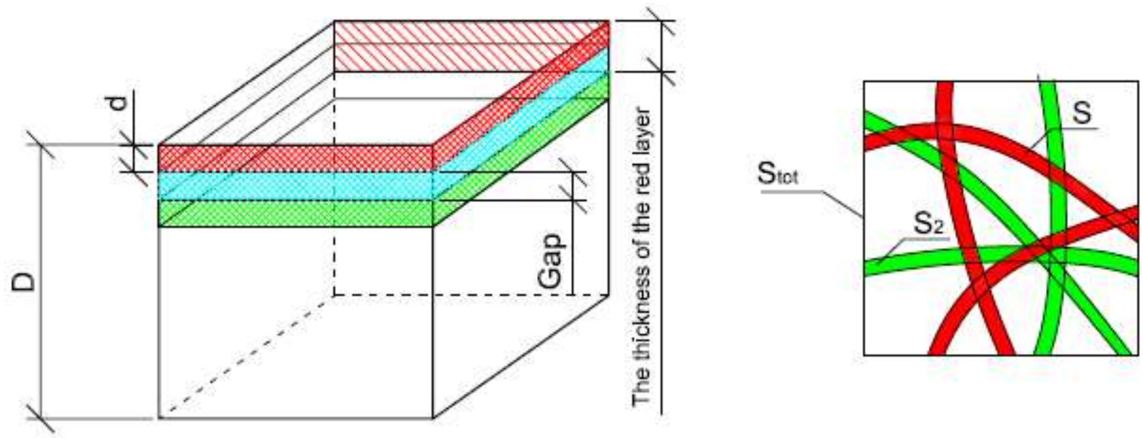

Fig. 2 On the left side: The model for calculation of number of layers in fabric. On the right side: Scheme of graphical separation of the first layer (red) from the surface structure of SEM photographs. Green fibers form the second layer.

It is also possible to calculate the number of layers:

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

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

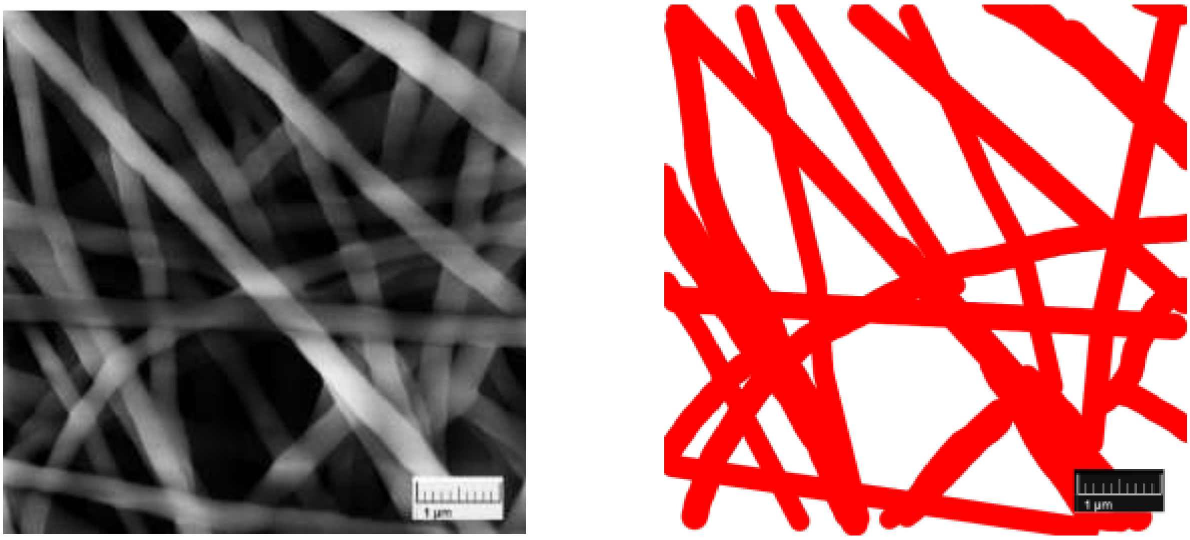

Fig. 3 Graphically coloured the first layer of nanofiber textile using GIMP 2.

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	Diameter of fibres [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 nanofibrous textiles 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 developed 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 are not very clear and also the fibers are intertwined in 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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