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Nanofiber Cellulose as New Generation Natural Materials for Biocomposite Filler

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1. Nanofiber Cellulose Overview

Cellulose, a ubiquitous and renewable biopolymer, has garnered significant attention for its potential in material applications. This overview highlights the properties and applications of cellulose nanofibers, a nanoscale form of cellulose with exceptional properties. Cellulose nanofiber exhibits high surface area-to-volume ratios, inherent crystallinity, and favorable mechanical properties. They can be extracted from various sources using chemical and mechanical treatments, including alkali treatment, bleaching, acid hydrolysis, and ultrasonication. These processes effectively reduce cellulose fibers to the nanoscale, enhancing their properties. Cellulose nanofiber has demonstrated significant potential as reinforcing agents in biocomposites, improving interfacial adhesion, homogeneity, and mechanical strength. Their applications extend to diverse sectors, including biomedicine, packaging, and 3D printing. In biomedicine, Cellulose nanofiber show promise in tissue engineering, drug delivery, and wound healing due to their biocompatibility. Their lightweight yet strong nature and biodegradability make them ideal for sustainable packaging solutions. Moreover, cellulose nanofiber serves as effective reinforcing agents in composites, enhancing the mechanical properties of polymers for applications in automotive and aerospace industries.

Cellulose is naturally abundant biopolymer found in both woody and non-woody plants, offers numerous advantages for material applications. These include its wide availability, non-toxicity, renewability, favorable mechanical properties, and inherent crystalline structure [1–3]. Cellulose can be extracted from various sources using chemical treatments such as delignification and bleaching [4].

In recent years, nanoscale cellulose has garnered significant interest due to its unique properties, including a high surface area-to-volume ratio. Nanocellulose technology holds

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immense potential across diverse sectors, including medicine, construction, and textiles. Among the various types of nanocellulose, cellulose nanocrystals have emerged as particularly promising reinforcing agents for high-performance nanocomposites [5,6]. Cellulose nanofibers are nanoscale cellulose fibers with dimensions ranging from 1 to 100 nm [7]. Cellulose possesses a structure composed of glucose units arranged in a crystalline configuration. This crystalline structure is typically characterized using X-ray diffraction analysis. The characteristic peaks associated with cellulose are observed at 2θ values around of 18° and 22°, corresponding to the amorphous and crystalline regions, respectively [8].

The nanofibers were extracted from water hyacinth fibers subjected to a combination of chemical and mechanical treatments. The chemical treatments involved alkali treatment, bleaching, and acid hydrolysis, while the mechanical treatment consisted of ultrasonication. Alkali treatment and bleaching effectively increased the cellulose content of the fibers compared to the untreated fibers. Acid hydrolysis and ultrasonication played crucial roles in depolymerizing and defibrillating the fibers, reducing them to the nanoscale [9,10]. The incorporation of cellulose nanofibers into polymer matrices represents a promising strategy for enhancing interfacial adhesion, mixture homogeneity, and the mechanical and thermal properties of biocomposites [11–13].

2. Potential Application as Biocomposite filler

Cellulose nanofibers represent a significant innovation in materials science, harnessing the inherent properties of cellulose, the most abundant biopolymer on Earth. Cellulose is a renewable and biodegradable resource, obtainable from various sources, including plants, algae, and bacteria [14–16]. The process of converting cellulose into nanofibers enhances its mechanical properties and expands its surface area [17]. Consequently, cellulose nanofiber finds applications in a wide range of industries.

The potential of cellulose nanofiber is particularly promising in sectors such as biomedicine, packaging, 3D printing, and as fillers in biocomposites [18–20]. In biomedicine, cellulose nanofiber is being explored for their use in tissue engineering, drug delivery systems, and wound healing due to their biocompatibility and ability to promote cell growth [21]. In packaging applications, their lightweight yet strong nature, coupled with their biodegradability, can contribute to more sustainable solutions by reducing reliance on synthetic materials [22,23]. Furthermore, in composite applications, cellulose nanofiber act as effective reinforcing agents for polymers, enhancing mechanical and physical properties while maintaining lightweight characteristics, making them highly relevant to the automotive and aerospace industries [24–26].

Biocomposites are solid materials created by combining two or more substances, where each substance retains its unique characteristics [27,28]. In the fabrication of biocomposites, fillers that leverage the potential of cellulose nanofiber are highly sought after [29]. Several studies report improvements in mechanical properties, thermal stability, and interfacial bonding resulting from the incorporation of cellulose nanofiber into various matrices. For instance, Asrofi et al. [30] developed biocomposites using starch reinforced with cellulose nanofiber extracted from sugarcane bagasse, aiming to create eco-friendly packaging materials. Their production process involved mechanical and chemical treatments, demonstrating that the incorporation of cellulose nanofiber led to improved mechanical properties in the resulting biocomposites.

3. Challenge and Opportunity for Future Research

The exploration of cellulose nanofibers presents both challenges and opportunities across various aspects of their development and application such as: interface bonding between matrix and fiber, biodegradability, biocompostability, process optimization, cost production, hydrophilicity properties, durability and stability.

The current research emphasis on nanoscale cellulose fibers stems from their exceptional properties. Their high surface area-to-volume ratio, lightweight nature, and impressive strength make them ideal for enhancing material performance. This has led to a surge in developing cellulose nanofiber for a wide range of advanced applications, including biomedicine, biosensors, and energy storage separators.

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