Effect of a Nano-fibrous Structure on the Nanofiber Mat's Hydrophobicity

L. Javazmi[1], A. Khoddami[2], Z. Mazrouei-Sebdani[2], J. Epaarachchi[1]
[1]Centre of Excellence in Engineered Fibre Composites (CEEFC), University of Southern Queensland, Toowoomba QLD 4350, Australia
[2]Department of Textile Engineering, Isfahan University of Technology, Isfahan, 84156-8311, Iran
Corresponding author: Leila.Javazmi@usq.edu.au

Abstract Summary: To improve hydrophobicity, both low surface energy and proper surface roughness are necessary. In this research, the possible surface roughening effect of PET nanofibers was applied to manipulate an appropriate surface topography for the mat composed of them while a fluorocarbon layer generated low surface energy.

Keywords: Hydrophobicity, surface roughness, nano-fibrous material

Introduction: Recently, nanofibers have been explored extensively due to their extremely high surface to volume ratio, highly porous structure with excellent pore interconnectivity. For many applications, the surface wettability plays a major role in determining the nanofibers functionalities [1]. Chemical composition and surface topography are important parameters for the wettability design of solid substrates [2]. Thus in this study, the effect of the nano-fibrous structure on the hydrophobicity of the nanofiber mat was compared by a smooth polyester film with no fibrous structure. A fluorocarbon layer was coated on the surface of the resultant nanofiber mat and smooth film for decreasing surface energy.

Experimentation:

Materials: The selected fluorocarbon, Rucostar EEE, was obtained from Rudolf, Germany, and solvents were purchased from Merck Company. A kind of PET chips was provided from Tondgooian Petrochemical Company in Iran.

Methods: 15% (w/v) PET solution was prepared by dissolving PET chips in 1:1 (v/v) DCM and TFA and stirred for 12 h. The solution was fed to a horizontal electrospinning via a syringe with flow rate of 0.2 mL/h and the electrospinning was done at a voltage of 13 kV. The distance of the syringe tip and a cylindrical collector was 15 cm. The smooth polyester film achieved by ambient-drying of PET solution on the bottom of a vessel.

Result and discussion: Table 1 compares water repellent properties of the nano-fibrous mat with the smooth film. Since the formed fibrous mat and smooth film exhibited an equal surface energy with 3M water repellency of 1 which can just repel water, the differences between contact and tilting angles are due to changes in the surface roughness [3]. Before and after the fluorochemical treatment, the tilting angles remained unchanged at 90º for the nanofiber mat and smooth film.

Table 1: Water repellency of the untreated and the fluoro-treated nano-fibrous mat and smooth film

Sample	WCA (º)		SA (º)		3M water repellency		Cassie-Baxter behavior	
	BFC*	AFC**	BFC	AFC	BFC	AFC	f_1	f_2
PF	55.6 (0.1)***	60.9 (1.0)	>90	>90	1	9-10	-	-
PNF	103.4 (0.2)	111.4 (0.6)	>90	>90	1	9-10	0.49	0.51

*Before fluorocarbon coating: BFC, **after fluorocarbon coating: AFC. ***Numbers in parenthesis is standard deviations.

The effect of fibrous structure on the hydrophobicity can be demonstrated by comparing the contact angle of the smooth polyester film (55.6º) with the nano-fibrous mat (103.4º). Thus, the higher hydrophobicity of the nanofiber mat can be attributed to intrinsic surface roughness of the sample appearing from the fibrous structure, Figure 1 (A). Also, the topological evaluation of the nanofibers mat was considered by its AFM image with the respected roughness and texture profiles in Figure 1(B). Figure 1 (B) shows changes in the texture graph from -10 to10 nm and the roughness graph from –2 to 2 nm. Thus, the SEM and AFM micrographs confirm that the proper surface irregularity occurs at nano-fibrous mat which is compatible with the reports related to the importance of the dual-scale surface roughness in relation to hydrophobic and super-hydrophobic properties [4].

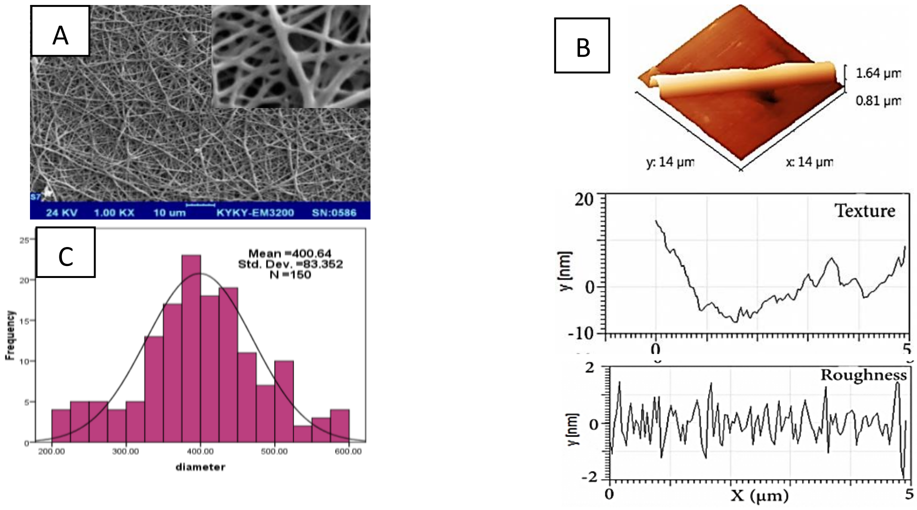

Figure. 1. The nanofiber mat (A) SEM, (B) AFM micrographs and (C) Histograms of diameter.

Although the electrospinning technique produces sufficient surface roughness for hydrophobicity (contact angle of more than 90°), this nano-fibrous substrate still doesn't provide major hydrophobic changes on the surfaces, which may need a fluorocarbon finishing [2] to lower the surface energy of the rough surface. The treated samples due to low surface energy of the fluorochemicals have 3M water repellency of 9-10. Figure 2 shows the contact angles of the fluoro-treated smooth film and nano-fibrous mat.

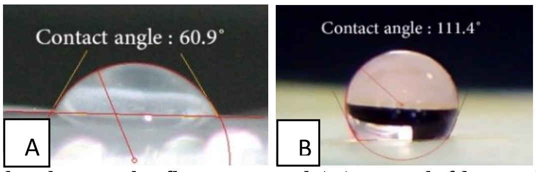

Figure 2 Sessile water droplets on the fluoro-treated (A) smooth film, and (B) nano-fibrous mat.

To determine solid/air and water/air fractions of the fluoro-treated, the Cassie-Baxter equation (1) was used.

$$\cos\theta' = f_1\cos\theta + f_2\cos 180 = f_1\cos\theta + f_1 - 1 \qquad (1)$$

$$f_1 + f_2 = 1 \qquad (2)$$

Where, f_1 and f_2 are the water/solid and air/water fractions, θ' and θ represent the contact angles of rough and smooth surfaces, respectively. The air/water fraction of the fluoro-treated nano-fibrous mat was found to be equal to 51% clearly indicated the entrapment of air in its surface in comparison with the smooth film (5%).

Conclusion: Results showed the inherent topology of nano-fibrous mat is a key factor to improve its hydrophobicity, compared to the smooth film. Thus, the roughness enhances the effect of the surface chemistry to produce the super-hydrophobicity.

References

[1] A. J. Fang, A. H. Wang, A. X. Wang, and T. Lin," Superhydrophobic nanofibre membranes: effects of particulate coating on hydrophobicity and surface properties," J. Text. Institute, Vol. 103, No. 9, pp. 937–944, September 2012.
[2] N. Nurxat, A. Waseem," Superhydrophobic electrospun nanofibers", J. Mater. Chem, A, Vol. 6, pp. 1929–1946, 2013.
[3] A. P. Rao, A. V. Rao and G. M. Pajonk, J. Appl. Surf. Sci., Vol. 253, pp. 6032–6040, 2007.
[4] Y. K. Lai1, Z. Chen and Ch. J. Lin," Recent progress on the superhydrophobic surfaces with special adhesion" JNAN, 2011, Vol.1, 18–34.