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Materials Today: Proceedings 3 (2016) 1320–1329

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Recent Advances In Nano Science And Technology 2015 (RAINSAT2015)

Effect of thickness of mat and testing parameters on tensile strength variability of electrospun nanofibrous mat

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Abstract

Tensile strength is one of the important characteristics of electrospun fibrous mat for all its applications such as filtration, composite reinforcement and tissue engineering. The mean and also the variance of tensile strength of mat have influence on its behavior during usage. In the present work, the mat thickness and tensile testing parameters viz., gauge length and testing speed were optimized to achieve lower Coefficient of Variation (CV %) of tensile strength. Poly acrylonitrile was electrospun and investigated for the interactive effects of three parameters by ANOVA and Response Surface Method. The mats were produced with thicknesses of 114 nm, 198 nm and 298 mm. The test was carried out with gauge length of 20mm, 30mm and 40mm with test speed of 1 mm/min, 5 mm/min and 10 mm/min. Majority of the PAN fibres had the diameter in the range of 160-240 nm. It was found that the CV% of tensile strength of nanofibrous mat was lower for 198 µm thickness mat tested at 20 mm gauge length and 1 mm.min-1 testing speed. The parameters optimized for Polyacrylonitrile was validated with the mat produced from Polyvinyl alcohol. Majority of the PVA fibers by electrospinning had diameters in the range of 120-220 nm. It is inferred from the results that there is a minimum thickness for the mat which yields lesser strength CV%. Minimum gauge length and minimum test speed results lesser strength CV%.

*Keywords:*ANOVA; Box and Behnken; electrospun mat; gauge length; tensile strength; CV%; testing speed

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2214-7853

1. Introduction

The application of nanofibers produced by electrospinning method is quite extensive. They are used in the form of mat (scaffold) in tissue engineering, micro filtration, photonics, protective clothing, sensorics, reinforcing composites and drug delivery etc [1]. Depending upon the application, the property of the electrospun fibrous mat (EFM) is customized i.e., for tissue engineering, the EFM should be biocompatible to enhance the cell growth and differentiation, whereas it need not be biocompatible in photonics application. However, for all the applications, the tensile strength of EFM plays a vital role. Tensile strength of nanofibrous mat is an important characteristic for being used as scaffold for tissue engineering, as it should possess adequate mechanical strength for growth of cellular functions [2]. The tensile behavior of electrospun mat depends on the nature of polymer, diameter of the nanofiber and orientation of fibers in the mat [3]. During the application, the electrospun mat is subjected to various stresses which would cause its structural deformation. The average tensile strength of mat is normally expressed as a measure of characteristic of the scaffold, however, higher average strength with wider distribution of individual strength values, evaluated by Coefficient of Variation percentage (CV%) may cause the mat to fail to meet the desired function. The determination of the tensile property of EFM had been carried out by many researchers using different testing parameters. Few from the past ten years are listed in Table 1.

Table.1 Parameters used for tensile testing of electrospun nanofibrous mat

Polymer	Gauge length , width (mm)	Testingspeed (mm.min-1)	Thickness of mat (mm)	Average tensile strength(MPa)	Reference
Polyamide 6	10, 6	2	*	34.9 ± 5.6	[7]
Poly(caprolactone)	60,10	50	0.02 to 0.03	5.6 and 12.8	[8]
Nylon 6 (10 % w/v)	40,3.5	5	0.01	10.1 ± 2.4	[9]
Poly (L- Lactic acid)	(ASTM D638)	20	0.05	8.32 ± 1.56	[10]
Poly(d,l-lactide) and Poly(l-lactide)	10,4	3	0.2 to 0.25	1.153 and 0.676	[11]
Chitosan/gelatin blend	30,*			37.91 and 6 4.42	
1,6-diisocyanatohexane-extended	40, 25	1	0.03	1.17 ± 0.06	[12]
poly(1,4-butylene succinate)	30, 10	20	0.12±0.01	1.67	[13]
poly (DL-lactide-glycolide)	70, 7	0.5	0.2	1.6	[6]
Polyethylene terepthalate (20 %)	50, 10	30	0.14 to .420	2.4	[14]
Gelatin/PVA (10 %)	20, 5	10	*	99 ±12	[15]
Polyacrylonitrile	30, *	30	*	7.25	[16]
Silk	30, 5	1.2	*	2.60	[17]
Gelatin (10 %)	30,10	10	0.05	1.40	[18]
Poly(caprolactone)	ASTM D638	10	*		[19]
Poly(vinyl chloride)	ASTM D638	10	*	0.90	[5]
Polyurethane	ASTM 1708D	5	*	*	[20]

* Not mentioned

It can be observed from the Table1 that the tensile strength values are not comparable with each other as they have been tested at different parameters.The researchers use different testing parameters, since there is no standard method available for testing the tensile property of the EFM as available for woven and nonwoven fabrics (ASTM D 5034). Testing procedures followed by earlier researchers were of those standards available for polymer film, composites and membranes (ASTM D638). In tensile testing of any material, dimension of material such as length, width, thickness and shape plays an important role. The samples prepared for tensile testing of electrospun mat were either in a rectangular or in a dumbbell/dog bone shape [4,5]. Additional care need to be taken while preparing samples as there should not be any deformation to the mat during testing and also wastage of material. Cutting to a dumbbell shape is complicate in preparation and testing, and also the material wastage is more. Hence, sample was prepared in the form of rectangle in this work. In most of the published works, the CV% of the tensile strength was not discussed and it was found to be more than 20% wherever mentioned. Higher the CV%, higher would be the spread of individual strength values. The mat should have sufficient thickness to withstand the stress applied during preparation and testing of samples. Insufficient thickness and wrong selection of testing parameters may cause higher tensile strength CV% even