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Electrospun nanofibers, nanocomposites and characterization of art: Insight on establishing fibers as product

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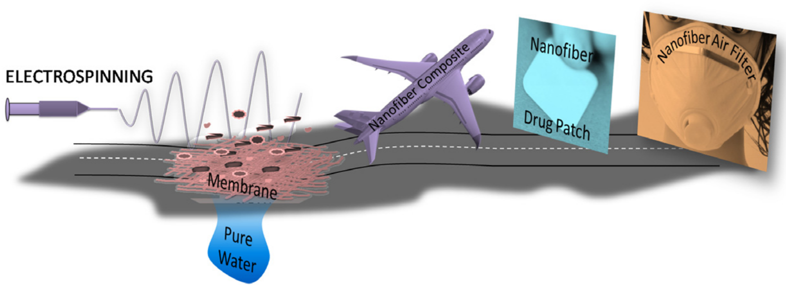
GRAPHICAL ABSTRACT



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ABSTRACT

Electrospun nanofibers generally result in as non-woven fibrous mats classified as high surface area materials as they pose surface-to-mass or volume ratio. Electrospinning technology has been widely used preparation of wide range of nano scale fibers for applications like high strength composite materials, electronic device making, drug delivery, food packaging, membrane filtration and energy applications. Since its reinvention in 1990s, electrospinning technique has undergone remarkable changes from lab scale single needle spinning process to multi-needle mass production and industrial scale nanofiber production using advanced bubble spinning technique.

Electrospinning technique can be uniquely modified for specialty nanofiber spinning depending upon end use. With slight change in electrospinning parameters, process can yield from simple randomly arranged nanofiber webs to highly oriented and packed nanofibers mat are being used commercially in the form of air purifiers, filtrations membranes and wound dressing pads. This review evaluates electrospun nanofibers for their characteristic properties as a product and properties in conjunction with respect their applications. This review also evaluates novel characterization techniques employed in recent times with an emphasis on to understand the morphology, physico-chemical and mechanical properties. Large scale production of electrospun nanofibers are being aimed to be used in wearable electronics applications having nanofibers as flexible electrodes, as composite nanomaterials in automobile and aerospace manufacturing.

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1. Introduction

Electrospinning is a microfiber or nanofiber fabrication technique that uses electrostatic forces to drive the fiber formation and has attracted more interest and attention in recent times due to its adaptability and prospective for applications in various fields. The electrospun nano scale fibers are being used in applications like electronics to drug delivery, textile, energy, membrane filtration as well as food packaging applications [1–5].

Electrospun nanofibers have also being used in special applications such as wound dressing, enzyme immobilization and tissue engineering [6]. Since electrospinning became popular most of known synthetic polymers have been electrospun for various applications and the biopolymer stock is increasing and gradually being used for nanofibers preparation. Also, the nanoscale fibers are being generated in the forms of pristine precursor fiber, blend, ceramic and nanocomposite by applying strong electric field on polymer solution.

On the other hand, advanced class of electrospun inorganic nanofibers commonly known as "*Ceramic*" micro and nanofibers attracted enormous technological interests due to their electrical, optical and magnetic properties, which find applications in various areas such as sensors, catalysts, batteries, automobile and insulators or separators. As several products have shown important application potentials, researchers now focus on new methods of producing nanofibers, including multi-step electrospinning techniques [7–11].

Due to extensive research and technological advancements in recent times, electrospinning technology has taken long leap from lab scale nanofibers mat to advanced products. This review will try to address the process through which lab scale sample transformed in to advanced and high performance product. Last decade has seen several large scale production activities and innovation that have improved the spinnability of several new precursors and technology adaptation to increase the speed of electrospinning. Exploration of new application fronts have led to large scale production with increase in the strength of product nanofiber mats and better control of electrospun fiber in terms of size, shape, diameter, fiber length, orientation, porosity and fiber alignments for technological important applications. This review reviews current progress towards developing novel product out of nanofibers and will discuss the influencing factor related to scale-up and product development. Electrospinning factors like precursor spinnability, solvent properties, influence of applied voltage, conductivity of precursor solution, viscoelastic properties of spinning solutions and importantly electrospinning unit design [12–16]. This review begins with a brief introduction to electrospinning technology and method description to produce nanofibers using electrospinning technique. We then discuss approaches to the controlled assembly and patterning of electrospun nanofibers with specific dope precursor involved for targeted products developed for the applications namely wound dressing, drug delivery, food packaging, mechanical, and other medical applications. Further, review will focus on highlighting recent applications enabled by electrospun ceramic nanofibers, with a focus on the mechanical properties of composite and ceramic nanofibers and their applications in energy and environmental technologies such as energy storage and membrane filtration applications. Review will conclude with future prospectus of electrospun nanofibers as product for vehicle for sustainable product in and as wound dressing agent, food packing material, filtration membrane and as energy material.

2. Electrospinning technology

The nanofibers preparation through electrospinning involves four main steps namely the base, the jet, the splay, and the collection Fig. 1(a). The interface of needle tip and solution jet is known as base region where the jet emerges from the needle tip to form a cone known as the *Taylor Cone*. Further, dope solution experiences high electric field at the tip of needle forming high intensity stretch known as straight jet. The shape of the Taylor cone depends upon the surface tension of the liquid and the force of the electric field. Highly charged jets undergo ejection depending on electric field existed between needle and collector. During the ejection of jets, dope solution experiences elongation and looping simultaneously that is essentially plane under the influence of applied electric field. Charging of the jet occurs at the base or Taylor cone formation stage, with solutions of higher conductivity being more conducive to jet formation. Due to elongation and looping dope solution's jet acceleration lead to formation of fibers with varying diameters and length. At higher electric field, jet gets decreased fiber diameter and higher lengths. On the other hand, solvents with high vapor pressures may result in rapid solvent evaporation resulting in decreased jet diameter and low elongation velocity. In the final stage, the radial charge repulsions cause the jet to splay or envelop cone splits jet into many small fibers of approximately equal diameter and charge per unit length. The final diameter of the electrospun fibers upon collection is dependent upon how many splits jet experienced under the influence of collector stretch [17–20]. As prepared nanofibers made of only polymers, blends of polymers, composites of different active molecules, and specialty fillers have been used for various applications ever since their discovery as shown in Fig. 1(b).

2.1. Properties of electrospun nanofibers

Electrospun nanofibers have been characterized using various techniques depending on their preparation methods and properties desired for applications. Generally, electrospun nanofiber structure and morphologies are characterized using microscopic techniques. Compositional characterizations of nanofibers are carried out using different spectroscopic techniques. The mechanical properties and thermal properties are being tested using various advanced tools.