Materials Science and Engineering B 217 (2017) 36–48

Contents lists available at ScienceDirect

Materials Science and Engineering B

journal homepage: www.elsevier.com/locate/mseb

Review

Electrospun nanofibers: New generation materials for advanced applications

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ARTICLE INFO

Article history:
Received 6 October 2016
Received in revised form 10 December 2016
Accepted 3 January 2017

Keywords:
Electrospinning technique
Nanofibers
Adsorbent
Catalyst
Sensor
Biomedical
Energy & environment

ABSTRACT

Electrospinning (E-spin) is a unique technique to fabricate polymeric as well as metal oxide nanofibers. Research on electrospun nanofibers is a very active field in material science owing to their novel applications in diverse domains. The main focus of this review is to provide an insight into E-spin technique by understanding the working principle, influencing parameters and applications of nanofibers in different walks of life. Several hundreds of papers are published on the preparation, modification and applications of nanofibers produced by E-spin technique in the areas like sensor development, decontamination, energy storage, biomedical and catalysis etc. Details on the industrial scale development of E-spin technique, current scenario and future developments are also covered in this review.

Contents

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http://dx.doi.org/10.1016/j.mseb.2017.01.001
0921-5107/

1. Introduction

One dimensional (1-D) materials like nanotubes, nanowires, nanorods and nanowhiskers have gained significance due to their potential applications in many fields such as electronics, energy storage cells, fuel cells, catalysis and filtering membranes. Recent years have witnessed voluminous reports on nanofibers (NFs) of polymers, composite metals and metal oxides with multi-functional properties. Nanofibers are always fascinating based on their unique properties like high tensile strength, large surface area and porosity. Electrospun nanofibers (E-spun NFs) also possess enough scope for easy surface modifications, stretchability in addition to simple and cost effective preparation. In the last two decades, many researchers have switched over their attention from nanoparticles to nanofibers because of the prospective application of the latter class of materials.

E-spin is the only method of choice for the large scale preparation of NFs over other available methods [1]. The reasons are easy to handle, minimum consumption of solution, controllable fiber diameter, convenient to process, cost effective, simple and reproducible in processing the fibers and has the technical advances (scale up process).

Though the origin of E-spin was traced way back to 1930, only during late 20th century noticeable advancements, growth in terms of instrumentation and working parameters are reported. Several hundred reports exploring the potential of E-spin technique were published after the year 2000 [2] and even now it is growing very well because of wide applications of nanofibers in various fields [3–11].

The basic principle of this technique is **"electrostatic interactions"**. In detail, the peristaltic pump pushes the solution from the needle where high voltage power supply is connected. Single droplet ejected at the tip of needle will be collected in a counter electrode called collector. It could be understand that electrostatic interactions lead to fiber formation. Apart from polymeric NFs and composites, ceramic NFs could also be prepared by changing the parameters such as, operational condition, solution property and ambient parameters. It is also possible to obtain fibers of different morphology, various chemical composition and tuneable diameter by this technique.

2. History and evolution of E-spun NFs research

The electrospray technique started in the late 1890s was transformed to electrospinning in the year 1900. For better understanding of the history behind this novel technique, we herein listed (Table 1) a comprehensive, year-wise development of electrospinning.

It is worth to mention here that most of the research publications after 2010 dealt mainly on the applications of E-spun fibers in many field using functionalised polymers, nanoparticle incorporated fibers and metal oxide composite nanofibers.

3. Working principle, instrumentation and operational parameters

3.1. Working principle

The fiber forming technology is based on the principle of **"electrostatic attraction"** of charges. The solution has its own surface tension inside the syringe which can be charged outside by applying a high voltage power supply at the tip of the needle. Oppositely charged collector is placed at some distance (~10 cm) to collect the ejected fibers. During the supply of high voltage (~10–30 kV), the solution in the syringe emerges out by overcoming the surface tension and form a cone like structure called "Taylore cone" (drops get ejected at the tip). Taylore cone can be elongated by high charge density on the collector [25]. Fig. 1 illustrates the working principle of E-spin technique.

3.2. Instrumentation

E-spin instrument consists of three major parts; first and foremost influencing part is high voltage power supply, second one is

Table 1
A comprehensive account on the advancements in E-spin technique.

S. no.	Year	Nature of advancements	References
1	1900, 1902	Process of E-spin patented by Cooley and Morton	[12]
2	1914	Jet ejection at tip of the metal capillary by John Zeleny	[13]
3	1934	Patent for the invention of E-spin instrument: Fabrication of cellulose acetate using acetone as the solvent by Formhals	[14]
4	1936	Patent for air-blast fibers formation from melt rather than solution by Norton	[15]
5	1938, 1940	Other patents by Formhals	[16–18]
6	1950–1959	Factory production of nanofibers as filter for gas mask application (only in USSR)	[19]
7	1960	Jet formation study and E-spun fibers as filtration material	[20]
8	1964	Formation of Taylor cone	[21]
9	1971	Apparatus to spin acrylic microfibers by Baumgarten	[22]
10	1995	Doshi and Reneker reported the fibers diameter decreases with increase in distance from collector to needle tip and Taylor cone	[23]
11	1996–2001	Publications related to the working parameters such as, solution, ambient and instrumental parameters.	[24–26]
12	2001–2005	Synthesis and characterisation of E-spun nanofibers. Different types of E-spin instrument were introduced by different researchers from various countries.	[27–30]
13	2006-till date	During these period most of the papers were put forward on the applications of E-spun nanofibers as sensors, tissue engineering materials, protection against chemical warfare stimulants, filters, scaffolds, batteries and catalyst. Also these nanofibers found significant application as drug delivery system in medical field.	[31–40]