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Recent review on synthesis, evaluation, and SWOT analysis of nanostructured cellulose in construction applications

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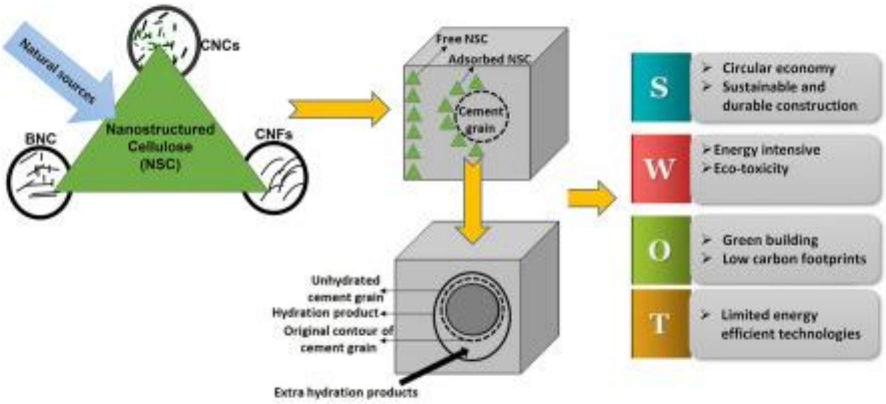
Abstract

In recent years, nanotechnology has become an essential means of producing sustainable and engineered materials, resulting in high value-added products in the construction industry. Nanostructured cellulose (NSC) is a next-generation sustainable and eco-friendly material due to its favorable physicochemical characteristics for various construction industry applications. The incorporation of NSC as a green reinforcement material in concrete has exhibited promising technical, environmental, and economic merits. The presence of NSC in concrete structures has shown significant improvement in mechanical strength, durability, and microstructure properties. In this present review, a brief overview of the different NSC synthesis processes, as well as their yield and physicochemical characteristics is presented. The review critically evaluates the performance of NSC in concrete applications as a cementitious material and fiber additive to understand and demonstrate the reaction kinetics, rheology, mechanical properties, durability, and microstructural characteristics. The reaction mechanisms involved in enhancing the properties of NSC-engineered cementitious composites are also compiled from the literature. The shortcomings in the synthesis and evaluation of the developed binders are highlighted. Strengths, weaknesses, opportunities, and threats (SWOT) analysis was used to evaluate NSC in construction applications for insight into the relevance of its adoption and the interpretation of an existing or planned NSC business model. Moreover,

potential recommendations have been drawn to bridge the knowledge gap between what is known and the future use of NSC in civil engineering applications.

Graphical abstract



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Introduction

The utilization of eco-friendly, sustainable, and biologically-based nano and micromaterials has gained enormous interest over the past few years and has been extensively explored for various applications [1]. Anselme Payen - a French scientist, was the first to extract a compound from wood and named it cellulose in 1838. In today's world, cellulose nanomaterials have recognized as a precursor having potential to solve a wide range of global industrial problems [2]. Cellulose is a highly abundant, sustainable, and renewable material found worldwide that has been widely investigated as a potential precursor for producing advanced materials [3]. The approximate annual production of cellulose has significantly increased to between 75 and 100 billion tons due to its availability from various agricultural products, different types of wastes, advancements in production, and modification of its properties [4].

Over the last decade, significant attention has been directed towards the production, modification, and application of three types of nanostructured cellulose (NSC), namely, cellulose nanocrystals (CNCs), cellulose nanofibers (CNFs), and bacterial nano cellulose (BNC). NSC possesses unique physicochemical properties, such as low density (1.5–1.6 g/cm^3), high surface area (100–500 m^2/g), high aspect ratio, high crystallinity, and excellent mechanical properties (a tensile modulus of 56–220 GPa and a tensile strength of 10 GPa). They also have a low thermal coefficient and permeability, reactive hydroxyl groups, nontoxicity, and biodegradability [3,5]. These exceptional intrinsic characteristics have revealed NSC as a highly promising non-toxic and emerging nanomaterial for a wide range of applications, including construction [6], biomedicines [7], insulation [8], waste water treatment [9] and packaging [10]. NSC materials have exhibited excellent characteristics in the construction industry, rendering them green and low-cost reinforcing materials suitable for the production of high-performance and sustainable concrete [11].

Construction of long-span concrete bridges, dams, and many other construction components require reinforcing material due to the inherent brittleness of concrete. Different types of reinforcing materials, such as steel, glass, other synthetic, and naturally abundant materials of varying sizes (macro, micro, or nano), are admixed with concrete to improve its toughness, tensile strength, and energy absorption capacity [[12], [13], [14], [15]]. However, some of the traditional reinforcing additives are non-durable, poorly shaped, and have high energy and production costs. For example, glass fibers provide poor bonding, exhibit less resistance to alkalis, and yield lower compressive and flexural strengths [[16], [17], [18]]. Carbon fibers are costly, as they are the aftermath of an energy-intensive process [19]. Owing to these drawbacks, there has been a shift towards the use of sustainable, low-cost, and environmentally friendly materials that yield high quality concrete structures. In this regard, nanotechnology has been recognized as a promising solution for construction materials. According to reviews of nanotechnology in the field of construction and building materials, it has been discovered that nanoparticles are capable of significantly enhancing the strength and durability of cementitious composites [20].

With the growing interest in nanomaterials in the construction industry, NSC materials have emerged as promising, versatile, and high-performance bio reinforcing agents for low-cost green concrete production [[21], [22], [23]]. Practically, one of the main benefits of utilizing cellulose-based materials in the cement and concrete industry can be ascribed to this class of materials being the most available biopolymer on Earth [24]. Other benefits of cellulose-based materials include the potential for significant improvement in concrete flexural and compressive strengths [[25], [26], [27]], an increased hydration rate due to release of water content [28], improvement in shrinkage rate [29], and increased freeze-thawing resistance [30]. Therefore, beside their technical merits, the application of NSC in the construction industry is an eco-friendly approach towards achieving a circular bioeconomy and reducing the carbon footprint [4].