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Cellulose reinforced nylon-6 nanofibrous membrane: Fabrication strategies, physicochemical characterizations, wicking properties and biomimetic mineralization

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ABSTRACT

The aim of the present study is to develop a facile, efficient approach to reinforce nylon 6 (N6) nanofibers with cellulose chains as well as to study the effect that cellulose regeneration has on the physicochemical properties of the composite fibers. Here, a cellulose acetate (CA) solution (17 wt%) was prepared in formic acid and was blended with N6 solution (20%, prepared in formic acid and acetic acid) in various proportions, and the blended solutions were then electrospun to produce hybrid N6/CA nanofibers. Cellulose was regenerated in-situ in the fiber via alkaline saponification of the CA content of the hybrid fiber, leading to cellulose-reinforced N6 (N6/CL) nanofibers. Electron microscopy studies suggest that the fiber diameter and hence pore size gradually decreases as the mass composition of CA increases in the electrospinning solution. Cellulose regeneration showed noticeable change in the polymorphic behavior of N6, as observed in the XRD and IR spectra. The strong interaction of the hydroxyl group of cellulose with amide group of N6, mainly via hydrogen bonding, has a pronounced effect on the polymorphic behavior of N6. The γ-phase was dominant in pristine N6 and N6/CA fibers while α- phase was dominant in the N6/CL fibers. The surface wettability, wicking properties, and the tensile stress were greatly improved for N6/CL fibers compared to the corresponding N6/CA hybrid fibers. Results of DSC/TGA revealed that N6/CL fibers were more thermally stable than pristine N6 and N6/CA nanofibers. Furthermore, regeneration of cellulose chain improved the ability to nucleate bioactive calcium phosphate crystals in a simulated body fluid solution.

1. Introduction

Polymeric nanofibers have recently attracted a considerable amount of attention in academia and industry due to their potential use in tissue engineering, filtration, barrier fabrics, protective clothing, sensors, pharmaceutical industries, and many other applications (Kumbar, James, Nukavarapu, & Laurencin, 2008; Ramakrishna, Fujihara, Teo, Yong, Ma, & Ramaseshan, 2006; Yang, Zhang, Zhao, Yu, & Ding, 2015). Among various techniques, electrospinning is a facile and efficient process to generate a micro-nanofibers for various polymers in a myriad of fibrous structures (Jayakumar, Prabaharan, Nair, & Tamura, 2010; Pham, Sharma, & Mikos, 2006; Ramakrishna et al., 2006). Synthetic polymer-based electrospun nanofibers have good mechanical properties, and in many cases, the degradation time can be controlled (Rosso, Marino, Giordano, Barbarisi, Parmeggiani, & Barbarisi, 2005). A number of synthetic and natural polymers have been studied to fabricate nanofibers for various applications. Among these, nylon-6 (N6), a synthetic polymer, has attracted a significant interest since it exhibits superior mechanical properties when compared to many other synthetic and natural polymeric materials (Abdal-hay, Hamdy, & Khalil, 2015). Furthermore, this material can be subjected

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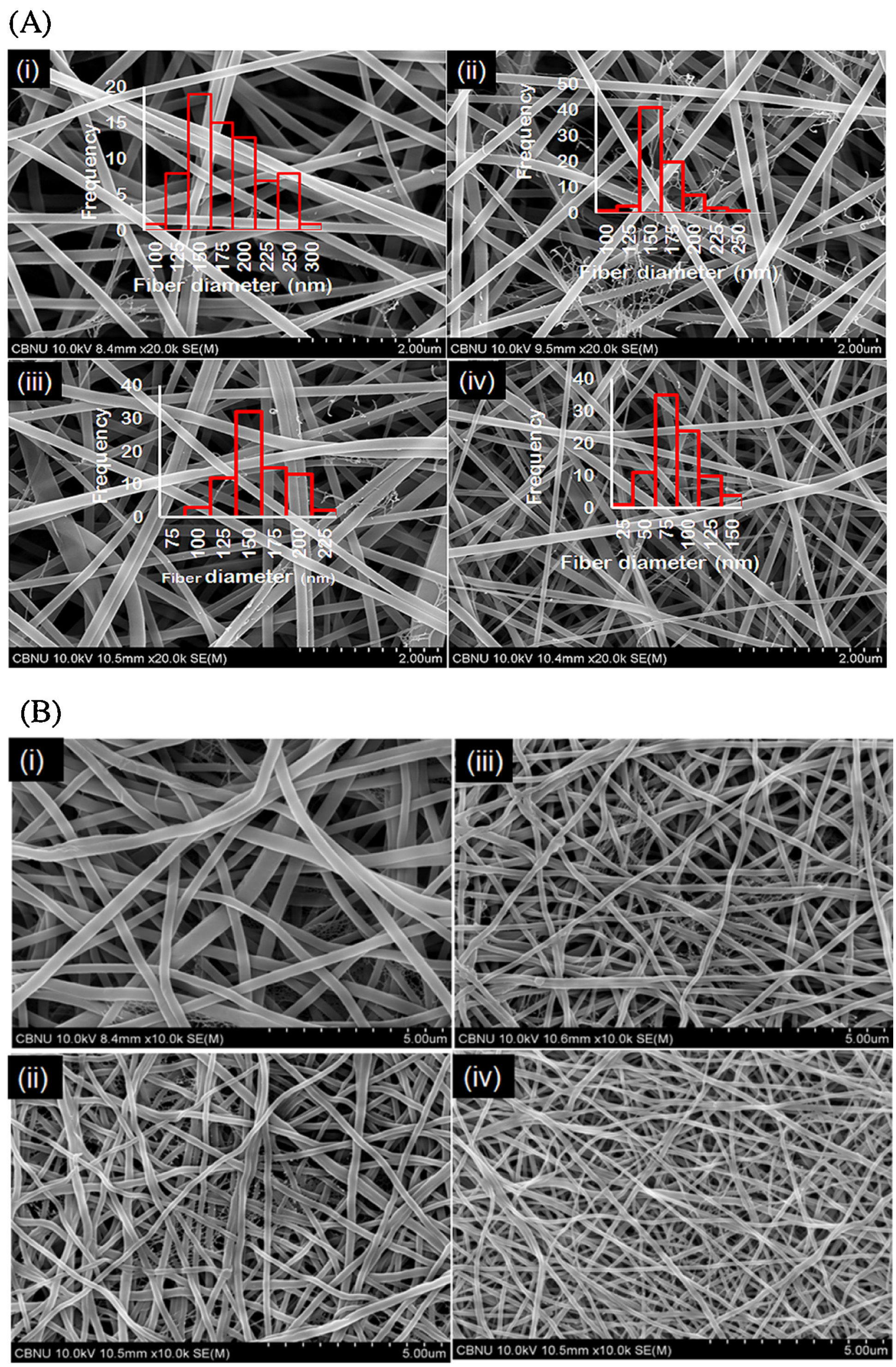

Fig. 1. FE-SEM images of the different mats. (A) Before saponification: (i) pristine N6, (ii) N6-90/CA-10, (iii) N6-75/CA-25 and (iv) N6-50/CA-50. (B) After saponification: (i) N6 mat, (ii) N6-90/CEL-10, (ii) N6-75/CEL-25, and (iv) N6-50/CEL-50.

to a wide range of conditions for processability and also has a superior fiber forming ability with strong chemical and thermal stability that can be achieved at a low cost, which altogether make N6 a good candidate for use in biomedical and industrial applications (Wang, Ding, Sun, Wang, & Yu, 2013). In addition, N6 resembles the collagen protein in its backbone structure, which makes it a potential candidate for use in bone tissue engineering (Das et al., 2003). Due to its excellent stability in human body fluids, N6 has also been used as a medical polymer in medical threads and artificial skin (Esfahani et al., 2015; Haines et al., 2014). In addition, N6 fibers have also been used in several area of the textile industry. However, their hydrophobic surface and tight crystalline structure cause difficulties during wet treatment and utilization (Abdal-hay, Tijing, & Lim, 2013). In particular, N6 lacks an ability for water retention and prevents hydraulic permeability through the membrane, which limits their applicability in biofilters, biosensors, and tissue engineering (J. Zhao et al., 2014). Therefore, several research groups have focused on improving the wettability of N6 nanofibers by incorporating