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Preparation and evaluation of nanocrystalline cellulose aerogels from raw cotton and cotton stalk

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ABSTRACT

Suspensions of nanocrystalline cellulose (NCC) were prepared by sulfuric acid hydrolysis of cotton and cotton stalk bleached pulps. The original pulps extracted from cotton and cotton stalk were analyzed by FT-IR spectroscopy, X-ray diffraction and scanning electron microscopy. The NCC products were investigated and their differences in morphology and other characteristics such as crystallinity index (CrI), zeta potential, particle size and thermal stability were studied. The results suggested that the pulp yields from cotton and cotton stalk were 77 and 23%, respectively. Raw cotton resulted in pulps with much higher quality than cotton stalk. Zeta potentials of the nanocrystalline cellulose obtained from cotton, (C-NCC), and cotton stalk, (CS-NCC), were −27.5 and −21.8 mV, respectively, in the stable range. TEM micrographs of both nanocrystalline cellulose presented rod like shapes of different dimensions. Surface areas of the aerogels prepared from cotton nanocrystalline cellulose, C-NCE, and cotton stalk nanocrystalline cellulose, CS-NCE, were 91.47 and 93.89 m^2/g, respectively. This study shows that the differences in characteristics of nanocrystalline cellulose and aerogel products obtained from cotton and cotton stalk pulps are not significant. Thus, the use of cotton stalk instead of cotton in the preparation of nanocrystalline cellulose and aerogel will be cost effective and environmentally friendly.

1. Introduction

Nanocrystalline cellulose has been prepared from a variety of cellulosic materials using mineral acid hydrolysis. Acid hydrolysis of cellulose causes bond cleavage of glycosidic bonds between two anhydroglucose units (Das et al., 2009). NCC is a rigid, rod-shaped whisker 1–100 nm in diameter and ten to hundreds of nanometers in length (Fan and Li, 2012). In the last decades, NCC has attracted significant interest because of its unique characteristics such as high young‘s modulus, high tensile strength, low coefficient of thermal expansion, high aspect ratio and large surface area. Availability, biocompatibility, biological degradability, and sustainability are the other benefits of this natural polymer (Chen et al., 2011). NCC can be used as (i) additive for coatings, paints, and adhesives, (ii) switchable optical devices, (iii) pharmaceuticals and drug delivery, (iv) bone replacement and tooth repair, (v) improved paper, packaging and building products, (vi) additive for food and cosmetics and (vii) aerogels as super insulators (Leung et al., 2013). Several sources of cellulose have been used to obtain NCC. Examples include cotton slivers (Das et al., 2009), wood, bamboo, wheat straw and flax fibers (Chen et al., 2011), bagasse, rice straw, cotton stalk (El-Sakhavi and Hassan, 2007), and raw cotton linter (Morais et al., 2013).

Cellulose nanocrystalline aerogels can be prepared from NCC. Aerogels are ultra-light and an important class of porous materials usually prepared by subjecting a wet-gel precursor to critical-point-drying (CPD) or lyophilization (freeze-drying) in order to remove the solvent without collapsing the network. Until now, most aerogels have been synthesized from silica (Hrubesh, 1998) or pyrolized organic polymers (Pekala, 1989; Pekala et al., 1998). A characteristic problem, which has restricted their application, is fragility, where mechanical robustness is needed. To overcome this problem, aerogels based on native cellulose nanofibril networks have been shown developed, which reduce brittleness and even flexibility in facile and relevant ways (Paakko et al., 2008). Aerogel properties make them interesting in application as thermal insulators (Gurav et al., 2010), porous catalysts for chemical processes (Gurav et al., 2010; Menzel et al., 2012; Zhang and Riduan, 2012), and porous ceramics for filtration and separation (Luyten et al., 2010). They also have optical applications and function as low-density cores in sandwich structures or as templates for precipitation of inorganic nanoparticles (Olsson et al., 2010).

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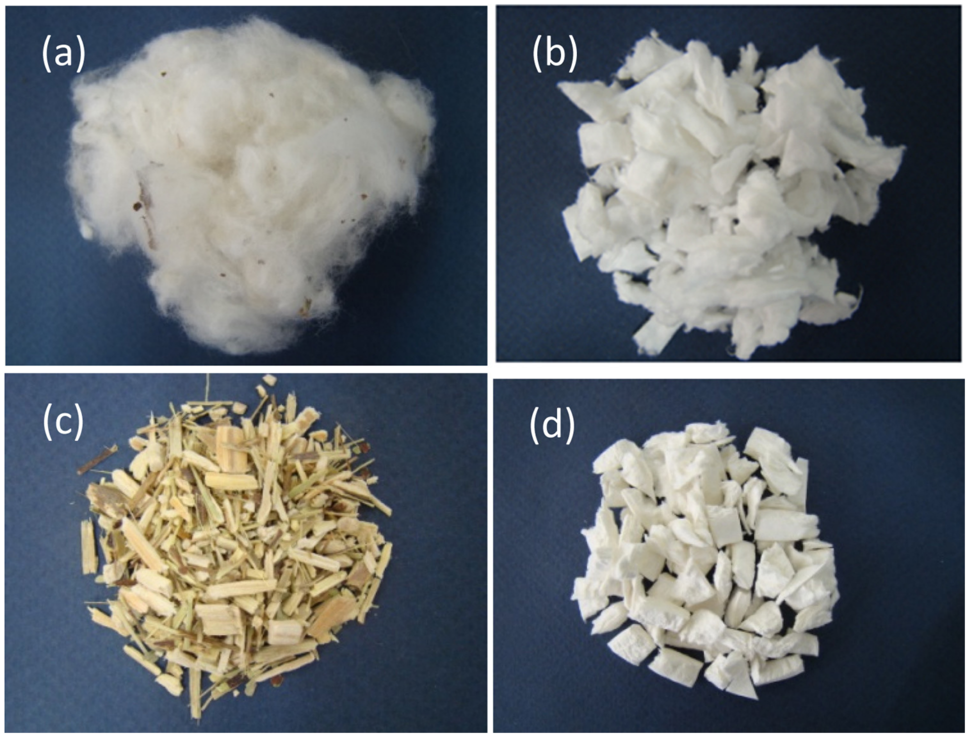

Fig. 1. Photographs of (a) cotton, (b) cotton pulp, (c) cotton stalk, (d) cotton Stalk pulp.

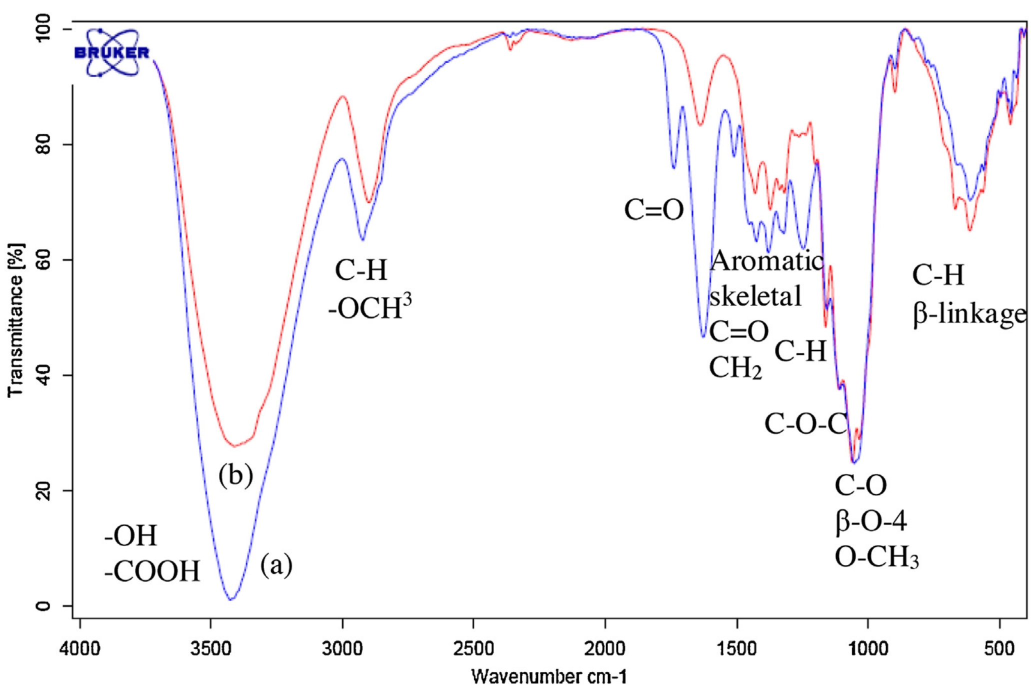

Fig. 2. FT-IR spectra of the (a) cotton stalk, (b) CS-pulp. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Cotton is one of the main field crops in Iran (86,000 t per year). Cellulose content of raw cotton is more than 80% making it a potential source of NCC. The cultivation of cotton generates plant residue equivalent to three to five times the weight of the fiber produced (Silanikove, 1986). The cotton plant residue left after harvest is mostly comprised of stalks (Reddy and Yang, 2009). Currently, cotton stalk is not utilized for any purpose and is mainly burned on the ground since it harbors diseases, which could affect future cotton crops. As a result, it can contribute to the greenhouse effect and pollution of the atmosphere. Since most of this residue is cellulose based materials, it represents a potential source of inexpensive NCC.

The source of cellulose mainly affects different properties of NCC and its aerogel product including the thermal and porosity properties, which are important in their future applications. In this work, pulps were extracted from raw cotton and cotton stalks