Carbon Nanofibers

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Contributor: Lilia Sabantina

Carbon nanofibers are nano-sized fibers that have a high degree of crystalline orientation. In recent years, ecological issues have led to the search for new green materials from biomass as precursors for producing carbon materials. Such green materials are more attractive than traditional petroleum-based materials, which are environmentally harmful and non-biodegradable.

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1. Introduction

Increasing environmental awareness and ecological problems have led in recent years to new green materials made from biomass as precursors for the production of carbon materials receiving more research attention, as they seemed to be more attractive than traditional petroleum-based materials, which are polluting, toxic and non-biodegradable [1]. At the same time, there is a need to develop cleaner, more economical, efficient and energy-saving materials and to focus the world’s attention on the new green, renewable energies. Converting biomass waste into carbon materials can help solve the problem of pollution and improve traditional processing methods for producing carbon in the face of the energy crisis and environmental problems [1]. Low-cost renewable biomass materials, such as sawdust, wood residues, rice husks, and corn stover, among many others, are available in large quantities as waste from forestry and agriculture. These renewable biomass materials can be considered promising candidates for carbon precursors [2].

Various techniques for synthesizing carbon nanofibers from biomass, such as electrospinning, pyrolysis, hydrothermal treatment, and ultrasonic treatment, are already known and have already been explained by many research groups [3][4][5][6][7][8][9].

Most of the techniques are complicated and require extensive use of energy resources. For example, the production of carbon nanofibers from hazelnut shell biomass as a carbon resource by hydrothermal technique goes through a series of complex processes, such as hydrothermal carbonization, heat treatment, potassium hydroxide activation, magnesium oxide templating to produce anode materials for lithium-ion batteries at the end of the process [10].

2. Carbon Nanofibers Application in Biotechnological and Medical Fields

Today's medicine progresses greatly and applies more therapeutic solutions based on the field of nanotechnology and nanomaterials. High-performance materials, such as carbon nanotubes, graphene, or carbon nanofibers, have already established their place in developing new implants and medical devices [11]. Due to their properties, high electrical conductivity, unique surface characteristics, and biomimetic shape, these nanomaterials are ideal for constructing implantable electrodes and biosensors. In addition, they can serve as tissue substrates for in vitro and in vivo applications. For this reason, stimulation of an electric field can regulate cell behavior both in vivo and in vitro due to the conductive properties of carbon substrates. Nanofibers resemble the natural structure of cell assembly and can be used in the form of porous mats as membranes for medical reconstruction, substrates for bone and cartilage development in post-traumatic tissues [12][13].

Carbon nanofibers are promising candidates for diverse medical applications thanks to their physical properties. Due to their conductivity, they can be used as biosensors and electrodes to stimulate the nervous system, as well as for the fabrication of scaffolds for regenerative medicine. As nonwovens, mats, membranes, or other various types of nanocomposites, nanofibers can be used in many biotechnological fields [14][15][16][17][18]. Aoki et al. investigated the application potential of organic nanofibers and electrospun carbon nanofibers for bone regenerative medicine [19].

Previously, the research focus centered on coating nanofiber mates with antibacterial substances. The efficacy of silver nanoparticles and the active healing properties of chitosan polymer hydrogels received numerous publications. With the development of electrospinning processes, the research focus increasingly shifted to electrospun nanofibers, which exhibit antimicrobial properties through the addition of nanoparticles [20][21]. Due to their high mechanical strength and good biocompatibility, carbon-based nanofibers offer further areas of application in biomedicine [22][23][24].

In 2019 Li et al. conducted a study of a superhydrophobic hemostatic material made from a nanocomposite dispersion of a dense network of carbon nanofibers and polytetrafluoroethylene (PTFE) or poly-dimethylsiloxane (PDMS) on support [25]. This nanofiber material has been used for its particular and distinctive way of blood coagulation, which allows rapid blood coagulation due to the presence of microfibers and reduces subsequent blood loss, regardless of the pressure applied, due to its superhydrophobic characteristics.

In tissue engineering for regeneration or organ reconstitution, cells are designed to attach, proliferate, multiply and regenerate multiple organs, such as skin, bone, cartilage, muscle, tendons, heart, nerves, and blood vessels. These strategies depend on appropriate biochemical and physicochemical properties and molecular influences or control of cellular behavior [26]. Carbon nanofibers are potential candidates for tissue engineering applications because they have suitable physical, structural, mechanical, and biological properties [27][28][29]. In addition, carbon nanofibers have exceptional mechanical properties, conductivity, and excellent cytocompatibility properties, as well as osteoblast adhesion, which are suitable for neural and bone tissue engineering applications. In terms of carbon nanofiber adhesion and proliferation, they show the interaction of astrocytes like glial scar tissue-forming cells. These functions of astrocytes make them able to minimize nanoscale fibers and scar tissue formation, reduce the glial scar tissue formation and show positive interaction with neurons, which would be a great support for neural implants [30][31][32].

Recent research indicates that carbon-based nanomaterials are potential candidates for biomedical applications, including drug delivery, repair and regeneration of various tissues, including nerves, muscles, bones, and for imaging [33][34][35]. Stocco et al. have investigated that carbon nanofibers have strong mechanical properties capable of surviving without affecting mesenchymal stem cells for tissue engineering of the knee meniscus [36]. Samadian et al. and Patel et al. have found that carbon nanofibers are promising platforms with a nanoscale surface area that are helpful for tissue healing and bone regeneration process through anti-inflammation, pro-angiogenesis and stem cell stimulation [35][37]. The research group of Serafin et al. has presented that the electrically conductive properties of carbon nanofibers can be used in cardiac or neural tissue engineering applications [38]. In addition, carbon nanofiber composites have special properties, such as large specific area, high porosity, good biodegradability, cytocompatibility and conductivity, etc., making them ideal candidates in the field of tissue engineering and biological medicine [39][40][41][42].

In addition, there is a wide range of further carbon nanostructures such as carbon nanotubes, carbon nanofibers, carbon nano-onions (CNOs), graphene, which have attracted a lot of attention recently due to the promising industrial application areas. Onion-like quasi-spherical CNPs (OCNPs) with hollow cage-like concentric graphene shells have been known since 1992 but are still under-researched compared to other allotropic forms of nanocarbons, such as carbon nanotubes, carbon fibers, fullerenes, graphene, and carbon dots. CNOs are a niche product that has not been explored as much as other carbon nanostructures and offer many advantages, unlike other carbon nanostructures. They exhibit lower toxicity, have one of the exceptional biocompatibilities and are, therefore, of particular interest for medical and biotechnological applications, such as imaging, drug delivery, tissue engineering, sensing and as [43][44][45]. Excellent electrochemical performance is offered by CNOs due to their high surface area, the small size of the carbon-oxygen functional groups and the micro-open 3D graphite structures. These properties provide sufficient space for ion storage, hierarchical porous channels for ion transfer and a carbon matrix with high conductivity for electron transfer [46]. Breczko et al. prepared composites of CNOs and poly(diallyldimethylammonium chloride) (PDDA) or chitosan (chit), and the electrochemical properties were tested and investigated [47]. In another study, CNO–PDDA composite films for dopamine detection were prepared in the presence of ascorbic acid and uric acid in solution [48]. The research group of Giordani et al. prepared a novel near-infrared (NIR)-fluorescent carbon-based nanomaterial, which consists of boron-difluoride azadipyrromethene fluorophores covalently bonded to carbon nano-onions [49]. The cytotoxicity and immunomodulatory properties of the synthesized fluorescein CNO derivative were elucidated and compared with similarly functionalized CNTs. CNOs were found to exhibit efficient cellular uptake, mild inflammatory potential, and low cytotoxicity. These discoveries make CNOs promising materials for biomedical application areas. Moreover, due to a novel concentric graphitic shell structure and a large surface area, CNOs possess many excellent physical properties, such as high electrical conductivity and can be used in the fields of magnetic and gas storage materials, lubricants, for nanoreactors or as substrates for catalyst carriers and electrochemical capacitors [49].

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