Functional Nanofibre: Enabling Material for the Next Generations Smart Textiles

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Abstract: Functional fibrous materials are a new family of fibre materials whose physical and chemical properties are sensitive to the change in the environment such as temperature, pressure, electric field, magnetic field, optical wavelength, adsorbed gas molecules and the pH value. This paper introduces a new approach to translate functions from nanoparticles to fibrous structures by co-electrospinning. Examples of nanofibres that have tailorable mechanical, electrical, magnetic, optical, thermal, hygroscopic, and antimicrobial functions are shown. The paper concludes with an example of the development of a multifunctional nanofibre scaffold for cartilage tissue regeneration.

Keywords: functional materials, nanofibres, coelectrospinning, nanocomposite, smart textiles

1. Introduction

Stronger, faster, lighter, safer and smarter - these are the characteristics of extreme textiles presented in the 2005 exhibition by the Cooper-Hewitt, National Design Museum of the Smithsonian Institute in New York [1]. These characteristics are also applicable to the performance goals of a new generation of sportswear. About the same time, in 2004, an exhibition entitled “Beyond Fibres” was held in the National Museum of Emerging Science and Innovation (MeSci) in Tokyo [2]. In this exhibit the central role of a large family of fibres, including nanofibres, in providing new functions for products ranging from sportswear to space exploration was demonstrated. These events signify the entry of the fibre and textile industry into the new era of functional materials. The 2008 joint symposium of TBIS-SMART which focuses on the interaction between fibrous materials and human physiology and on sports medicine and rehabilitation therapy respectively provide a timely forum for the discussion of a new generation of enabling materials for SMART textiles in general and sportswear in specific.

Functional materials are a new family of materials whose physical and chemical properties are sensitive to the change in the environment such as temperature, pressure, electric field, magnetic field, optical wavelength, adsorbed gas molecules and the pH value. The functional materials utilize the native properties and functions of their own to achieve an intelligent action [3]. Functional materials in the form of fibres bring additional attribute as a carrier of the functions to higher order structures ranging from medical devices to clothing such as sportswear.

In the search for functional material concepts one can find abundant of clues in nature. In fact multifunctionality is a norm rather than exception in living systems. Fibrous materials in nanometer scale are the fundamental building blocks of living systems. From the 1.5 nm double helix strand of DNA molecules, including cytoskeleton filaments with diameters around 30 nm, to sensory cells such as hair cells and rod cells of the eyes, nanoscale fibres form the extra-cellular matrices or the multifunctional structural backbone for tissues and organs. Specific junctions between these cells conduct electrical and chemical signals that result from various kinds of stimulation. The signals direct normal functions of the cells such as energy storage, information storage and retrieval, tissue regeneration, and sensing. Analogous to nature’s design, nanofibres and their composites can provide fundamental building blocks for the construction of devices and structures that perform unique new functions. The areas expected

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to be impacted by the nanofibre based technology include drug delivery systems and scaffolds for tissue engineering, wires, super capacitors, transistors and diodes for information technology, systems for energy transport, conversion and storage, as well as smart structural composites for medical devices.

In this paper we introduce a new approach to translate functions from nanoparticles to fibrous structures by the co-electrospinning process. Examples of nanofibres that have tailorable mechanical, electrical, magnetic, optical, thermal, hygroscopic, and antimicrobial functions are presented. The paper concludes with an example of the development of a multifunctional nanofibre scaffold for cartilage tissue regeneration.

1.1 Nanofibre Effects

Nanofibres are solid-state linear nanomaterials characterized by flexibility and an aspect ratio greater than 1000:1. According to the National Science Foundation (NSF), nanomaterials are matters that have at least one dimension equal to or less than 100 nanometers. Therefore, nanofibres are fibres that have diameter equal to or less than 100 nm. It should be noted that this definition is often relaxed in the industry to include all fibres that have submicron diameter. Materials in fibre form are of great practical and fundamental importance. The combination of high specific surface area, flexibility and superior directional strength makes fibre a preferred material form for many applications ranging from clothing to reinforcements for aerospace structures. Some observations on the nanofibre size effect are presented herein.

Effect of Fibre Size on Surface Area - One of the most significant characteristic of nanofibres is the enormous availability of surface area per unit mass. For fibres having diameters from 5 to 500 nanometers, as shown in Figure 1, the surface area per unit mass is around 10, 000 to 1,000,000 square meters per kilogram. In nanofibres that are three nanometers in diameter, and which contain about 40 molecules; about half of the molecules are on the surface. The high surface area of nanofibres provides a remarkable capacity for the attachment or release of functional groups, absorbed molecules, ions, catalytic moieties and nanometer scale particles of many kinds.

Effect of Fibre Size on Bioactivity -Considering the importance of surfaces for cell adhesion and migration experiments were carried out in our laboratory using osteoblasts isolated from neonatal rat calvarias and grown to confluence in Ham's F-12 medium (GIBCO), supplemented with 12% Sigma fetal bovine on Polylactic-glycolic acid (PLAGA) sintered spheres, 3-D braided filament bundles and nanofibrils. [4]. Four matrices were fabricated for the cell culture experiments. These matrices include 1) 150 - 300 µm PLAGA sintered spheres 2) Unidirectional bundles of 20 m filaments 3) 3-D braided structure consisting of 20 bundles of 20 µm filaments 4) Nonwoven consisting of nanofibrils. The most proliferate cell growth was observed for the nanofibrils scaffold as shown in the Thymadine-time relationship illustrated in Figure 2 This can be attributed to the greater available surfaces for cell adhesion as a result of the small fibre diameter that facilitates cell attachment.

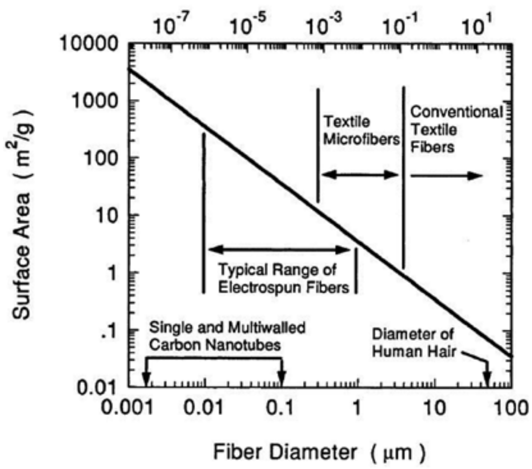

Figure 1 Relationship of fibre diameter to surface area

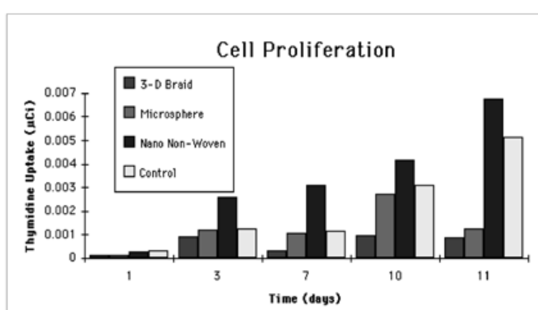

Figure 2 Fibroblast cell proliferation as indicated by the Thymidine uptake of cell as a function of time showing that PLAGA nanofibre scaffold is most favorable for cell growth.