Needleless electrospun magnetic carbon nanofiber mats for sensor applications

Marah Trabelsi [1,2], Al Mamun [1], Michaela Klöcker [3] and Lilia Sabantina [1]

[1] *Bielefeld University of Applied Sciences, Department of Engineering and Mathematics, Interaktion 1, 33619, Bielefeld, Germany*

[2] *Ecole Nationale d'Ingénieurs de Sfax, Sfax 3038, Tunisia*

[3] *Bielefeld University of Applied Sciences, Department of Engineering and Mathematics, Interaktion 1, 33619, Bielefeld, Germany*

8th International Symposium on Sensor Science, I3S 2021, online, 17 – 28 May 2021.

Abstract

Magnetic nanofibers can be fabricated by adding nanoparticles in polymer solution using the electrospinning method. The advantages of such nanofibers include a large surface-to-volume ratio and high porosity, which makes them promising for sensing applications. In addition, carbonization of such nanofibers increases electrical conductivity. In this study, the chemical and morphological properties of magnetic nanofiber mats prepared from polyacrylonitrile (PAN)/magnetite and carbonized at 500 ° C, 600 ° C, 800 ° C and 1000 ° C. Resulting surface morphologies with some agglomerations are discussed. Addition of nanoparticles increased average fiber diameter and improved dimensional stability.

Introduction

Magnetic nanofibers are produced by introducing magnetic nanoparticles into a polymer solution using an electrospinning process, which is simple and cost-effective [1-2]. Due to their high surface-to-volume ratio and high porosity, nanofibers have excellent sensitivity and high sensing performance, which makes them attractive for sensing applications such as detection of various gases, strain sensors etc. [3-4]. The nanofiber mats produced by electrospinning are widely applied in filtration, separation, sensors, catalyst support, energy storage, in biomedicine, etc. This study deals with electrospun magnetic nanofiber mats of polyacrylonitrile (PAN) and magnetite nanoparticles using the low toxic solvent dimethyl sulfoxide (DMSO). The different nanofibers morphologies of the oxidatively stabilized and carbonized were investigated using AFM and SEM/EDS and discussed.

Materials and methods

The polymer spinning solution contains 14% polyacrylonitrile (X-PAN, Dralon, Dormagen, Germany) dissolved in DMSO (min 99. 9%, purchased from S3 chemicals, Bad Oeynhausen, Germany), 20% magnetic nanoparticles Fe_3O_4 (magnetite, 50-10 nm diameter, Merck KGaA, Darmstadt, Germany).

The polymer solution stirred for 2h on a magnetic stirrer and before electrospinning additionally in an ultrasonic bath for 40 min at 35 °C with a frequency of 37 kHz. Needleless electrospinning machine "Nanospider Lab" (Elmarco, Liberec, Czech Republic) was used.

Optical investigations were made with FlexAFM Axiom (Nanosurf, Liestal, Switzerland), confocal laser scanning microscope (CLSM) VK-8710 (Keyence), Zeiss 1450VPSE scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDS) was used for more detailed investigations. For Fourier-transform infrared (FTIR) spectroscopy, an Excalibur 3100 (Varian, Inc.) was used.

Results and discussions

Figure 1 shows AFM pictures of magnetite nanofiber mats, after electrospinning (1a), stabilization (1b) and carbonization (1c). After electrospinning the nanofibers are relatively straight but after oxidative stabilization at 280° C (1b) and carbonization at 600° C (1c), the nanofibers exhibit shortening and contraction. In addition, the diameter of the nanofibers decreases and the beads do not disappear and are still visible.

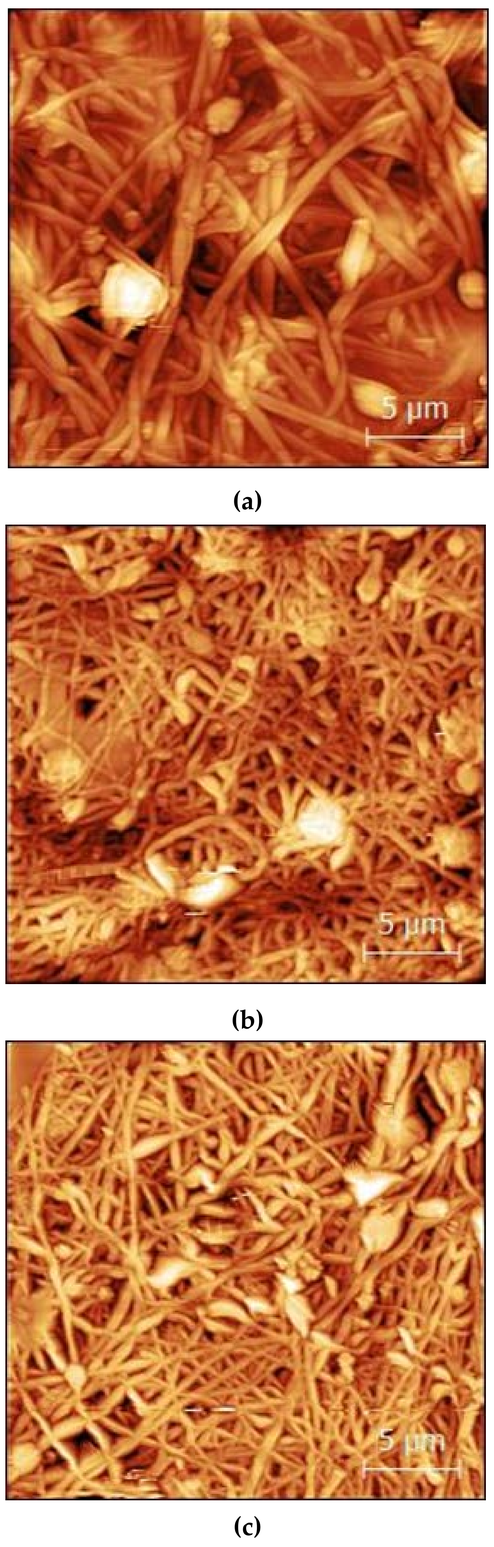

Fig 1. AFM images of (a) PAN/magnetite after electrospinning, (b) PAN/magnetite stabilized at 280° C and (c) PAN/magnetite carbonized at 600° C. The scale bars indicate 5 µm.

The PAN/magnetite nanofiber mats (605 ± 160) (fig. 2b) nm showed a larger average as well as a wider distribution of nanofiber diameters compared to pure PAN diameter (364 ± 82) nm (fig. 2a). This means that with the addition of magnetite, the nanofibers diameter has increased.

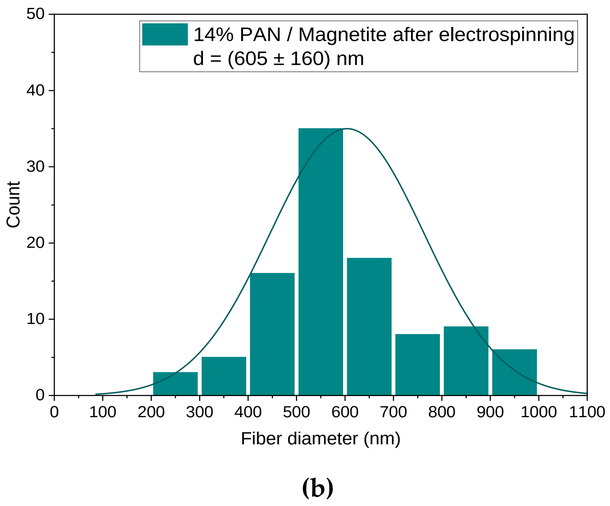

Fig. 2. Distributions of the fiber diameters of: (a) pure PAN; (b) PAN/magnetite nanofiber mat.

The SEM images and EDS spectrum clearly show that the highest concentration of particles is located in the beads (not shown here). In addition, the EDS spectrum shows strong peaks of the elements iron (Fe), confirming that the magnetite nanoparticles are agglomerated within the beads.

Conclusion

In this study, PAN/magnetite nanofibers were prepared by adding nanoparticles into a polymer solution by electrospinning method. Oxidative stabilization and carbonization at 500 °C, 600 °C, 800 °C, and 1000 °C were performed, and resulting surface morphologies of the nanofiber mats were studied and discussed. According to the study, addition of nanoparticles increased the fiber average and improved the dimensional stability. Moreover, the agglomeration of magnetite nanoparticles was largely detected in beads by means of SEM and EDS spectra. The results show that more attention should be given to the aspects of the morphological studies, which deals with the effect of thermal treatment on the surface structure of nanofiber mats. According to the study, agglomeration of magnetic particles are located on the surface and inside the nanofiber mats..

References

[1] Storck, J.L.; Grothe, T.; Mamun, A.; Sabantina, L.; Klöcker, M.; Blachowicz, T.; Ehrmann, A. Orientation of Electrospun Magnetic Nanofibers Near Conductive Areas. Materials 2020, 13, 47.

[2] Döpke, C.; Grothe, T.; Steblinski, P.; Klöcker, M.; Sabantina, L.; Kosmalska, D.; Blachowicz, T.; Ehrmann, A. Magnetic Nanofiber Mats for Data Storage and Transfer. Nanomaterials 2019, 9, 92.

[3] Trabelsi, M.; Mamun, A.; Klöcker, M.; Sabantina, L.; Großerhode, C.; Blachowicz, T.; Ehrmann, A. Increased Mechanical Properties of Carbon Nanofiber Mats for Possible Medical Applications. Fibers 2019, 7, 98.

[4] Yu, G.F; Li, G.T; Pan, W.; He, X.X.; Zhang, Y.J.; Gong, M.G.; Yu M.; Zhang, Z.M.; Long, Y.Z.; Electromagnetic function-alized ultrafine polymer/γ-Fe2O3 fibers prepared by magnetic-mechanical spinning and their application as strain sensors with ultrahigh stretchability, Composites Science and Technology 2017, 139, 1-7.

[5] Wortmann, M.; Frese, N.; Mamun, A.; Trabelsi, M.; Keil, W.; Büker, B.; Javed, A.; Tiemann, M.; Moritzer, E.; Ehrmann, A.; Hütten, A.; Schmidt, C.; Gölzhäuser, A.; Hüsgen, B.; Sabantina, L. Chemical and Morphological Transition of Poly(acrylonitrile)/Poly(vinylidene Fluoride) Blend Nanofibers during Oxidative Stabilization and Incipient Carboniza-tion. Nanomaterials 2020, 10, 1210.

[6] Rothschild, A.; Komem, Y. The effect of grain size on the sensitivity of nanocrystalline metal-oxide gas sensors. J. Appl. Phys. 2004, 95, 6374–6380.

[7] Wang, C.; Yin, L.; Zhang, L.; Xiang, D.; Gao, R. Metal oxide gas sensors: Sensitivity and influencing factors. Sensors 2010, 10, 2088–2106. Barsan, N.; Weimar, U. Conduction model of metal oxide gas sensors. J. Electroceramics 2001, 7, 143–167.

Fachhochschule Bielefeld
Interaktion 1
33619 Bielefeld
↗ www.fh-bielefeld.de

Correspondence: lilia.sabantina@fh-bielefeld.de
https://www.fh-bielefeld.de/ium/forschung/arbeitsgruppen/nanomaterials

Nanomaterials
Junior Research Group

FH Bielefeld
University of
Applied Sciences