State-of-the-Art of Cellulose Nanocrystals and Optimal Method for their Dispersion for Construction-Related Applications

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Abstract

In this paper, we reviewed the existing literature on the fabrication of nanocomposites based on cellulose and cellulose nanocrystals (CNCs), and analyzed their dispersion mechanism with respect to their use in the field of construction. First, the existing literature on CNC-based nanocomposites that exhibit the physical and chemical properties of nanocellulose and CNCs was reviewed. Next, keeping the use of these nanocomposites in the field of construction in mind, we determined the optimal mechanical method for their dispersion as an alternative to the ...ntly used harmful chemical techniques. To ...end, we evaluated the dispersibility of colloidal CNCs using two dispersion methods:

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was found that the difference in the average diameter was reduced by approximately 76% at 1587 × 10^5 Pa during high-pressure dispersion.

Keywords: cellulose nano-crystals (CNC); optimal dispersion; construction applications

1. Introduction

Nanocellulose is a biological material that shows tensile strength that is similar to that of steel or Kevlar (100 to 160 GPa) along with low density (0.8 to 1.5 g/cm^3), high specific surface area, and good biodegradability [1]. Given these advantages, it is being explored for use in various devices and fields, including packaging materials, biomedical devices, adhesives, and electronic and electrical materials [2,3,4,5,6,7,8,9,10,11,12,13,14,15].

Recently, Cao et al. [16] explored novel cellulose cement composites with improved mechanical performance based on cellulose nanocrystals (CNCs). CNCs are environmentally friendly because they can be produced from abundantly available natural sources and are biodegradable in nature. Scanning electron microscopy (SEM) analysis has revealed that CNCs dispersed in an unhydrated cement core act as water channels and enhance hydration in the core, thus improving the strength of the ...nt.

...lain [17] studied the Young's modulus of nanocellulose with the density of crystalline size and zeta potential of the CNC particles. It was found that the difference in the average diameter was reduced by approximately 76% at 1587 × 10^5 Pa during high-pressure dispersion.

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1. Introduction

Nanocellulose is a biological material that shows tensile strength that is similar to that of steel or Kevlar (100 to 160 GPa) along with low density (0.8 to 1.5 g/cm^3), high specific surface area, and good biodegradability [1]. Given these advantages, it is being explored for use in various devices and fields, including packaging materials, biomedical devices, adhesives, and electronic and electrical materials [2,3,4,5,6,7,8,9,10,11,12,13,14,15].

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Alain [17] studied the Young's modulus of nanocellulose with the density of crystalline cellulose of approximately 1.5–1.6 g/cm^3. Further, it is known that CNCs are stronger than steel (Young's modulus of 200–220 GPa, density of approximately 8 g/cm^3.) While the process for producing CNCs is a complex one, the final product suggests improvements in the cement composites by improving mechanical properties. Calcium silicate hydrate (CSH) gel formation was improved in CNC cement mortar, with the compressive strength of the mortar being 42–45% higher than that of conventional cement mortar. The formation of the CSH gel improved the strength of the cement by improving its hydration. In order to quantify the performance of cement composites based on CNCs, their degree of hydration was measured using an isothermal calorimeter and a thermogravimetric analyzer [18,19].

Studies on the application of cement to conventional CNCs have been carried out only in some strength studies using optimal mixing conditions. Ultrasonic methods are primarily used to disperse CNCs [16,18,19,20,21]. However, ultrasonic dispersion techniques have certain limitations with respect to the production of cement paste and mortar, because they can only produce small amounts of CNC suspensions (10–250 mL by Sonics and ...ssor USA). When attempting to produce large amounts of CNC suspensions, as is the case when making concrete mixtures, the ultrasonic dispersion equipment may exhibit problems caused by prolonged use.

Therefore, methods should be developed that allow one to prepare CNC-based concrete on a large scale while causing fewer equipment problems. In this study, we attempted to determine the optimal CNC dispersion conditions based on an evaluation of the previously reported dispersion data with the aim of using CNCs as a construction material.

2. Review of Existing Research

We reviewed previous studies on cellulose and cellulose nanomaterials that are relevant to the field of construction. Table 1 summarizes the review of the existing literature on CNCs.

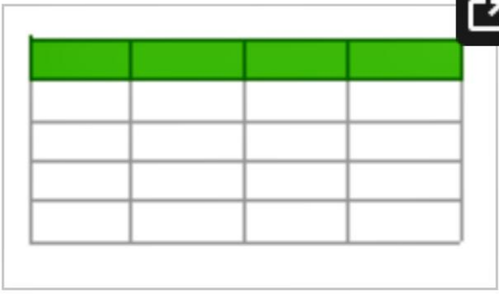
Table 1. Review of existing literature on cellulose nanocrystals (CNCs).

3. Application of CNCs

3.1. CNC-Based Nanocomposites

the case of nanostructured organic composites, the surface area between the filler material and the organic matrix must be large. The dispersibility of the filler is the most important factor affecting the available surface area. If the dispersion is poor, the filler will form aggregates owing to van der Waals bonding; this will reduce the surface area in contact with the organic material and result in poor-quality nanocomposites. In addition, strong bonding at the interface between the filler and the organic material is essential. Otherwise, any external force acting on the nanocomposite will not be transferred to the filler, resulting in poor mechanical performance. CNCs can be used as reinforcing materials in multiphase composite materials based on polymers, as they lead to significant improvements in the mechanical strength, even at very low volume fractions. In addition, CNCs have been employed in biomimetic foams, reinforced paper, and flexible panels for flat panel electronics and displays [32]. **Table 2** lists the various technologies that currently use nanocellulose materials.

Table 2. Use of nanocellulose in the industry.



se of CNCs in Construction Applications

The use of nanomaterials in existing