Review UDK 677.4.017.3
doi: 10.7251/COMEN1202148L

# POTENTIAL APPLICATIONS OF NONWOVEN POLYMER MATS – REVIEW

*P. Louda*[1,*], *M. Fijałkowski*[1], *Z. Rożek*[1], *T. Bakalova*[1]

[1]Technical University of Liberec, Faculty of Mechanical Engineering, Department of Material Science, Studentska 2, 461 17 Liberec, Czech Republic

**Abstract:** Nonwoven polymer mats with fibre diameters in the nanometer and micrometer range are distinguished for their high porosity with very small pore size, interconnectivity and controllable mesh thickness. These characteristics associated to the easy way to obtain the polymer nanofibres and a large surface area to volume ratio make the nonwoven fiber mats a suitable material for different applications, such as biosensor, electronic materials and filters. Polymer nanofibers mats are being considered for use in biomedical applications, including the production of artificial blood vessels, scaffolds for engineered tissues, wound dressings.

**Keywords:** electrospinning; nonwoven fiber mats.

## 1. INTRODUCTION

Nonwoven polymer mats can be produced by using techniques such as melt-blown [1] or the jet blowing [2]. However, the most common and most effective method for the production of this material is the technology of electrospinning. This technology was developed at the beginning of the 20th century [3]. It requires the use of a high voltage electrostatic field to generate an electrically charged stream of polymer solution or melt. In a typical process, high voltage is used between a grounded collector and a capillary tube. A droplet of a liquid polymer is brought to the tip of a capillary and upon voltage application the droplet forms a Taylor-cone. When the applied electric field overcomes the surface tension of the droplet, a charged jet of liquid is ejected from the tip of the cone. During the jet's travel, the solvent gradually evaporates, and a charged polymer fiber is left to accumulate on the grounded target. The fibers are deposited randomly on the electrode collector forming a nonwoven nanofiber mat. A lot of research centers have been working on the modification of this method, and one of them is Nanospider™ technology [4]. The scheme of the Nanospider™ system is shown in Figure 1.

The innovative idea of the Nanospider is based on the possibility of producing nanofibers from a thin layer of a liquid polymer. In this case Taylor cones (the source of nanofibers) are created on the surface of a rotating roller, immersed in a polymer solution. Since the Taylor streams are formed next to each other, throughout the entire length of the roller, the Nanospider™ technology is characterized by high productivity.

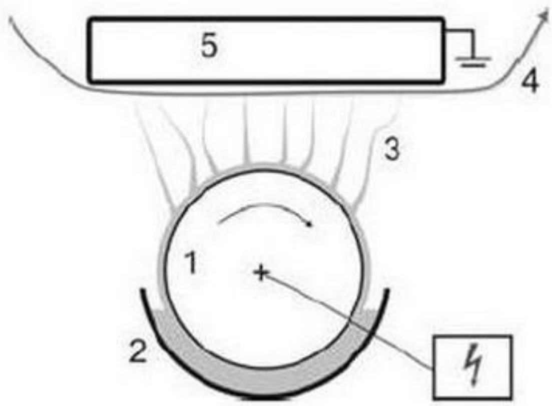


*Figure 1. The scheme of Nanospider™ system: 1- metal roller (positive electrode), 2- reservoir, 3- charged jet of liquid, 4 - polypropylene non-woven fabric, 5- electrode collector.*

The properties of the polymer nanofibers depend on the process parameters such as electric field, the distance between the electrodes, environmental conditions and the type of the polymer. The structural properties of nonwoven polymer mats include high porosity with very small pore size, interconnectivity and controllable mesh thickness. All these

* Corresponding author: petr.louda@tul.cz

properties, together with the large surface area to volume ratio, make the nonwoven fiber mats a suitable material for different applications, some of which will be described in this paper.

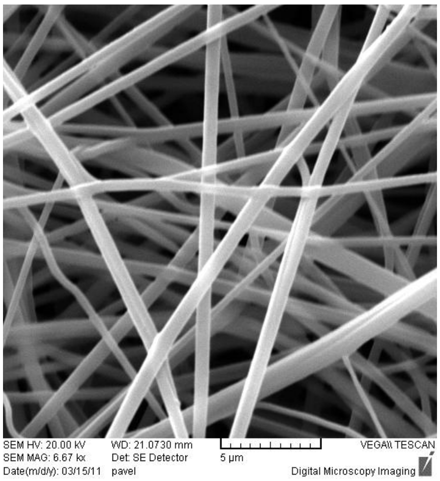


*Figure 2. SEM images of a nanofibers*

## 2. REGENERATION OF BONE TISSUE

One of the most important components of a bone are osteoblasts. These cells are responsible for bone growth and remodeling [5]. Studies on the possibility of osteoblasts proliferation on the nanofiber mats made from biodegradable polymers (poly(ε-caprolactone) (PCL), poly(glycolic acid) (PGA) poly(lactic-co-glycolic acid) (PLGA)) have been widely documented [6-8]. For bone tissue engineering, nanofibers based on natural polymers (collagen / PLGA, chitosan / poly(ethylene oxide) (PEO)) have been also studied [9, 10]. Other materials that can be used in this area are polymer/hydroxyapatite (HAp) nanocomposites e.g. chitozan/HAp PLGA/HAp [11,12]. The efficacy of silk nanofibers in filling bone defects has been also proven [13].

## 3. REGENERATION OF CARTILAGE TISSUE

The articulating surfaces of bones are covered by a dense connective tissue called cartilage. Chondrocyte cells are one of the main structural components of cartilage. They are responsible for the regeneration of cartilage tissues [14]. The main function of cartilage is the absorption of mechanical energy generated during the motion. Furthermore, cartilage provides uniform distribution of the load on the surface of the bones and a low-friction wear resistant surface [15]. Articular cartilage is unique since it has no nerve endings or blood supply. Therefore it has limited ability to reproduce itself. In this case, the use of polymer nanofiber mats appears to be a highly promising approach for repairing cartilage defects. The feasibility of using electrospun poly(3-hydroxybutyrate-*co*-3-hydroxyvalerate) (PHBV) nanofibrous mats to culture chondrocyte has been studied [16]. The results have shown that PHBV nanofibers support cell adhesion and cell growth. Collagen nanofiber mats were also used to culture chondrocyte cells. It was found that collagen nanofibers promoted cell proliferation and differentiation [15].

## 4. SKIN REGENERATION

The skin covers the entire outer surface of the body, and is the largest organ that separates the internal environment of the organism from external environment. Skin has unique abilities - it prevents moisture loss, regulates body temperature, prevents bacteria from entering the body and protects the body against harmful radiation. Skin can be damaged by burn, external wound, pressure ulcers, chronic ulcerations, etc. Some of those wounds can be very complex and very difficult to treat. Autografts and allografts are effective but their use is limited due to their limited availability and high cost. Regeneration and repair of skin is an intricate process where fibroblast cells play an important role [17]. Nanofiber mats from different types of polymers have been investigated in vitro with fibroblast cells. The studies have been performed by using natural polymers such as collagen [18], gelatin [19] and synthetic polymers such as PLGA [20], PCL [21]. The results showed that the electrospun nanofiber mats could support the attachment and proliferation of fibroblast cells.

## 5. CARDIOLOGICAL APPLICATIONS

In the case of vascular implants there are particular problems with grafts whose diameter is less than 6 mm. The blood flow through the implant of such a small diameter is relatively slow. This extends the contact time of blood platelets with the vessel wall, resulting in their activation, thus leading to clot formation, which in turn can lead to vessel occlusion [22]. Such reactions of the blood with artificial vessel blood are largely dictated by the absence of endothelial cells on their inner surface. These cells play an important role in maintaining the patency of blood vessels, inhibit the adhesion and activation of platelets [23].

The problem related to the colonization of polymeric nanofibers mats by endothelial cells has been discussed in many publications. Scientific studies have confirmed the development of endothelial cells on the surface of silk nanofibers mats [24]. Positive results were also obtained for nanofibers made from synthetic polymer polyethylene terephthalate (PET) [23] and nanofibers based on natural polymers collagen/elastin/PLGA [25]. In vivo studies on the use of an implant made from nanofibers PCL/collagen demonstrated the possibility of using this material in the implantation of blood vessels [26]. In this case an artificial graft was used to perform aorto-iliac span in the body of a rabbit.

## 6. FILTRATION

A variety of filtration systems are currently used in almost every area of human life. Filters based on polymer nanofibers have been used for purifying gases and liquids for more than 20 years [27]. They can be also employed in specific biomedical applications. Lee et al. have shown the possibility of using polyethersulfone (PES) and polysulfone (PS) nanofibrous mats in the process of blood dialysis [28].

The presence of microorganisms in the air is one of the reasons why there is a need to develop new filter materials. Electrospun nanofiber mats contribute to improving air filtration efficiency. It has been established, that polyacrylonitrile (PAN) nanofiber mats are extremely efficient in trapping NaCl particles smaller than 80 nm [29].

Nanofiber mats also form highly effective filters for water contaminants, including heavy metal ions such as chromium, cadmium, arsenic, copper. Heavy metal ions can cause nausea, dizziness, lack of muscle coordination, allergic reactions. In addition, these metal ions can lead to lung failure and liver damage [30]. It has been confirmed that the electrospun wool keratose (WK)/silk fibroin (SF) nanofiber mats exhibit an excellent performance as a heavy metal ions adsorbent [31].

## 7. SENSORS

Currently, sensors are commonly used for detecting hazardous chemicals and controlling industrial processes. They are an important tool in medical diagnostics as well. The primary function of sensors is detection. Therefore they should possess high sensitivity, selectivity and fast response time. These parameters largely depend on the properties of the sensor material. To obtain adequate sensitivity and response time, a porous structure with large surface area is required [32]. Polymer nanofibers completely correspond to this requirement. The possibility of their use in gas sensors is subject of much research work. In this case nanofibers made of PAN have been studied [146].

## 8. CONCLUSION

Currently, the use of nanometric materials in all fields of our life is growing exponentially. This naturally brings new technological and scientific challenges, most of which are related to the protection of our health and sometimes our life. Recently, the electrospinning has been recognized as an efficient method for the production of polymer nanofiber mats. This material is able to support the attachment and proliferation of a variety of cell types. Hence, polymer nanofibers are being considered for use as scaffolds for tissue engineering. Polymer nanofiber mats have a low basis weight, a small fiber diameter and pore size and a large surface area. These qualities make their application in filtration, cardiology and sensing very successful.

## 9. ACKNOWLEDGEMENTS

This article was written under the project ME10145.

## 10. REFERENCES

[1] J. H. Beard, R. L. Shambaugh, B. R. Shambaugh, D. W. Schmidtke, *On-line Measurement of Fiber Motion During Melt Blowing*, Industrial & Engineering Chemistry Research Vol. 46 (2007) 7340−7352.

[2] S. Borkar, B. Gu, M. Dirmyer, R. Delicado, A. Sen, B. R. Jackson, J. V. Badding, *Polytetrafluoroethylene nano/microfibers by jet blowing*, Polymer 47 (2006) 8337−8343.

[3] D. R. Nisbet, A. E. Rodda, D. I. Finkelsteinb, M. K. Hornec, J. S. Forsythea, W. Shend, *Surface and bulk characterisation of electrospun membranes: Problems and improvements*, Colloids and Surfaces B: Biointerfaces 71 (2009) 1–12.

[4] O Jirsak, F Sanetrnik, D Lukas, V Kotek, L Martinova and J. Chaloupek, WO2005-024101 (2005), Czech. Pat.

[5] K. Park1, Y. M. Ju, J. S. Son, K.-D. Ahn, D. K. Han, *Surface modification of biodegradable electrospun nanofiber scaffolds and their interaction*

*with fibroblasts*, Journal of Biomaterials Science, Polymer Edition, Vol. 18 (2007) 369–382.

[6] W.-J. Li, R. Tuli, X. Huang, P. Laquerriere, R. S. Tuan, *Multilineage differentiation of human mesenchymal stem cells in a three-dimensional nanofibrous scaffold*, Biomaterials 26 (2005) 5158–5166.

[7] W. J. Li, J. A. Cooper Jr., R. L. Mauck, R. S. Tuan, *Fabrication and characterization of six electrospun poly(α-hydroxyester)-based fibrous scaffolds for tissue engineering applications*, Acta Biomaterialia, Vol. 2 (2006) 377–385.

[8] X. Xin, M. Hussain, J. J. Mao, *Continuing differentiation of human mesenchymal stem cells and induced chondrogenic and osteogenic lineages in electrospun PLGA nanofiber scaffold*, Biomaterials, Vol. 28 (2007) 316–325.

[9] K. Ma, C. K. Chan, S. Liao, W. Y. K. Hwang, Q. Feng, S. Ramakrishna, *Electrospun nanofiber scaffolds for rapid and rich capture of bone marrow-derived hematopoietic stem cells*, Biomaterials, Vol. 29 (2008) 2096−2103.

[10] N. Bhattarai, D. Edmondson, O. Veiseh, F. A. Matsen, M. Zhang, *Electrospun chitosan-based nanofibers and their cellular compatibility*, Biomaterials, Vol. 26 (2005) 6176–6184.

[11] Y. Zhang, J. R. Venugopal, A. El-Turki, S. Ramakrishna, B. Su, C. T. Lim, *Electrospun biomimetic nanocomposite nanofibers of hydroxyapatite/chitosan for bone tissue engineering*, Biomaterials, Vol. 29 (2008) 4314–4322.

[12] M. V. Jose, V. Thomas, K. T. Johnson, D. R. Dean, E. Nyairo, *Aligned PLGA/HA nanofibrous nanocomposite scaffolds for bone tissue engineering*, Acta Biomaterialia, Vol. 5 (2009) 305–315.

[13] K.H. Kim, L. Jeong, H. N. Park, S. Y. Shin, W. H. Park, S. C. Lee, T. I. Kim et al., *Biological efficacy of silk fibroin nanofiber membranes for guided bone regeneration*, Journal of Biotechnology, Vol. 120 (2005) 327–339.

[14] R. Wilson, J. M. Whitelock, J. F. Bateman: *Proteomics makes progress in cartilage and arthritis research*, Matrix Biology, Vol. 28 (2009) 121−128.

[15] S. Sell, C. Barnes, M. Smith, M. McClure, P. Madurantakam, J. Grant, M. McManus, G. Bowlin, *Review extracellular matrix regenerated: tissue engineering via electrospun biomimetic nanofibers*, Polymer International, Vol. 56 (2007) 1349–1360.

[16] O. H. Kwon, I. S. Lee, Y.-G. Ko, W. Meng, K. H. Jung, I. K. Kang, Y. Ito, *Electrospinning of microbial polyester for cell culture*, Biomedical Materials, Vol. 2 (2007) 52–S58.

[17] Y. I. Ba, A. Kalén, O. Risto, O. Wahlström, *Fibroblast proliferation due to exposure to a platelet concentrate in vitro is pH dependent*, Wound Repair and Regeneration, Vol. 10 (2002) 336–340.

[18] H. M. Powell, D. M. Supp, S. T. Boyce, *Influence of electrospun collagen on wound contraction of engineered skin substitutes*, Biomaterials, Vol. 29 (2008) 834–843.

[19] Y.Z. Zhang, J. Venugopal, Z.-M. Huang, C.T. Lim, S. Ramakrishna, *Crosslinking of the electrospun gelatin nanofibers*, Polymer, Vol. 47 (2006) 2911−2917.

[20] X. Zhu, W. Cui, X. Li, Y. Jin: *Electrospun fibrous mats with high porosity as potential scaffolds for skin tissue engineering*, Biomacromolecules, Vol. 9 (2008) 1795–1801.

[21] Chen M, Patra P K, Warner S B, et al., *Role of fiber diameter in adhesion and proliferation of NIH 3T3 fibroblast on electrospun polycaprolactone scaffolds*, Tissue Engineering, Vol. 13 (2007) 579−587.

[22] A. Łukasiewicz, T. Drewa, S. Molski, *Postępy w inżynierii naczyń krwionośnych*, Polski Merkuriusz Lekarski, Vol. 138 (2007) 439− 442.

[23] Z. Ma, M. Kotaki, T. Yong, W. He, S. Ramakrishna: *Surface engineering of electrospun polyethylene terephthalate (PET) nanofibers towards development of a new material for blood vessel engineering*, Biomaterials, Vol. 26 (2005) 2527–2536.

[24] X. Zhang, C. B. Baughman, D. L. Kaplan: *In vitro evaluation of electrospun silk fibroin scaffolds for vascular cell growth*, Biomaterials, Vol. 29 (2008) 2217−2227.

[25] J. Stitzel, J. Liu, S. J. Lee, M. Komura, J. Berry, S. Soker i inni: *Controlled fabrication of a biological vascular substitute*, Biomaterials, Vol. 27 (2006) 1088–1094.

[26] B. W. Tillman, S. K. Yazdani, S. J. Lee, R. L. Geary, A. Atala, J. J. Yoo: *The in vivo stability of electrospun polycaprolactone-collagen scaffolds in vascular reconstruction*, Biomaterials, Vol. 30 (2009) 583–588.

[27] L. Li, M. W. Frey, T. B. Green: *Modification of air filter media with nylon-6 nanofibers*, Journal of Engineered Fibers and Fabric, Vol. 1 (2006) 1–22.

[28] K. H. Lee, D. J. Kim, B. G. Min, S. H. Lee: *Polymeric nanofiber web-based artificial renal microfluidic chip*, Biomed Microdevices, Vol. 9 (2007) 435–442.

[29] K. M. Yun, C. J. Hogan Jr., Y. Matsubayashi, M. Kawabe, F. Iskandar, K. Okuyama, *Nanoparticle filtration by electrospun polymer fibers*, Chemical Engineering Science, Vol. 62 (2007) 4751– 4759.

[30] M. Iqbal, A. Saeed, S. I. Zafar, *Hybrid biosorbent: an innovative matrix to enhance the biosorption of Cd(II) from aqueous solution*, Journal of Hazardous Materials, Vol. 148 (2007) 47−55.

[31] C. S. Ki, E. H. Gang, I. C. Um, Y. H. Park, *Nanofibrous membrane of wool keratose/silk fibroin blend for heavy metal ion adsorption*: Journal of Membrane Science, Vol. 302 (2007) 20–26.

[32] F. Jian, N. H. Tao, L. Tong, W, X. Gai, *Applications of electrospun nanofibers*, Chinese Science Bulletin, Vol. 53 (2008) 2265−2286.

[33] A. Z. Sadek, C. O. Baker, D. A. Powell, W. Wlodarski, R. B. Kaner, K. K. Zadeh, *Polyaniline Nanofiber based surface acoustic wave gas sensors—effect of nanofiber diameter on H2 response*, IEEE Sensors Journal, Vol. 7 (2007) 213−218.

ПОТЕНЦИЈАЛНЕ ПРИМЈЕНЕ НЕТКАНИХ ПОЛИМЕРНИХ МРЕЖА - ПРЕГЛЕД

**Сажетак:** Неткане полимерне мреже са пречником влакана у нанометарском и микрометарском опсегу издвајају се по својој високој порозности са веома малом величином пора, међусобном повезаности и дебљином мреже коју је могуће контролисати. Због ових карактеристика, повезаних са лаким начином добијања полимерних нановлакана и великог односа површине и запремине, неткане влакнасте мреже су погодан материјал за разне примјене, као што су биосензори, електронски материјали и филтери. Разматра се употреба мрежа од полимерних нановлакана у биомедицинске сврхе, укључујући производњу вјештачких крвних судова, потпорних матрица у инжењерингу ткива, и за завоје за ране.

**Кључне ријечи:** електроиспредање, неткане влакнасте мреже.