



Nanocellulose in Cementitious Composites: Rheology, Buildability, Interlayer Bonding, and Mechanical Performance — A Systematic Literature Review

Agung Prabowo^{*1}, Tegar Abdillah Ramadhan², and Ibnu Eka Rahayu¹

¹Chemical Engineering Department, Politeknik Negeri Samarinda, Samarinda, 75131, Indonesia

²Civil Engineering Department, Politeknik Negeri Samarinda, Samarinda, 75131, Indonesia

*Corresponding Author: agungprabowo@polnes.ac.id

ARTICLE INFO

Article history:

Received 28 August 2026

Revised 17 September 2026

Accepted 29 September 2026

Available online 08 October 2026

E-ISSN: [2656-1492](#)

How to cite:

Agung Prabowo, Tegar Abdillah Ramadhan and Ibnu Eka Rahayu. Nanocellulose in Cementitious Composites: Rheology, Buildability, Interlayer Bonding, and Mechanical Performance — A Systematic Literature Review. Journal of Chemical Natural Resources. 2026. 8(1):43-60.

ABSTRACT

Nanocellulose, comprising cellulose nanocrystals (CNC), cellulose nanofibers (CNF), and bacterial nanocellulose, is gaining attention as a bio-based additive for modifying the fresh- and hardened-state behaviour of cementitious composites, yet the evidence remains scattered across cement paste, mortar, geopolymer, ultra-high-performance concrete (UHPC), and 3D-printed systems. This systematic review synthesises available evidence on nanocellulose-modified cementitious composites, focusing on rheology, buildability, interlayer bonding, and mechanical performance. Following the PRISMA 2020 guideline, a search of the ScienceDirect database identified 127 records, of which 37 met the eligibility criteria: primary, English-language, peer-reviewed articles reporting nanocellulose incorporation into a cementitious or geopolymer binder with at least one of the four target outcomes measured. Data on nanocellulose type and dosage, binder system, and reported outcomes were extracted and synthesised narratively. Low-dosage CNC and CNF additions (typically below 0.5 wt% of binder) were consistently associated with increased yield stress and viscosity, delayed or modified hydration, and higher early-age compressive and flexural strength, attributable to internal curing, nucleation, and nanoscale reinforcement; excessive dosages tended to cause agglomeration and porosity increases that offset these gains. Studies addressing buildability and interlayer bonding directly, mostly concerning 3D-printed systems, were comparatively few. The certainty of evidence is limited by heterogeneity in nanocellulose source, dosage, and testing protocol, by reliance on laboratory-scale specimens, and by the restriction of the search to a single database. Nanocellulose is a viable rheology-modifying and strength-enhancing additive for cementitious systems, and dosage optimisation and standardised testing protocols remain priorities for future research. The evidence base is markedly uneven across outcomes (mechanical performance, 35 of 37 studies; rheology, 12; buildability, 6; interlayer bonding, 2), and screening and appraisal relied on titles, abstracts and metadata rather than full-text articles, which the Discussion identifies as the principal limitations on the certainty of these conclusions.

Keyword: Nanocellulose, Cellulose Nanocrystals, Cellulose Nanofibers, Cementitious Composites, Rheology

ABSTRAK

Nanoselulosa, yang meliputi *cellulose nanocrystals* (CNC), *cellulose nanofibers* (CNF), dan nanoselulosa bakteri, semakin mendapat perhatian sebagai aditif berbasis hayati untuk memodifikasi perilaku komposit berbasis semen pada kondisi segar maupun setelah pengerasan. Namun, bukti yang tersedia masih tersebar pada berbagai sistem, termasuk pasta semen, mortar, geopolimer, *ultra-high-performance concrete* (UHPC), dan sistem pencetakan 3D. Tinjauan sistematis ini mensintesis bukti mengenai komposit berbasis semen yang dimodifikasi nanoselulosa, dengan fokus pada reologi, *buildability*, ikatan antarlapis, dan kinerja mekanik. Mengikuti pedoman PRISMA 2020, pencarian pada basis data ScienceDirect mengidentifikasi 127 artikel, dengan 37 artikel memenuhi kriteria kelayakan, yaitu artikel primer berbahasa Inggris dan *peer-reviewed* yang melaporkan penambahan nanoselulosa ke dalam pengikat berbasis semen atau geopolimer serta mengukur setidaknya satu dari empat parameter yang ditargetkan. Data mengenai jenis dan dosis nanoselulosa, sistem pengikat, serta



This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International.
<https://doi.org/10.32734/jcnar.v8i1.27151>

hasil yang dilaporkan diekstraksi dan disintesis secara naratif. Penambahan CNC dan CNF dalam dosis rendah (umumnya $<0,5\%$ berat pengikat) secara konsisten dikaitkan dengan peningkatan *yield stress* dan viskositas, perlambatan atau modifikasi hidrasi, serta peningkatan kuat tekan dan kuat lentur pada usia awal, yang dikaitkan dengan mekanisme *internal curing*, nukleasi, dan penguatan pada skala nano. Sebaliknya, dosis berlebihan cenderung menyebabkan aglomerasi dan peningkatan porositas sehingga mengurangi keuntungan tersebut. Studi yang secara langsung membahas *buildability* dan ikatan antarlapis, terutama pada sistem pencetakan 3D, masih relatif terbatas. Tingkat kepastian bukti dibatasi oleh heterogenitas sumber dan dosis nanoselulosa, protokol pengujian, ketergantungan pada spesimen berskala laboratorium, serta pembatasan pencarian pada satu basis data. Basis bukti juga menunjukkan ketidakmerataan antarparameter, dengan 35 dari 37 studi membahas kinerja mekanik, 12 reologi, 6 *buildability*, dan hanya 2 ikatan antarlapis. Selain itu, penyaringan dan penilaian didasarkan pada judul, abstrak, dan metadata, bukan teks lengkap, yang menjadi keterbatasan utama terhadap kepastian kesimpulan. Secara keseluruhan, nanoselulosa menunjukkan potensi sebagai aditif untuk memodifikasi sifat reologi dan meningkatkan kekuatan sistem berbasis semen, sementara optimasi dosis dan standarisasi protokol pengujian tetap menjadi prioritas penelitian selanjutnya.

Kata Kunci: Nanoselulosa, Nanokristal Selulosa, Nanofiber Selulosa, Komposit Sementisius, Reologi

1. Introduction

The cement and concrete industry is one of the largest contributors to anthropogenic carbon dioxide emissions, owing mainly to the energy-intensive production of Portland cement and the process-related CO₂ released during clinker formation. Growing attention has therefore turned to strategies that reduce cement consumption, improve material efficiency and durability, and raise construction performance without compromising structural integrity. Bio-based nanomaterials have drawn particular interest within this effort, since they can deliver functional improvements at relatively low addition levels while supporting a shift toward more sustainable construction materials. Nanocellulose is one such material: derived from renewable biomass such as wood pulp, agricultural residues, and bacterial fermentation, it is generally classified into cellulose nanocrystals (CNC), cellulose nanofibers or nanofibrils (CNF), and bacterial nanocellulose (BNC). These forms differ in morphology, aspect ratio, crystallinity, and surface chemistry, which leads to distinct interactions with cementitious matrices [1]. The relatively rigid, rod-like structure of CNC tends to promote heterogeneous nucleation and modify the rheology of cement-based suspensions, whereas the high aspect ratio and interconnected fibrillar network of CNF contributes more to water retention and microcrack bridging.

Interest in nanocellulose-modified cementitious materials stems from both a material-performance and a construction-process perspective. In conventional cement paste, mortar, concrete, and geopolymers systems, nanocellulose has been investigated for its ability to modify hydration, refine pore structure, improve internal curing, control moisture migration, and enhance early-age and hardened-state mechanical properties. The nanoscale reinforcing network it forms may also improve resistance to microcracking and shrinkage, with consequences for the long-term integrity of the matrix. These effects, however, are not governed by the presence of nanocellulose alone; they depend strongly on nanocellulose type, dosage, dispersion, surface characteristics, binder composition, water-to-binder ratio, and interaction with other admixtures. A systematic assessment is therefore needed to determine how consistent the reported improvements are across different cementitious systems, and under which conditions nanocellulose delivers the greatest benefit.

Beyond conventional casting, the rise of additive manufacturing has introduced new requirements for the fresh-state behaviour of cementitious materials. Three-dimensional concrete printing relies on controlled extrusion and layer-by-layer deposition without conventional formwork, so a printable mixture must be flowable and extrudable during pumping and deposition while also building up enough structural strength to hold its shape immediately after placement. Balancing these competing rheological demands is not straightforward: too low a yield stress or viscosity causes deformation and poor shape retention, while too much flow resistance hinders pumping and extrusion. The quality of the bond between successive printed layers matters just as much, since a weak interlayer bond creates planes of weakness that reduce the mechanical performance of the printed structure. Nanocellulose has attracted interest as a bio-based rheology modifier and reinforcing agent that could address several of these challenges at once [2]; its capacity to form interconnected

nanoscale networks, retain water, and influence structural build-up suggests it may improve extrudability, buildability, and interlayer bonding while also contributing to hardened-state mechanical performance.

Because rheology, buildability, interlayer bonding, and mechanical performance are closely linked rather than independent, this review treats them as interconnected outcomes. Changes in rheology affect water distribution, particle arrangement, hydration, and pore structure, which in turn affect mechanical performance; improved structural build-up may enhance buildability but could reduce extrudability or the effective contact area between printed layers. Understanding how nanocellulose characteristics and dosage relate to these four outcomes together, rather than in isolation, is therefore essential to judging its practical potential as a multifunctional bio-based additive.

The literature on nanocellulose in cement-based materials remains fragmented across material types, nanocellulose classifications, and application contexts, and previous reviews have generally covered only part of this space. Al-Askary et al. reviewed cellulose nanocrystals in cement-based composites broadly but did not examine 3D-printed cementitious systems in depth [1]; Jin et al. reviewed micro- and nanoscale additives for 3D concrete printing but treated nanocellulose as one additive among several rather than evaluating it systematically as a distinct bio-based material [2]; and Hamada et al. examined natural fibres in cement concrete, but their focus was predominantly on macro- and micro-scale fibre reinforcement rather than nanoscale cellulose [3]. None of these reviews integrates evidence on nanocellulose across both conventional and additively manufactured cementitious systems. More specifically, systematic evidence is lacking on how different nanocellulose types and dosages influence rheology, buildability, interlayer bonding, and mechanical performance as interconnected outcomes. This matters because nanocellulose performance cannot be judged on strength alone: a 3D-printed mixture with high compressive strength may still be unsuitable if it prints poorly or bonds weakly between layers, while a mixture with favourable rheology may not deliver sufficient hardened-state strength. A synthesis that considers these outcomes together is needed to separate consistent findings from formulation-specific effects, identify dosage–performance relationships, and pinpoint where the evidence remains thin or contradictory.

Accordingly, this systematic review synthesises primary research on nanocellulose-modified cementitious and geopolymer systems, focusing on how nanocellulose characteristics relate to four performance domains: rheology, buildability, interlayer bonding, and mechanical performance. It follows the PRISMA 2020 reporting guideline to identify, screen, and synthesise the relevant studies [4]. The population comprises cementitious and geopolymer composite systems — cement paste, mortar, concrete, geopolymer or alkali-activated binders, and 3D-printed formulations; the intervention is CNC, CNF, or BNC used as an additive or reinforcing agent; and the comparator is a plain or reference mixture without nanocellulose. Outcomes of interest are fresh-state rheological behaviour, buildability or shape retention, interlayer bonding strength, and hardened-state mechanical performance (compressive, flexural, and tensile strength). Specifically, the review aims to identify the types and characteristics of nanocellulose used, evaluate how nanocellulose type and dosage affect rheological and printability-related properties, assess effects on interlayer bonding and mechanical performance, examine relationships between mixture composition and reported outcomes, and identify key research gaps and priorities for future work. By bringing together evidence from conventional and additively manufactured cementitious systems, this review seeks a more complete understanding of nanocellulose as a multifunctional bio-based additive that can support more sustainable, higher-performance cementitious materials.

2. Methods

2.1. Protocol and Registration

This review was not registered prospectively in PROSPERO or an equivalent registry. The eligibility criteria were revised once during the review: the population was initially restricted to 3D-printed cementitious systems only, but was broadened after an initial screening round to include conventional (cast) cementitious and geopolymer composites, because the narrower scope yielded too small an evidence base (seven studies) for a meaningful synthesis. This post hoc broadening was a deviation from the originally intended scope rather than a planned, staged search, and it was not accompanied by a corresponding revision of a prospectively registered protocol, since none existed. The absence of prospective registration and the unregistered change in eligibility criteria are acknowledged as methodological limitations of this review, and are revisited in the Discussion.

2.2. Eligibility Criteria

Eligibility was defined using a Population–Intervention–Comparator–Outcome (PICO) framework, summarised in Table 1.

Table 1. Eligibility criteria for study selection

Criterion	Inclusion	Exclusion
Population	Cementitious or geopolymer composite systems (cement paste, mortar, concrete, geopolymer/alkali-activated binders, including 3D-printed formulations)	Non-cementitious matrices (e.g., polymer, ceramic, or standalone nanocellulose materials with no cementitious application)
Intervention	Incorporation of nanocellulose (CNC, CNF/nanofibrillated cellulose, bacterial nanocellulose, or nanocrystalline cellulose) as an additive or reinforcing agent	No nanocellulose component; use of micro-scale or conventional (non-nano) natural fibres only
Comparator	Plain or conventionally fibre-reinforced mixtures without nanocellulose (implicit or explicit control)	Not applicable / no comparator reported
Outcome	At least one of: fresh-state rheology, buildability/shape retention, interlayer bonding strength, or hardened-state mechanical performance	No relevant outcome reported (e.g., studies limited to chloride ingress, water transport, or non-target durability metrics only)
Study design	Primary, empirical (experimental/laboratory) research	Review articles, commentaries, or non-empirical studies
Publication type	Peer-reviewed journal article	Conference proceedings, book chapters, theses, preprints
Language	English	Non-English-language publications

2.3. Information Sources

Records were identified through a search of the ScienceDirect database. No trial registers, grey literature sources, or citation-searching methods were used. The search was last conducted in August 2026.

2.4. Search Strategy

The following representative Boolean search string was applied to ScienceDirect and is reconstructed here from the composition of the retrieved record set: (“nanocellulose” OR “cellulose nanocrystal*” OR “cellulose nanofib*” OR “nanofibrillated cellulose” OR “bacterial cellulose” OR “nanocrystalline cellulose”) AND (“cement” OR “concrete” OR “mortar” OR “geopolymer” OR “cementitious”) AND (“rheolog” OR “buildability” OR “interlayer bond” OR “mechanical propert” OR “compressive strength” OR “flexural strength”). Searches were limited to journal articles published in English, with no restriction on publication date; the retrieved records spanned 2023 to 2026. Because the exact query as executed was not preserved at the time of searching, the string above is a best-effort reconstruction rather than a verified record, which departs from PRISMA 2020 reporting standards for search strategies; this is treated as a limitation of the review (Section 4.3), and any update of this work should log and retain the verbatim search string and export files at the time of searching. The search was limited to a single database, ScienceDirect; Scopus, Web of Science and PubMed/Google Scholar were not searched, mainly owing to resource and access constraints, and this restriction is likely to have omitted eligible studies, particularly those published in journals not indexed by ScienceDirect.

2.5. Selection Process

Title and abstract screening were performed by one reviewer against the eligibility criteria in Table 1, with a second reviewer independently verifying the inclusion decisions; disagreements were resolved by discussion. No automation tool (e.g., Rayyan or ASReview) was used.

2.6. Data Collection Process

Data were extracted from the titles, abstracts, and available bibliographic metadata of eligible records by one reviewer and cross-checked by a second reviewer, with disagreements resolved by discussion. No standardised electronic data-collection form or software was used; data were tabulated directly into the study characteristics table (Table 2). This abbreviated, title/abstract/metadata-based extraction departs from full-text-based systematic review practice and instead follows the more limited abstraction approach described for rapid and resource-constrained reviews [43]; it was adopted because full-text access to a subset of the 37 included articles was not available within the resources of this review. Consequently, this review is more accurately characterised as an abbreviated (rapid) systematic review than a full-text-based systematic review, and dosage values, mechanisms and quantitative findings reported in Table 2 should be verified against the original full texts before being relied upon for mix design or further quantitative synthesis. This constraint, and its implications for the certainty of the findings, are discussed further in Section 4.3.

2.7. Data Items

For each included study, the following data items were sought: nanocellulose type and source, tested or optimum dosage range, cementitious/geopolymer binder system, the outcome domain(s) reported (rheology, buildability, interlayer bonding, mechanical performance), and the principal quantitative findings for the relevant outcome(s).

2.8. Study Risk of Bias Assessment

Methodological quality was appraised using the Mixed Methods Appraisal Tool (MMAT), version 2018 [5], applying the criteria for quantitative non-randomised studies as the closest available category for laboratory-based experimental materials research. Appraisal was conducted by one reviewer and verified by a second. Because appraisal was based on titles and abstracts rather than full manuscripts, ratings for criteria requiring methodological detail not typically reported in an abstract (e.g., confounding control) are reported as “cannot tell” rather than inferred. MMAT was selected because, unlike tools designed specifically for randomised or clinical designs, it provides a single set of screening questions applicable across quantitative non-randomised, quantitative descriptive and mixed-methods designs, and its quantitative non-randomised category maps reasonably well onto controlled, non-randomised laboratory comparisons of the kind reported in the included materials-science studies (a treated mixture compared with an untreated control at a fixed time point). No appraisal tool has been validated specifically for laboratory-based materials science, so this represents an adaptation rather than a validated application of MMAT, and the appraisal should be read as an indicative, transparency-focused screen rather than a formal risk-of-bias judgement.

2.9. Effect Measures

Not applicable. No meta-analytic pooling of effect sizes was undertaken because of substantial heterogeneity in nanocellulose type, dosage, binder system, and outcome metrics across the included studies; findings are reported using the effect measures (e.g., percentage change in compressive strength, yield stress) as presented in the original studies.

2.10. Synthesis Methods

A narrative synthesis was conducted. Studies were grouped by outcome domain (rheology, buildability, interlayer bonding, mechanical performance) and, within each domain, compared according to nanocellulose type, dosage, and binder system to identify consistent dosage–response patterns. No subgroup analysis, meta-regression, or sensitivity analysis was performed, given the absence of pooled effect estimates and the exploratory nature of the synthesis.

2.11. Reporting Bias Assessment

A formal assessment of reporting bias (e.g., funnel plot analysis) was not undertaken, as this is not applicable to a narrative synthesis of heterogeneous laboratory studies without pooled effect sizes. The restriction of the search to a single database is noted as a factor that may increase the risk of missing relevant records.

2.12. Certainty Assessment

The GRADE approach was not formally applied, as it is designed primarily for intervention research in clinical and public health contexts. Instead, the certainty of evidence for each outcome domain was considered narratively with reference to the number of independent studies, consistency of direction of effect, and

methodological transparency. Specifically, certainty was rated “moderate” where an outcome was addressed by 15 or more independent studies with a consistent direction of effect across different binder systems and nanocellulose types; “low” where an outcome was addressed by 6–14 studies, or where direction of effect was consistent but concentrated in a narrow range of materials or equipment; and “very low” where an outcome was addressed by fewer than 6 studies. These thresholds are a narrative convention adopted for this review, not a validated grading framework, and are reported here explicitly so that the certainty ratings in Section 3.6 are reproducible.

3. Results

3.1. Study Selection

The ScienceDirect search identified 127 records. After removing one duplicate, 126 records were screened at the title/abstract level, of which 71 were excluded because they did not report a nanocellulose component. The remaining 55 records were assessed against the full eligibility criteria using the available titles, abstracts, and keywords. Eighteen records were excluded at this stage: six for addressing a non-cementitious or otherwise ineligible population (e.g., nanocellulose applied in phase-change materials, wastewater treatment, or soil-based bricks rather than a cementitious binder system), two for being review articles rather than primary research, and ten for not reporting any of the four target outcomes (e.g., studies limited to chloride ingress or water-transport properties). Thirty-seven studies met all eligibility criteria and were included in the synthesis. The study selection process is summarised in Figure 1.

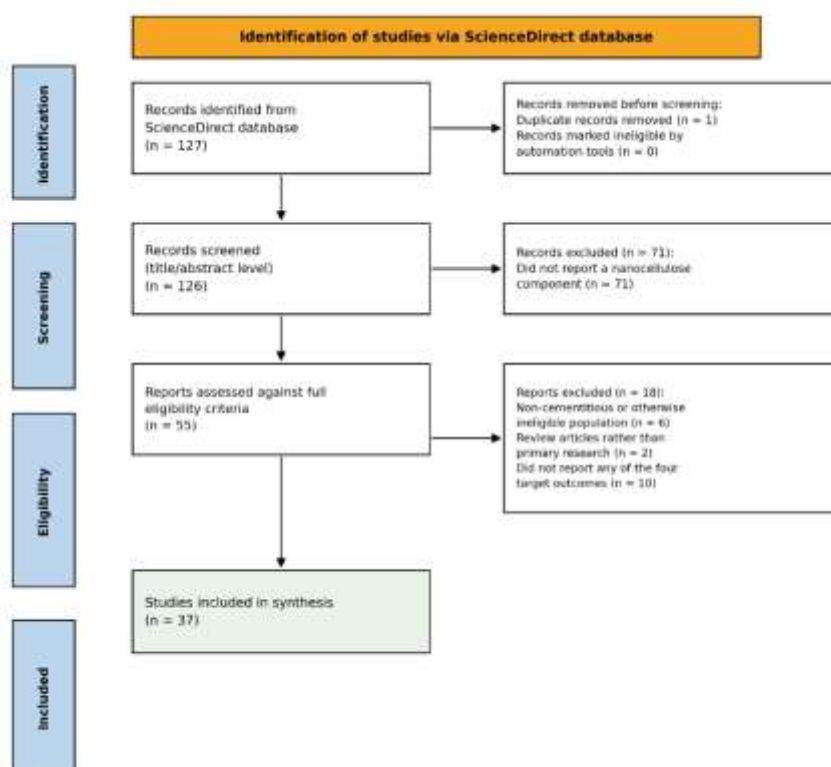


Figure 1. PRISMA 2020 flow diagram of study selection

3.2. Study Characteristics

The 37 included studies were published between 2023 and 2026 across eleven journals, predominantly Construction and Building Materials (n = 16), Journal of Building Engineering (n = 7), and Cement and Concrete Composites (n = 5). Cellulose nanocrystals (CNC or NCC) were the most frequently studied nanocellulose type (approximately 20 studies), followed by cellulose nanofibers/nanofibrils (CNF/NFC, approximately 13 studies) and bacterial nanocellulose (3 studies); several studies combined nanocellulose with a secondary reinforcement phase such as graphene oxide, steel fibre, or layered double hydroxides. In terms of binder system, the majority of studies evaluated nanocellulose in cement paste, mortar, or plain concrete (approximately 24 studies); a smaller subset addressed ultra-high-performance concrete or geopolymers/alkali-activated systems (approximately 8 studies); and seven studies specifically addressed 3D-printed cementitious

systems. Table 2 summarises the nanocellulose type, dosage, binder system, outcome domain(s), and key findings for each included study. For consistency, this review uses CNC (cellulose nanocrystals) and CNF (cellulose nanofibers/nanofibrils) as the primary terms throughout the text; NCC and NFC, used by some original authors for the same materials, are treated as synonyms of CNC and CNF respectively and are retained in Table 2 only where they reproduce a study's own terminology. The temporal distribution of the included studies by publication year and nanocellulose type is presented in Figure 2, and the cross-tabulation of nanocellulose type against binder system and application/outcome domain is presented in Figure 3.

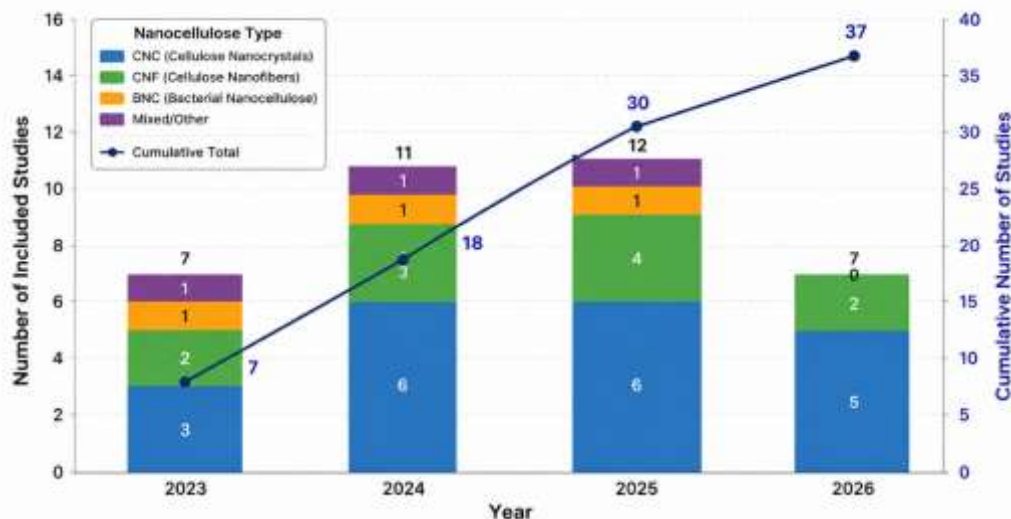


Figure 2. Temporal distribution of included studies by publication year and nanocellulose type (N = 37)



Figure 3. Cross-tabulation of nanocellulose type by binder system and application/outcome domain (N = 37 studies)

Table 2. Characteristics and key findings of included studies (N = 37)

Study	Nanocellulose type	Dosage	Binder system	Outcome domain(s)	Key finding
Kaur et al. [6]	Bacterial cellulose	0–0.75% (opt. 0.3%)	Cement composite	Mechanical	Compressive strength +40–41% at 0.3%; agglomeration and strength loss above 0.5%
Lu et al. [7]	CNC	<0.1 wt% (opt.)	Foamed concrete grout	Rheology, Mechanical	Compressive/flexural strength +44.7%/+38.5% at 0.1 wt% with CO ₂ curing; excess CNC reduced strength

S. Zhang et al. [8]	CNF (in-situ)	0–0.5 (CNF ratio)	Geopolymer (EGC/PVA fibre)	Mechanical	Compressive strength +46.2%; tensile strength +143%; tensile strain 5.94% at optimum
Liu et al. [9]	NCC	0.5 wt% (opt.)	Cement paste	Mechanical	Compressive strength +21.5%; drying shrinkage –28.2%; reversed at 1.0 wt%
Jaha et al. [10]	CNC (dual-template)	Not dose-varied	Cementitious composite (C-S-H)	Mechanical	Flexural strength 123 MPa at density 0.91 g/cm ³ ; toughness 3264 kJ/m ³
Haj Fattouh et al. [11]	CNF (wood/pineapple/chitin)	0.1 wt%	Mortar	Rheology, Mechanical	Flexural strength +28–37.7%; compressive strength +4–14% depending on fibre source
Rajendran et al. [12]	CNC	Not specified (process model)	3D-printed cementitious mixture (LCA)	Mechanical (LCA)	Minimum selling price \$423/m ³ ; GWP 1704.81 kg CO ₂ -eq/m ³ ; favourable per-strength-unit economics
Rahmawati et al. [13]	Nanocellulose (bemban fibre)	0–3% (opt. 1%)	Cement-based composite	Mechanical	Compressive strength +9.38% at 1% BFNC
Fan et al. [14]	CNF + graphene oxide	0.05% CNF + 0.025% GO	Cement mortar	Mechanical	Flexural strength +44.72–72.96%; compressive strength +25.14–26.71%
Salifu et al. [15]	NFC + CNC	NFC 0–0.25%; CNC 0.05–0.15%	3D-printed concrete (limestone-blended cement)	Rheology, Buildability, Interlayer bonding, Mechanical	Optimum at w/b 0.38, NFC 0.25%, CNC 0.15%; balanced rheology, strength and interlayer bond
de Souza et al. [16]	MCC + NFC	Up to 0.04% NFC; MCC range	Cement paste	Rheology	Yield stress +136% (0.04% NFC) and +94% (MCC); non-monotonic static behaviour for MCC
L. Zhang et al. [17]	CNF@LDH nanocomposite	0.3 wt% (opt.)	Geopolymer	Mechanical	Compressive +25.8%, flexural +28.2%, modulus +30.5% at 0.3 wt%; workability loss at 0.5 wt%
Pan et al. [18]	CNF (dual organic network)	Not specified (SIPN system)	3D-printed concrete (3DPC)	Buildability, Interlayer bonding, Mechanical	Flexural +138.92%, compressive +52.82%, interlayer bond +87.5%; harmful pores –89.61%
Soares et al. [19]	Bacterial NFC	0.05–0.25 wt%	Lightweight mortar (vermiculite)	Rheology, Mechanical	Compressive strength –18.23% at 0.25%; improved water retention and workability at 0.15%

dos Reis et al. [20]	CNF		0.1–0.3 wt%	Lightweight mortar	Rheology, Mechanical	Compressive strength +52.36%; nanoindentation modulus +16.4% at 0.3%
Zhu et al. [21]	CNC		Not specified	Alkali-activated recycled UHPC	Mechanical (pore structure)	Reduced porosity and refined pore size; mitigated drying shrinkage
Safanelli et al. [22]	CNC		0.015–0.500 wt%	Cement paste / 3D-printed concrete	Rheology, Buildability	Yield stress and structuring rate increased at higher CNC; hydration delayed up to 22 h; improved buildability
Guo et al. [23]	PEGylated (PCNC)	CNC	0.1% (opt.)	Cement paste (HPC/UHPC context)	Rheology, Mechanical	Flowability +10.73%; 28-day compressive strength +30.63% at optimum PCNC dosage
Fahim et al. [24]	CNC		Not specified	3D-printed carbonatable ternary cement	Buildability, Mechanical	Flexural strength +25%; improved extrudability/buildability; GWP reduced 30–65%
Zaoui et al. [25]	PEG-coated CNF		0.1 wt%	Concrete	Mechanical	Compressive +37%, tensile +72%; markedly reduced strength variability (CoV 0.7–1.4%)
Q. Fan et al. [26]	CNC		0.1 wt%	Engineered cementitious composite (ECC)	Mechanical (durability)	Strength/strain loss under sulfate attack reduced by 39.9%/41.2% relative to unmodified ECC
Fan et al. [27]	CNF + graphene oxide		0.05% CNF + 0.025% GO	Cement-based nanocomposite	Mechanical	Compressive strength +88.99%; flexural strength +43.14% at optimum ratio
Zhu et al. [28]	CNC		0.1 wt% (opt.)	Alkali-activated slag–fly ash binder	Mechanical	Early strength –7.69%; later-stage compressive strength +8.6 MPa relative to control
Du et al. [29]	CNC (fibre coating)		1.0% (critical conc.)	UHPC (steel fibre-reinforced)	Mechanical	Flexural strength +14%, toughness +18%; performance reversed above 1.5% coating concentration
Rajendran et al. [30]	CNF		Not specified (process model)	Concrete (LCA)	Mechanical (LCA)	12% lower selling price per unit strength; mixed environmental impact depending on functional unit
Wu et al. [31]	CNF/CNC + reduced steel fibre		Not specified	UHPC	Mechanical	Compressive +8.3%, tensile +16.0%, flexural +26.9% with longer CNF

						at reduced steel-fibre content
Feng et al. [32]	CNC		0.1–0.2 wt% (opt.)	Cement paste	Mechanical (durability)	Compressive/tensile/flexural strength +18.8–44.67%; reduced strength loss under chloride erosion
Liu et al. [33]	Carboxylated (bamboo)	CNF	0.10 wt%	Cement paste	Mechanical	3-day compressive strength +24.56%; 28-day +8.97%; harmful porosity –55.0%
De La Rosa et al. [34]	CNF		0.05–0.5 wt%	Cement paste (pozzolan-blended)	Rheology, Mechanical	0.05% optimal for strength; 0.5% improved ductility despite reduced strength
Shen et al. [35]	Carboxylated CNF		0.5 wt%	Alkali-activated UHPC	Rheology, Mechanical	Autogenous/drying shrinkage reduced 53.9%/73.6%; later compressive strength –18% at 0.5%
Feng et al. [36]	CNC		Not specified	Cement/fly ash paste	Mechanical	Dosage- and fly-ash-dependent enhancement of mechanical properties and hydration
Lee et al. [37]	CNC + graphene oxide		CNC 0.1% + GO 0.05%	Cement paste	Rheology, Mechanical	Compressive strength +50.98% (99.24 MPa) at optimum CNC/GO combination
Fahim et al. [38]	CNC		Up to 1%	3D-printed alkali-activated composite	Buildability, Mechanical	Extrusion pressure –35%; mechanical performance +8–20%; flexural strength +20% at 0.30%
Alfarra et al. [39]	Nanocellulose (antifreeze)		Not specified	Masonry mortar	Mechanical	Compressive/flexural bond strength +3%/+27% when combined with sodium nitrite at –10°C curing
Wu et al. [40]	CNC + reduced steel fibre		Up to 0.6%	UHPC	Mechanical	Compressive +16.1%, tensile +19.6%, flexural +64.3% at optimum CNC content
Kilic et al. [41]	CNF		≥0.3 wt%	3D-printable cement composite	Rheology, Buildability, Mechanical	Favourable rheological and buildability properties from 0.3 wt% CNF onward
Zhou et al. [42]	MCC + carboxylated CNF (C-S-H nanocomposite)		Not specified	Cement paste	Mechanical	Improved flexural/compressive strength via seed effect and crack-bridging of C-S-H/cellulose nanocomposite

3.3. Risk of Bias in Studies

Methodological quality, appraised using the MMAT criteria for quantitative non-randomised studies, was judged consistently across the included studies. All 37 studies presented a clearly stated research question, employed measurement techniques appropriate to the outcomes assessed (e.g., rotational rheometry, isothermal calorimetry, compressive/flexural testing, and standard microstructural characterisation methods such as SEM, XRD, and TGA), reported complete quantitative outcome data, and administered the nanocellulose intervention at clearly specified dosages consistent with the stated study aims. The extent to which confounding variables (e.g., ambient curing conditions, raw material batch variability) were controlled could not be determined from the titles and abstracts available for this review and is reported as “can't tell” for all studies. A summary is presented in Table 3.

Table 3. Summary of methodological quality appraisal (MMAT criteria for quantitative non-randomised studies)

Study	Clear research question	Appropriate measurements	Complete outcome data	Confounders accounted for	Intervention as intended
Kaur et al. [6]	Yes	Yes	Yes	Can't tell	Yes
Lu et al. [7]	Yes	Yes	Yes	Can't tell	Yes
S. Zhang et al. [8]	Yes	Yes	Yes	Can't tell	Yes
Liu et al. [9]	Yes	Yes	Yes	Can't tell	Yes
Jaha et al. [10]	Yes	Yes	Yes	Can't tell	Yes
Haj Fattouh et al. [11]	Yes	Yes	Yes	Can't tell	Yes
Rajendran et al. [12]	Yes	Yes	Yes	Can't tell	Yes
Rahmawati et al. [13]	Yes	Yes	Yes	Can't tell	Yes
Fan et al. [14]	Yes	Yes	Yes	Can't tell	Yes
Salifu et al. [15]	Yes	Yes	Yes	Can't tell	Yes
de Souza et al. [16]	Yes	Yes	Yes	Can't tell	Yes
L. Zhang et al. [17]	Yes	Yes	Yes	Can't tell	Yes
Pan et al. [18]	Yes	Yes	Yes	Can't tell	Yes
Soares et al. [19]	Yes	Yes	Yes	Can't tell	Yes
dos Reis et al. [20]	Yes	Yes	Yes	Can't tell	Yes
Zhu et al. [21]	Yes	Yes	Yes	Can't tell	Yes
Safanelli et al. [22]	Yes	Yes	Yes	Can't tell	Yes
Guo et al. [23]	Yes	Yes	Yes	Can't tell	Yes
Fahim et al. [24]	Yes	Yes	Yes	Can't tell	Yes
Zaoui et al. [25]	Yes	Yes	Yes	Can't tell	Yes
Q. Fan et al. [26]	Yes	Yes	Yes	Can't tell	Yes
Fan et al. [27]	Yes	Yes	Yes	Can't tell	Yes
Zhu et al. [28]	Yes	Yes	Yes	Can't tell	Yes
Du et al. [29]	Yes	Yes	Yes	Can't tell	Yes
Rajendran et al. [30]	Yes	Yes	Yes	Can't tell	Yes
Wu et al. [31]	Yes	Yes	Yes	Can't tell	Yes

Feng et al. [32]	Yes	Yes	Yes	Can't tell	Yes
Liu et al. [33]	Yes	Yes	Yes	Can't tell	Yes
De La Rosa et al. [34]	Yes	Yes	Yes	Can't tell	Yes
Shen et al. [35]	Yes	Yes	Yes	Can't tell	Yes
Feng et al. [36]	Yes	Yes	Yes	Can't tell	Yes
Lee et al. [37]	Yes	Yes	Yes	Can't tell	Yes
Fahim et al. [38]	Yes	Yes	Yes	Can't tell	Yes
Alfarra et al. [39]	Yes	Yes	Yes	Can't tell	Yes
Wu et al. [40]	Yes	Yes	Yes	Can't tell	Yes
Kilic et al. [41]	Yes	Yes	Yes	Can't tell	Yes
Zhou et al. [42]	Yes	Yes	Yes	Can't tell	Yes

3.4. Results of Individual Studies and Results of Synthesis

Findings are synthesised below by outcome domain; individual study findings are reported in Table 2 and referenced by number throughout.

Rheological Behaviour

Twelve studies reported fresh-state rheological outcomes. Across these, the addition of CNC or CNF consistently increased yield stress and apparent viscosity relative to unmodified control mixtures, even at low dosages. De Souza et al. [16] reported yield stress increases of up to 136% with 0.040% nanofibrillated cellulose, while Safanelli et al. [22] observed that increasing crystalline nanocellulose content raised both yield stress and structuring rate, particularly when combined with superplasticiser or sonication. This stiffening effect is generally attributed to the water-retention capacity and fibrillar or crystalline network structure of nanocellulose, which restricts free water mobility within the paste. A recurring caveat across the rheology-focused studies was a trade-off between structural build-up, favourable for shape retention, and flowability or pumpability, favourable for mixing and extrusion; several studies (e.g., Guo et al. [23]; Kilic et al. [41]) identified a dosage threshold, commonly around 0.1–0.3 wt%, beyond which flowability declined sharply.

Buildability and Printability

Six studies addressed buildability directly, all in the context of 3D-printed cementitious systems. Fahim et al. [38] reported a 35% reduction in extrusion pressure with increasing CNC content, attributed to the viscosity-modifying properties of CNC in alkali-activated systems, while Salifu et al. [15] used response surface methodology to identify combined nanofibrillated cellulose and CNC dosages that satisfied rheological, mechanical, and interlayer-bonding targets simultaneously. Safanelli et al. [22] established a direct link between fresh-state rheological parameters and printed-layer buildability, finding that CNC contents beyond 0.100 wt% produced structuring rates favourable for layer stacking without compromising pumpability. Collectively, these studies indicate that nanocellulose can serve as a natural alternative to synthetic viscosity-modifying admixtures in 3D concrete printing, although reported optimum dosages varied considerably, likely reflecting differences in nanocellulose source, binder chemistry, and printing equipment.

Interlayer Bonding

Only two of the 37 included studies reported interlayer bonding strength as an outcome, reflecting a marked evidence gap for this domain. Pan et al. [18] reported an 87.5% increase in interlayer bonding strength through a self-assembled dual organic network designed to disperse cellulose nanofiber and suppress agglomeration, alongside substantial gains in flexural and compressive strength. Salifu et al. [15] found that interlayer bond strength could be optimised jointly with rheological and mechanical targets through mixture design, though the achievable balance depended on the specific performance priorities set. Given the centrality of interlayer bonding to the structural integrity of 3D-printed concrete, the scarcity of dedicated evidence on this outcome represents one of the most significant gaps identified by this review.

Mechanical Performance

Mechanical performance was the most extensively reported outcome, addressed in 36 of the 37 included studies. The dominant pattern across binder systems, nanocellulose types, and dosages was an improvement

in compressive, flexural, and/or tensile strength at low-to-moderate dosages, typically in the range of 0.05 to 0.3 wt% of binder, with reported gains commonly between 10% and 50% and several studies reporting substantially larger effects in specific configurations (e.g., a 138.92% increase in flexural strength reported by Pan et al. [18], and a 143% increase in tensile strength reported by S. Zhang et al. [8], both achieved through composite reinforcement strategies combining nanocellulose with a secondary phase). The mechanisms cited most consistently across studies were internal curing and water retention, nucleation of calcium-silicate-hydrate and related hydration products, nanoscale crack-bridging by the fibrillar or crystalline nanocellulose network, and refinement of the pore structure. A consistent dosage–response pattern emerged across a majority of studies: mechanical performance improved with increasing nanocellulose content up to a threshold, beyond which agglomeration, workability loss, and increased porosity reversed the trend, documented explicitly by, among others, Kaur et al. [6], L. Zhang et al. [17], Zhu et al. [28], Du et al. [29], and Wu et al. [40,31]. Studies combining nanocellulose with a secondary reinforcing phase, such as graphene oxide, steel fibre, or layered double hydroxides, generally reported larger mechanical gains than nanocellulose alone, suggesting synergistic rather than purely additive reinforcement mechanisms. The consistent dosage–response relationship observed across the rheology, buildability, interlayer bonding, and mechanical performance domains, together with the dosage thresholds and underlying mechanisms, is illustrated in Figure 4. This dosage pattern should not be read as a single universal optimum: it is a heuristic that recurs across many, but not all, of the included studies, and the optimum reported within any individual study depended on nanocellulose type, dispersion method, binder composition and testing protocol (Table 2). It is also weighted by the eleven studies in which nanocellulose was combined with a secondary reinforcing phase (graphene oxide, steel fibre or layered double hydroxides); in these studies, the reported gains reflect the combined system and cannot be attributed to nanocellulose alone.

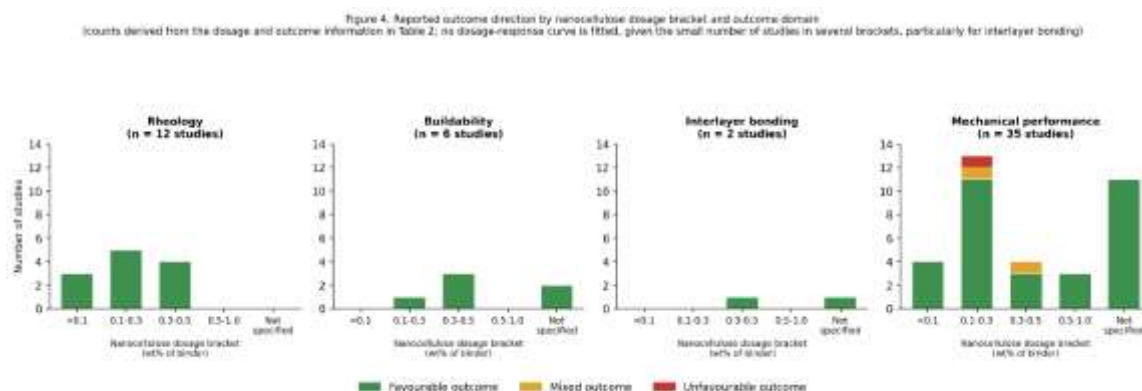


Figure 4. Effect of nanocellulose dosage on rheology, buildability, interlayer bonding, and mechanical performance relative to control

3.5. Reporting Biases

A formal assessment of reporting bias was not conducted. However, the predominance of studies reporting statistically favourable or optimised dosage outcomes, common in materials-science dosage-optimisation research, raises the possibility that null or negative findings are underrepresented in the published literature. The restriction of the search to a single database further increases the risk that relevant studies, particularly those indexed exclusively in Scopus, Web of Science, or regional databases, were not captured.

3.6. Certainty of Evidence

The certainty of evidence was judged to be moderate for the mechanical performance outcome, given the number of independent studies (36) and the consistency of direction of effect across diverse binder systems and nanocellulose types, despite considerable heterogeneity in reported magnitudes. Certainty was judged low for the rheology outcome, owing to variation in testing protocols and equipment across the twelve contributing studies. Certainty was judged low for buildability, given the smaller number of contributing studies (six) and their concentration within a narrow range of 3D-printing equipment and mixture designs. Certainty was judged very low for interlayer bonding, given that only two studies addressed this outcome directly.

4. Discussion

4.1. Summary of Evidence

This review synthesised evidence from 37 studies on the incorporation of nanocellulose into cementitious and geopolymers, examining effects on rheology, buildability, interlayer bonding, and mechanical performance. The findings indicate that nanocellulose, whether in crystalline (CNC) or fibrillar (CNF) form,

functions primarily as a rheology modifier and nucleation agent at low dosages, generally below 0.3 wt% of binder, producing measurable gains in early-age and later-age mechanical performance across a wide range of binder systems, from conventional Portland cement paste to geopolymers and ultra-high-performance concrete. These findings extend the narrower scope of prior reviews: whereas Al-Askary et al. [1] focused specifically on CNC in cement-based composites and Jin et al. [2] addressed nanoscale additives for 3D concrete printing without isolating nanocellulose as a distinct category, this review brings both application contexts, conventional casting and additive manufacturing, together under a common outcome-based framework. Doing so reveals that the evidence base for mechanical performance is considerably more mature than that for buildability or interlayer bonding specifically. The scarcity of interlayer-bonding evidence, just two of the 37 included studies, is not a peripheral gap but arguably the central finding of this review for additive-manufacturing applications: interlayer bonding governs the structural integrity of a 3D-printed element in a way that compressive strength alone does not capture, so the current evidence base cannot yet support general claims about nanocellulose as an interlayer-bonding solution, only that it is a promising and under-investigated direction. More broadly, the included studies function largely as a set of individually optimised dosage-response experiments rather than a body of evidence that explains why nanocellulose helps in some systems and not others: reported mechanisms (water retention, heterogeneous nucleation, pore refinement, crack bridging) are consistent in direction but rarely isolated from one another within a single study, so it is not yet possible to say, for a given binder system and nanocellulose type, which mechanism dominates or why some studies (e.g., Soares et al. [19]; Shen et al. [35]) report reduced strength at dosages similar to those reported as optimal elsewhere. The mechanistic pathway linking nanocellulose characteristics, fresh-state mechanisms, hydration and microstructural evolution, and resulting performance outcomes, including the consequences of excessive dosage, is summarised in Figure 5.

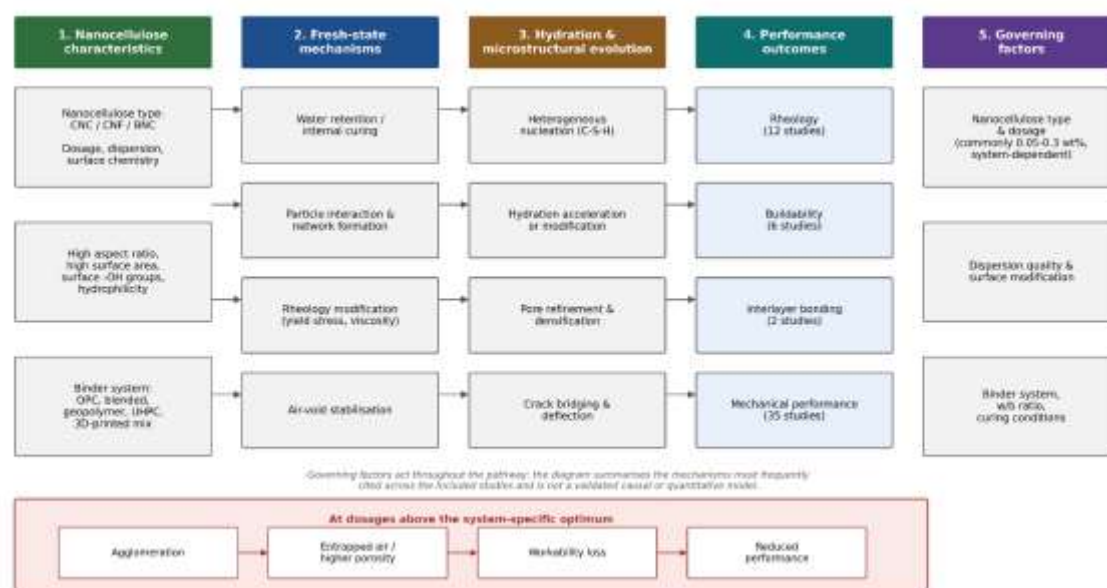


Figure 5. Mechanistic pathway from nanocellulose characteristics to performance outcomes in cementitious composites

4.2. Implications

For practice, the synthesised evidence suggests that nanocellulose dosages below approximately 0.3 wt% of binder represent a reasonable starting point for researchers and practitioners seeking to enhance rheological control and early-age mechanical performance across most cementitious systems, though optimum dosages remain system-specific and should be verified experimentally for a given mixture design. This range is best treated as a starting search window for experimental optimisation rather than a transferable design value, given that it is drawn predominantly from mechanical-performance studies and that the small number of studies addressing buildability and, especially, interlayer bonding directly provide too little evidence to justify the same range for those outcomes in 3D-printed systems. For research, four priorities emerge from this synthesis: standardisation of dosage reporting and rheological testing protocols to enable cross-study comparison; a substantially expanded evidence base directly targeting buildability and interlayer bonding in 3D-printed cementitious systems, given the current concentration of research on mechanical performance in conventionally cast systems; multi-database, full-text systematic reviews and, where the evidence permits, meta-analyses once a larger and more methodologically homogeneous body of literature accumulates; and

validation studies at structural or field scale, together with durability assessment under service conditions, to establish whether laboratory-scale gains translate into practical performance benefits. The current evidence



base by outcome domain, the key research gaps identified, and a prioritised roadmap for future research are summarised in Figure 6.

Figure 6. Current evidence base, key research gaps, and future research roadmap for nanocellulose-modified cementitious composites

5. Conclusion

This systematic review synthesised evidence from 37 primary studies on nanocellulose-modified cementitious and geopolymer composites. Nanocellulose, in both crystalline and fibrillar forms, was consistently associated with enhanced rheological structuring and mechanical performance at low dosages, generally below 0.3 wt% of binder, with excessive dosages tending to reverse these gains through agglomeration and increased porosity. This dosage pattern is a recurring heuristic drawn mainly from mechanical-performance studies, not a validated design rule, and it does not extend with the same confidence to buildability or interlayer bonding, where the evidence base remains too small to generalise. Evidence relating specifically to buildability and interlayer bonding in 3D-printed cementitious systems, while promising, remains considerably sparser than evidence for mechanical performance in conventionally cast systems. Future research would benefit from standardised testing protocols, expanded investigation of buildability and interlayer bonding outcomes, and validation at structural scale, supported by systematic reviews conducted across multiple databases with full-text-based screening and appraisal.

6. Conflict of Interest

The authors declare no conflict of interest.

References

- [1] Al-Askary ASJ, Kopecskó K, Oktay D. Cellulose nanocrystals and their utilization in cement-based composites: A comprehensive review. *Case Studies in Construction Materials*. 2025;23:e05550. <https://doi.org/10.1016/j.cscm.2025.e05550>
- [2] Jin P, Hasany M, Kohestanian M, Mehrali M. Micro/nano additives in 3D printing concrete. *Cement and Concrete Composites*. 2025;155:105799. <https://doi.org/10.1016/j.cemconcomp.2024.105799>
- [3] Hamada HM, Shi J, Al Jawahery MS, Majdi A, Yousif ST, Kaplan G. Application of natural fibres in cement concrete: A critical review. *Materials Today Communications*. 2023;35:105833. <https://doi.org/10.1016/j.mtcomm.2023.105833>
- [4] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. <https://doi.org/10.1136/bmj.n71>
- [5] Hong QN, Fàbregues S, Bartlett G, Boardman F, Cargo M, Dagenais P, Gagnon M-P, Griffiths F, Nicolau B, O'Cathain A, Rousseau M-C, Vedel I, Pluye P. The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *Education for Information*. 2018;34(4):285-291. <https://doi.org/10.3233/EFI-180221>
- [6] Kaur H, Orasutthikul S, Jongvivatsakul P, Nair SD, Sathidvongkun P, Hashimoto K. Effect of optimized dosage and curing conditions on the performance enhancement of cementitious composites using bacterial

- cellulose. *Construction and Building Materials*. 2025;472:140950. <https://doi.org/10.1016/j.conbuildmat.2025.140950>
- [7] Lu Q, Sha A, Chen Y, Li M, Liu Z, Jiao W. Influence of CNC modification and CO₂ curing on the macroscopic, microstructural, and durability properties of foamed concrete grouts. *Journal of Building Engineering*. 2026;128:116490. <https://doi.org/10.1016/j.job.2026.116490>
- [8] Zhang S, Wang Q, Zhou W, Chang X, Zhang Z, Jiang Z, Zheng Q. Multiscale enhancement mechanisms of engineered geopolymer composites incorporating in-situ cellulose nanofibers: From matrix to fiber-matrix interface. *Cement and Concrete Composites*. 2026;171:106624. <https://doi.org/10.1016/j.cemconcomp.2026.106624>
- [9] Liu J, Li Y, Du X, Lin H, Zang Y. Effect and mechanism analysis of NCC on mechanical and shrinkage properties of cement paste under low atmospheric pressure and low humidity. *Construction and Building Materials*. 2025;494:143459. <https://doi.org/10.1016/j.conbuildmat.2025.143459>
- [10] Jaha N, Bao Y, Meng W. Dual template directed C-S-H mineralization enables lightweight, strong, and ductile cementitious composites. *Cement and Concrete Composites*. 2026;174:106802. <https://doi.org/10.1016/j.cemconcomp.2026.106802>
- [11] Haj Fattouh I, Salim MH, Dali MHA, Tardy BL, Kim TY. Cellulose and chitin nanofibers from food waste for reinforcing cementitious composites. *Journal of Building Engineering*. 2026;127:116410. <https://doi.org/10.1016/j.job.2026.116410>
- [12] Rajendran N, Runge T, Bergman R, Nepal P, Ali SD, Fahim AA, Moradillo MK. Economic and environmental impact analysis of cellulose nanocrystal-reinforced cementitious mixture in 3D printing. *Resources, Conservation and Recycling*. 2025;218:108252. <https://doi.org/10.1016/j.resconrec.2025.108252>
- [13] Rahmawati C, Faisal M, Roslidar, Fitriani, Ahmad J, Muliana I. Extraction and characterization of nanocellulose from bemban fibre for cement-based composite. *Case Studies in Construction Materials*. 2025;22:e04100. <https://doi.org/10.1016/j.cscm.2024.e04100>
- [14] Fan L, Wu C, Zheng J, Song F, Wang H, Li F. Mechanical properties and micro-mechanism of cement-based materials strengthened by organic-inorganic synergistic effects of cellulose nanofibers and graphene oxide. *Construction and Building Materials*. 2025;476:141296. <https://doi.org/10.1016/j.conbuildmat.2025.141296>
- [15] Salifu N, Bassuoni M, Guven G. Performance evaluation of limestone-blended cement and cellulose nanomaterials in 3D concrete printing. *Case Studies in Construction Materials*. 2025;22:e04758. <https://doi.org/10.1016/j.cscm.2025.e04758>
- [16] de Souza LO, de Souza LMS, Silva FdA, Mechtcherine V. Rheological characterization of cement pastes with microcrystalline and nano-fibrillated cellulose under static and dynamic regimes. *Cement and Concrete Composites*. 2023;142:105219. <https://doi.org/10.1016/j.cemconcomp.2023.105219>
- [17] Zhang L, Chen Y, Liu Z, Yu Q. Enhancing geopolymer stiffness via in-situ seed-mediated growth of LDHs on cellulose nanofibrils. *Cement and Concrete Research*. 2026;205:108238. <https://doi.org/10.1016/j.cemconres.2026.108238>
- [18] Pan M, Yang S, Li X, Ma C, Ma G, Wang L, Wang Q. Synergistically toughening 3D-printed concrete performance via self-assembled dual organic network. *Construction and Building Materials*. 2026;535:146927. <https://doi.org/10.1016/j.conbuildmat.2026.146927>
- [19] Soares TV, Effting C, Miranda KW, Schackow A. Application of bacterial nanofibrillated cellulose for performance improvement in vermiculite lightweight mortar. *Construction and Building Materials*. 2024;449:138474. <https://doi.org/10.1016/j.conbuildmat.2024.138474>
- [20] dos Reis RR, Effting C, Schackow A. Cellulose nanofibrils on lightweight mortars for improvement of the performance of cement systems. *Carbohydrate Polymer Technologies and Applications*. 2023;5:100303. <https://doi.org/10.1016/j.carpta.2023.100303>
- [21] Zhu S, Luo L, Qin Y, Li Y. Study on the effect of cellulose nanocrystals on the pore structure and drying shrinkage of alkali-activated recycled ultra-high performance concrete: A multifractal theory. *Construction and Building Materials*. 2025;463:140113. <https://doi.org/10.1016/j.conbuildmat.2025.140113>
- [22] Safanelli N, Schackow A, Effting C, de Matos PR. The effect of crystalline nanocellulose on the rheology, hydration of cement pastes, and buildability of 3D-printed concrete. *Journal of Building Engineering*. 2025;113:114000. <https://doi.org/10.1016/j.job.2025.114000>
- [23] Guo A, Geng Y, Ma H, Gao D, Feng H, Zhang Y, Hao F, Yu Z, Sun Z. Hydration kinetics and mechanism of cement pastes with PEGylated cellulose nanocrystals. *Construction and Building Materials*. 2026;508:145130. <https://doi.org/10.1016/j.conbuildmat.2026.145130>

- [24] Fahim AA, Bukhari SJS, Khanzadeh Moradllo M. Additive manufacturing of carbonatable ternary cementitious systems with cellulose nanocrystals. *Construction and Building Materials*. 2025;495:143753. <https://doi.org/10.1016/j.conbuildmat.2025.143753>
- [25] Zaoui A, Ben Rejeb Z, Kwon OS, Park CB. Fine-tuning the microstructure of concrete composite: Impact of surface-coated nanocellulose on the increase of strength and decrease of strength variation in concrete. *Construction and Building Materials*. 2025;484:141620. <https://doi.org/10.1016/j.conbuildmat.2025.141620>
- [26] Fan Q, Meng D, Wu H, Zheng Y, Jiao Y. Wettability driven nano-modification of engineered cementitious composites for enhanced sulfate resistance by cellulose nanocrystals. *Construction and Building Materials*. 2025;504:144593. <https://doi.org/10.1016/j.conbuildmat.2025.144593>
- [27] Fan L, Wu C, Zheng J, Song F, Wang H, Li F. Cement-based nanocomposites: The synergic effect of graphene oxide and cellulose nanofibers on microstructural features and mechanical performance. *Diamond and Related Materials*. 2025;158:112609. <https://doi.org/10.1016/j.diamond.2025.112609>
- [28] Zhu S, Luo L, Qin Y, Zheng T, Cheng J, Tian J. Study on the early performance of alkali-activated slag-fly ash binders incorporating cellulose nanocrystals. *Case Studies in Construction Materials*. 2025;22:e04498. <https://doi.org/10.1016/j.cscm.2025.e04498>
- [29] Du J, Wang Y, Guo P, Meng W. Tailoring of steel fiber surface by coating cellulose nanocrystal for enhanced flexural properties of UHPC. *Cement and Concrete Composites*. 2024;154:105773. <https://doi.org/10.1016/j.cemconcomp.2024.105773>
- [30] Rajendran N, Runge T, Bergman RD, Nepal P, Nair N, Ashraf W. Economic and environmental impact analysis of cellulose nanofiber-reinforced concrete mixture production. *Resources, Conservation and Recycling*. 2025;212:107917. <https://doi.org/10.1016/j.resconrec.2024.107917>
- [31] Wu J, Guo Y, Huang G, Yang J, Lu Q, Yao C, Ren G, Shen A. Green empowerment of ultra-high-performance concrete: reinforcement effects and multi-scale mechanisms of cellulose nanofibers and cellulose nanocrystals. *Construction and Building Materials*. 2026;514:145548. <https://doi.org/10.1016/j.conbuildmat.2026.145548>
- [32] Feng H, Zheng Z, Guo A, Sun Z, Yu Z, Yao C, Du Y. Mechanical properties and microstructure of cellulose nanocrystal modified cement pastes subject to chloride erosion. *Journal of Building Engineering*. 2025;107:112670. <https://doi.org/10.1016/j.jobe.2025.112670>
- [33] Liu Q, Cao Z, Liu Z, Sun X, Zhou Z. Tuning characteristics of nanocellulose and its effects on the strength development and microstructure evolution of cement pastes. *Construction and Building Materials*. 2026;538:147280. <https://doi.org/10.1016/j.conbuildmat.2026.147280>
- [34] De La Rosa Á, Ruiz G, Husillos-Rodríguez N, Moreno R. Effect of cellulose nanofibers on the rheological and mechanical properties of cement pastes with metakaolin and natural volcanic pozzolan. *Construction and Building Materials*. 2024;452:138823. <https://doi.org/10.1016/j.conbuildmat.2024.138823>
- [35] Shen J, Li Y, Lin H, Liu J, Li Y, Sun J. Research on the performance and mechanism of carboxylated cellulose nanofiber modified alkali-activated ultra-high performance concrete matrix. *Construction and Building Materials*. 2026;515:145656. <https://doi.org/10.1016/j.conbuildmat.2026.145656>
- [36] Feng H, Su Y, Guo A, Yu Z, Guo Z. Mechanical properties of cellulose nanocrystal modified cement/fly ash pastes under various water/binder ratios. *Construction and Building Materials*. 2024;447:138213. <https://doi.org/10.1016/j.conbuildmat.2024.138213>
- [37] Lee YK, Kim JH, Chung CW. A synergistic combination of cellulose nanocrystal and graphene oxide for cementitious materials. *Construction and Building Materials*. 2026;527:146418. <https://doi.org/10.1016/j.conbuildmat.2026.146418>
- [38] Fahim AA, Admassu N, Dailey G, Khanzadeh Moradllo M. Application of cellulose nanocrystals in 3D printed alkali-activated cementitious composites. *Journal of Building Engineering*. 2024;82:108380. <https://doi.org/10.1016/j.jobe.2023.108380>
- [39] Alfarra J, Wegner LD, Boulfiza M. Effects of antifreeze admixtures on masonry performance at subfreezing temperatures. *Canadian Journal of Civil Engineering*. 2024;52:738. <https://doi.org/10.1139/cjce-2024-0294>
- [40] Wu J, Guo Y, Yang J, Lu Q, Jiang P, Yao C, Shen A. Multi-scale enhancement of UHPC by cellulose nanocrystals and reduced-content steel fibers: from micro-mechanisms to macro-properties. *Journal of Building Engineering*. 2025;116:114703. <https://doi.org/10.1016/j.jobe.2025.114703>
- [41] Kilic U, Soliman N, Omran A, Ozbulut OE. Effects of cellulose nanofibrils on rheological and mechanical properties of 3D printable cement composites. *Cement and Concrete Composites*. 2024;152:105617. <https://doi.org/10.1016/j.cemconcomp.2024.105617>

- [42] Zhou H, Zheng S, Li H, Ran Q, Ma J. Hydrothermal synthesis of C-S-H/cellulose nanocomposites and its enhancement effect on the mechanical performance of cement-based materials. *Journal of Building Engineering*. 2025;102:112014. <https://doi.org/10.1016/j.jobe.2025.112014>
- [43] Garritty C, Gartlehner G, Nussbaumer-Streit B, King VJ, Hamel C, Kamel C, Affengruber L, Stevens A. Cochrane Rapid Reviews Methods Group offers evidence-informed guidance to conduct rapid reviews. *Journal of Clinical Epidemiology*. 2021;130:13-22. <https://doi.org/10.1016/j.jclinepi.2020.10.007>