



THE EFFECT OF CELLULOSE FIBERS RECOVERED FROM PRIMARY SLUDGE ON CONCRETE PERFORMANCE

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ABSTRACT

The construction industry faces urgent pressure to adopt sustainable, low-carbon materials. Fiber reinforced concrete appears as a more sustainable alternative to conventional concrete due to its improved mechanical properties and durability. Commonly tested synthetic fibers do not provide holistic economic and environmental benefits. Wastewater treatment plants (WWTP) are emerging as resource recovery hubs for biopolymers like cellulose, offering an eco-friendly alternative to synthetic fibers. However, the application of sewage-derived cellulose fibers in cementitious composites remains under-explored. This study evaluates the integration of cellulose fibers, extracted from primary sludge of a WWTP as an alternative to synthetic fibers in concrete applications. We incorporated recovered cellulose fibers at a 0.2% w/w into concrete (0.5% v/v) and evaluated the fresh and hardened properties of this fiber reinforced concrete. While fiber addition reduced workability due to high water absorption, it significantly improved mechanical performance. Compressive strength increased by 5% at 7 days and 6% at 28 days. These improvements are attributed to internal curing effects and enhanced fiber-matrix bonding. This research demonstrated a viable pathway for upcycling sewage-derived cellulose into sustainable construction materials within a circular economy framework.

1. INTRODUCTION

Concrete, mainly made of cement, is widely utilized in the construction industry as it is the primary material in modern infrastructure. However, its widespread use and continuous production bring a significant environmental burden, as it remains a major contributor to global carbon dioxide (CO₂) emissions. The industry's expansion is inextricably linked to the urgent climate action asked for by the Paris Agreement, which seeks to limit global warming to 1.5°C above pre-industrial levels. In order to meet these ambitious requirements, there is an urgent need to transition from conventional concrete to sustainable alternatives in building operations. Decarbonizing the sector involves using renewable resources and upcycling biomass waste to minimize energy consumption and greenhouse gas emissions [1-3]. Consequently, researchers are investigating eco-friendly cementitious materials and concrete-compatible admixtures to maintain structural integrity while reducing environmental impact of construction sector. One promising strategy involves converting industrial by-products and waste materials into nanoscale admixtures for cementitious materials [4,5]. Incorporating nanomaterials into concrete provides many benefits, such as improved compaction, reduced porosity, and enhanced load-bearing capacity, as they act as nucleation sites for hydration products, fill interstitial voids within cement paste and provide fiber reinforcement [6]. Nanomaterials that are frequently used include silica [7], titanium dioxide [8], nano clays [9], carbon nanotubes [10] and carbon nanofibers [11]. There is a growing interest in the potential of cellulose nanofibers as a sustainable, bio-based alternative to these admixtures [12,13,14].

Cellulose (C₆H₁₀O₅) is a renewable, biodegradable and widely accessible natural polymer. Due to its unique chemical and physical properties, it is commonly utilized in a variety of sectors such as biomedical applications, packaging materials, paper industry and biodegradable materials [13,15]. In the construction industry, natural cellulose fibers offer an ecologically and economically viable strategy for developing sustainable fiber-reinforced concrete (FRC). When incorporated into a cementitious matrix, cellulose fibers enhance critical performance metrics such as tensile strength, crack resistance, and overall durability [4,5,16]. Compared to synthetic alternatives, cellulose fibers provide a high aspect ratio and a lightweight structure with a much lower carbon footprint. These properties make them an effective, eco-friendly option for advancing green construction practices while maintaining or even exceeding the performance standards of traditional cementitious materials [13,14,16]. Recently, researchers are increasingly utilizing cellulose nanocrystals and nanofibers recovered from waste sources like fruit pulp, cigarette filters and other paper products to further improve the performance and sustainability of cementitious materials [3,16,17,18,19].

Among different by-products and waste streams, a largely overlooked but highly consistent source of cellulose is domestic wastewater. Cellulose is a prevalent component of domestic wastewater, constituting a significant portion of the organic matter in sewage. It retains its fibrous structure during transit through sewer systems and eventually accumulates at wastewater treatment plants (WWTPs) [14]. The amount of toilet paper that people annually contribute to the sewer system ranges from 10 to 14 kg, according to a report published by the Foundation for Applied Water Research [20]. Consequently, cellulose serves as one of the primary carbohydrate sources in primary sludge, accounting for approximately $26.2 \pm 2.6\%$ of its dry matter and represents 30% to 50% of the total suspended solids in raw wastewater [21]. Compared to many other organic compounds that degrade quickly, cellulose hydrolysis is slower which limits sludge digestibility and decreases the efficiency of downstream sludge handling processes. Therefore, recovering cellulose from sewage can create an alternative source for the production cellulose nanofibers while simultaneously improving subsequent sludge treatment performance in WWTPs. The high cellulose content of domestic wastewater streams indicates a substantial and continuous recovery potential, enabling the production of cellulose nanofibers for development of green construction materials. Despite the established use of industrial cellulose in cementitious materials, fibers recovered from municipal wastewater streams remain scarcely explored in the literature. Therefore, it is necessary to assess the potential of recovered cellulose as an admixture for cementitious composites.

This study presents the use of cellulose fibers recovered from municipal wastewater as an admixture in concrete production. Cellulose fibers were extracted from primary sedimentation sludge obtained from a municipal WWTP. Concrete specimens containing the recovered cellulose fibers were compared with control specimens in terms of their fresh and hardened properties. This study addresses a critical research gap and contributes to the development of construction materials in the scope of circular economy principles, by systematically evaluating both material performance and the recovery potential of cellulose from wastewater treatment plants.

2. MATERIALS AND METHODS

The primary sludge was obtained from a Municipal Wastewater Treatment plant. Sodium hydroxide (NaOH-99.85%), sodium chlorite (NaClO₂-30%), sulphuric acid (H₂SO₄-98%), and glacial acetic acid (CH₃COOH-98%) were obtained from Sigma. The primary sludge was characterized by a pH of 7.2, indicating a neutral condition. Additionally, the total suspended solids (TSS) concentration was measured as 12.08 g/L, reflecting the high solid content in the sludge.

2.1. Cellulose Recovery from Domestic Wastewater

Primary sludge collected in December 2023 had a total suspended solids (TSS) concentration of $12.08 \pm 0.1 \text{ g L}^{-1}$ and contained 30% cellulose (7.12 grams in 2 L). Cellulose recovery was performed by modifying the method described by Espíndola et al. (2021) [22]. The procedure involved adding 10 grams of NaOH to the sludge, followed by stirring at 80 °C for 1 hour. Afterward, the mixing process was continued at 60 °C for another 24-hour period, resulting in a dark brownish mixture. The mixture was then sieved, washed thoroughly with water until the filtrate was clear and pH-neutral, and the

remaining pulp was immersed in 2 liters of 2% NaOH solution. This solution was stirred at 80 °C for 2 hours, followed by another 24 hours at 60 °C. The mixture obtained had a reddish-brown color. This mixture was sieved again and washed with distilled water. Obtained pulp was bleached using a prepared acetate buffer (pH 4.6) and sodium chlorite solution (1.7% NaClO₂) in a 1:1 ratio. This was stirred at 70 °C for 18 hours, followed by 6 hours in an oven at 60 °C. After washing to a clear, pH-neutral filtrate, the pulp was dried. The final acid hydrolysis step was conducted using 200 mL of 1M H₂SO₄ at 50 °C for 2 hours. After hydrolysis, the pulp was separated, rinsed with cold deionized water. After solid-liquid separation, the obtained cellulose fibers were dried in an oven for a day. Cellulose fibers obtained from primary sludge can be seen in Figure 1a. The method by which cellulose is recovered from primary sludge from domestic wastewater was presented in Figure 2.

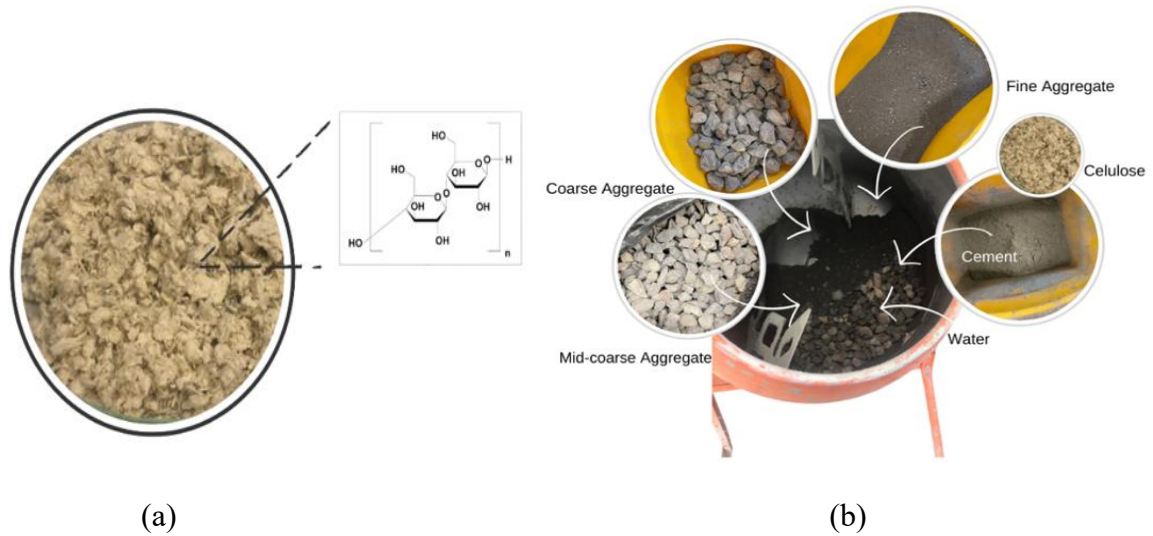


Figure 1. (a) Cellulose fibers obtained from primary sludge. (b) The concrete preparation process.

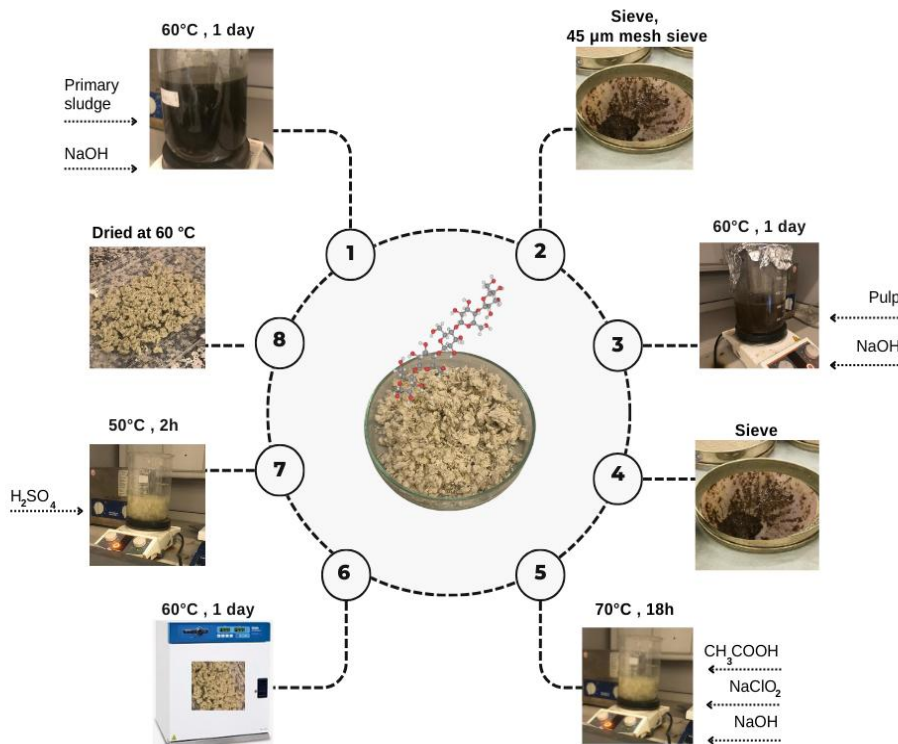


Figure 2. Stepwise cellulose recovery process from primary sludge.

2.2. Mix Design and Specimen Preparation

CEM II/A-LL 42.5R Portland-limestone cement was used. This type of CEM II was used to incorporate supplementary additives, which enhance workability and durability of the concrete mixtures. Limestone-based natural aggregates were used in concrete mixtures, which influence concrete's mechanical properties and durability. The aggregates were graded into various size fractions in accordance with TS 706 EN 12620 (2009) standards, by applying a sieve analysis. Using various aggregate sizes is critical for concrete density and workability, and thus the resulting mechanical properties and durability of the concrete [23].

All mix designs, specimen preparation, and testing procedures were conducted according to ASTM and ACI guidelines to ensure consistency and quality control across all test batches. Concrete mixtures were designed in accordance with ACI 211, consisting of eight steps to determine mix proportions based on target strength, workability and durability requirements. Non-air-entrained C30/37 grade concrete with a fixed w/c ratio of 0.54 was prepared (Table 1). Cellulose fibers were incorporated into the mixture to evaluate their effect on performance by following the methodology defined by Banthia et al. (2014) [24]. The effect of sewage-derived cellulose fibers on fresh and hardened concrete properties, two mixtures were prepared; (i) CC (control concrete) and (ii) 0.5CF (concrete with 0.5% cellulose fiber volume fraction) [25]. Throughout the manuscript, the control sample and cellulose fiber-reinforced samples were defined as CC and 0.5CF, respectively. The concrete mix designs were given in Table 1 and the preparation process was shown in Figure 1b. Cellulose fibers were added during mixing of the concrete to ensure a homogeneous mixture.

Table 1. Component ratios of concrete.

Material	Quantity (kg/m ³)
Cement	354
Mass of Coarse Aggregate	1113
Mass of Fine Aggregate	735
Water	193
Cellulose Fibers CC and 0.5CF	0 and 5.5

2.3. Structural and Morphological Characterization Studies of Cellulose

The cellulose fibers were analysed using several techniques to assess their structural and thermal properties. The surface morphologies of the fibers were analyzed by scanning electron microscope (SEM, Zeiss Gemini) using 10 kV acceleration voltage after the gold coating process. In the study, Fourier Transform Infrared Spectroscopy (FT-IR) method was used to determine the functional groups of the fibers. The analyses were carried out in the wavenumber range of 525–4000 cm⁻¹. To examine the crystal structure of cellulose, the X-ray Diffraction (XRD) method was applied, and diffraction patterns were examined from different angles. Thermal properties were evaluated using Perkin Elmer STA 8000 analyser and Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) methods. Samples (7 mg) were taken from recovered cellulose and heated from 30°C to 700°C at a heating rate of 10°C/min under a nitrogen atmosphere. Additionally, records were taken to test the thermal stability and behaviour of the samples.

2.4. Assessment of Concrete Properties

Fresh concrete properties were assessed by conducting flow and slump tests in accordance with ASTM C143. For each mix, a single test was conducted immediately after preparing the mix.

Compressive strength tests were performed with 15x15x15 cm cube samples, and the applied tests were given in Table 2. These tests are frequently used to evaluate the bearing capacity of concrete and mechanical properties [26]. For the latter, 7-day and 28-day compressive strengths were measured for concrete specimens in accordance with the ASTM C39 standards. Compressive strength tests after 7 days of curing represent approximately 65% of the final strength of concrete [27]. Therefore, 7-day strength values are important to obtain a general idea about the strength development of concrete. These

tests help assess the concrete's long-term strength and durability by comparing 7-day and 28-day results to understand strength development over time.

Table 2. Specifics of the specimens used in various tests.

Test Method	Number of Samples	Curing Age	Standard
Slump Test	1	-	ASTM C143
Compressive Strength	3	7	ASTMC39
Compressive Strength	3	28	ASTMC39

Test procedure starts with the sieve analysis of the aggregates used in concrete specimens to use identical particle size fractions and ends with the compressive strength tests of the specimens with and without cellulose fibers, as shown in Figure 3.



Figure 3. Schematic representation of the stepwise test procedure of CC and 0.5CF specimens.

3. RESULTS AND DISCUSSION

3.1. Characterization of Sewage-Derived Cellulose Fibers

The Scanning Electron Microscopy (SEM) micrographs demonstrating the cellulose fibers in the recovered pulp were given in Figure 4. Recovered cellulose fibers had a rougher surface compared to natural cellulose fibers which might increase the adherence between the fibers and the cement matrix [4]. Consequently, this enhanced adherence can improve the strength of the concrete. Similar nanofiber structures enhancing the mechanical properties of the material were reported by Kolour (2019) [28]. The fiber morphology observed in this study was also consistent with that of cellulose fibers previously reported in wastewater by Ruiken et al. (2013) [29].

FT-IR (Fourier Transform Infrared Spectroscopy) analysis was used to characterize recovered cellulose fibers and to find the functional groups. Obtained FTIR spectrum was presented in Figure 5a. Cellulose was represented in the spectrum by an O-H group peak at 3337 cm^{-1} and a CH_3 and CH_2 stretching vibration at 2918 cm^{-1} . This peak was distinct from the absorption band typically observed at around 1633 cm^{-1} , which was attributed to the bending vibration of water molecules, representing the presence of water or humidity [30]. The extracted cellulose sample showed a comparable vibration at 2918 cm^{-1} , while the C-H stretching vibration for commercial cellulose appeared at 2900 cm^{-1} [31]. Furthermore, at 1162 cm^{-1} , a C-O-C stretching vibration linked to cellulose was observed, and the C-O stretching vibration of carbohydrates was represented by a prominent peak at 1030 cm^{-1} [21]. These peaks collectively confirmed that the recovered solid fraction was composed of cellulose.

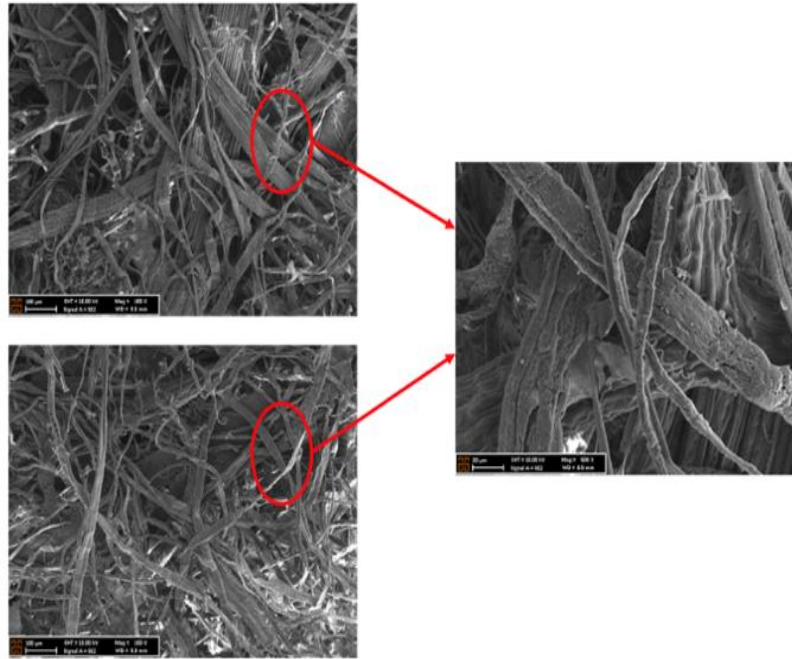


Figure 4. SEM images of cellulose fibers surface morphology.

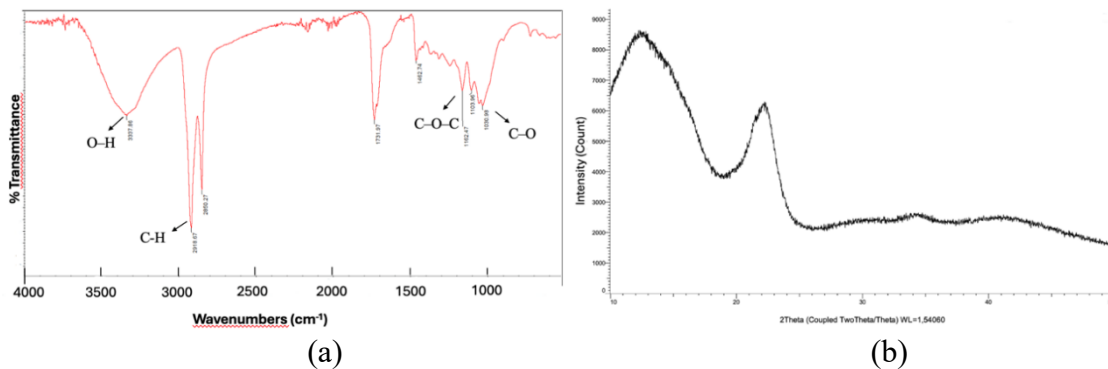


Figure 5. (a) FTIR spectrum showing the chemical structure of cellulose obtained from sludge separated at the first stage of municipal wastewater. (b) XRD patterns showing the crystal structure of cellulose obtained from the same source.

Figure 5b shows the X-ray diffraction (XRD) pattern of the cellulose sample. In this pattern, distinct diffraction peaks corresponding to the angles $2\theta = 14.0^\circ$, 22.5° , and 34.0° revealed that the recovered cellulose fibers' crystal structure was consistent with the native cellulose (cellulose I) crystal structure [32].

Heat resistance of cellulose recovered from municipal primary sludge was determined using TGA and the obtained results were shown in Figure 6. Different stages of thermal degradation were observed through weight loss analysis. Initially, a steady decrease in weight up to 150°C was attributed to the evaporation of water and humidity. The first degradation stage, between 68°C and 154°C , was characterized by a 7.68% weight loss due to fiber dehydration [33]. Only a minor weight loss was observed at the temperature range between 154°C and 250°C , indicating the thermal stability of the fiber within this temperature range. Considerable mass loss occurred between 250°C and 350°C , extending slightly to 400°C , with a total weight reduction of approximately 75%. This rapid decomposition was attributed to the depolymerization of the native cellulose structure. The process is driven by the cleavage of glycosidic bonds and cellulose chains, resulting in the release of glucose units and volatile compounds [34-36]. These findings align with the pyrolysis behavior of cellulose reported by Yang et al. (2007) and Bhuiyan et al. (2000) [35,36]. TGA results of the recovered cellulose nanofibers (Figure 6) indicated a

cellulose purity of 67%. This value was determined by comparing the observed weight loss percentages and degradation profiles of the recovered samples with the TGA results of analytical grade cellulose samples reported in existing literature. The sample exhibited a major mass loss of approximately 62% between 250°C and 350°C, featuring a distinct linear weight loss from 312°C to 350°C which is a characteristic thermal signature of crystalline cellulose [37]. While the recovered cellulose demonstrated high thermal stability, the presence of hemicellulose and residuals was determined. Above 380 °C, rapid carbon residue formation occurred as the final stage of the depolymerization process. Weight stabilization was observed above 580°C, indicating that the fibers were fully calcined with no further oxidative degradation.

As seen in Figure 6, DSC analysis was used to evaluate the distribution of energy consumption of the recovered cellulose. In the obtained DSC thermogram, four distinct peaks were observed. Two of the peaks were exothermic, and the other two were endothermic. The decomposition of residual unstable peroxides used in bleaching process during the cellulose recovery process caused a minor exothermic peak at around 65 °C. The first endothermic peak was observed around 330-360 °C, corresponding to the primary thermal depolymerization of cellulose. The second endothermic peak was observed in the 500-520 °C range, which was associated with the degradation of residual lignin impurities derived from the primary sludge [33, 37]. The strong exothermic peak at 600-630 °C was due to the crystallization of inorganic residues or solid-solid transformation, as the mass loss at this temperature range was negligible. In conclusion, DSC and TGA tests revealed that the cellulose obtained from primary sludge was of high purity and exhibited significant thermal resistance to high temperatures. The major impurity appeared to be the lignin, degradation of which gave a distinct endothermic peak at around 520°C.

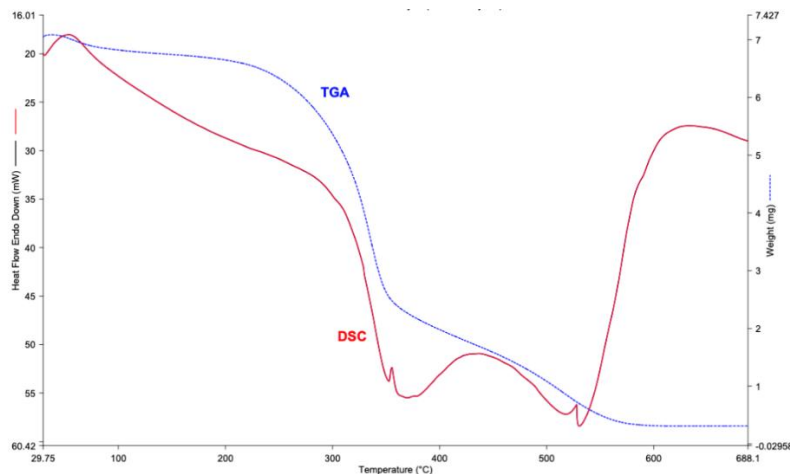


Figure 6. TGA and DSC curve for cellulose recovered from municipal primary sludge.

3.2. Slump and Compressive Strength

The results revealed that a slump value of 45 mm was measured for the CC mix and 30 mm for the 0.5CF mix. This indicated a 33.33% reduction in workability for the 0.5CF mixture compared to the CC mixture due to the addition of cellulose fibers. This decrease was primarily attributed to the hygroscopic nature of cellulose fibers incorporated into the concrete mix [25]. Demiralay et al. (2021), reported that the swelling rates of carboxymethyl cellulose-based hydrogels were enhanced due to the high-water retention capacity of cellulose [38]. Cellulose fibers have a high affinity for water and can absorb a significant portion of the mix water and hence reducing the available free water and increasing the overall viscosity of the fresh concrete. While this absorption may potentially extend the setting time, the subsequent gradual release of this absorbed water during the hydration phase facilitates internal curing. This mechanism is expected to enhance the long-term durability of concrete by mitigating autogenous shrinkage, reducing the formation of shrinkage cracks and facilitating autogenous self-healing of micro-cracks [6,25].

Mechanical properties of the hardened concrete specimens were assessed by compressive strength tests conducted on day 7 and day 28. Table 3 shows the 7-day and 28-day compressive strength values obtained for CC and 0.5CF specimens.

Table 3. 7-Day and 28-Day compressive strength test results.

Mix Design	7 days Compressive Strength (MPa)		28 days Compressive Strength (MPa)	
	Load (kN)	Stress (MPa) Average ± STDV	Load (kN)	Stress (MPa) Average ± STDV
CC	761.1	34.07±0.2	1026.4	45.63±0.56
0.5CF	789.3	35.62±1.32	1090.4	48.45±0.35

As presented in Table 3 and demonstrated in Figure 7, the compressive strength values of the concrete containing cellulose fiber (0.5CF) were 5% higher than the control sample (CC) during the seven-day curing period. This increase indicated that sewage-derived cellulose fibers were compatible with the concrete matrix and enhanced the mechanical performance of concrete at early ages. In conventional concrete, hydration continues during the hardening process as the pores in the cement paste are partially filled, which results in shrinkage and stress induced cracks. Internal curing improves this process by adding more internal water to the concrete, allowing the pores in the cement paste to become more saturated. Therefore, internal curing provides an advantage over traditional curing by reducing premature shrinkage of concrete and the resulting cracks. It also promotes improved hydration of the cementitious material in concrete. As a result, shrinkage, cracking, and early deformations like bending/warping of the concrete are minimized. In addition, strength increases while permeability decreases, making the concrete more resistant to chloride penetration [25].

The test results showed that at the end of the 28-day curing period, the compressive strength of the concrete containing 0.5% cellulose fiber (CF) was still 6% higher than that of the control concrete (CC). These results indicated that, in longer curing periods, cellulose fibers did not have any negative effect on the hydration reactions and the strength development. Additionally, internal curing effect of the cellulose fibers might further improve the overall hydration of the concrete and increased the 28-day strength. Possible other reasons than internal curing effect can be the good mechanical and chemical properties of cellulose fibers, better adherence and compatibility of recovered cellulose fibers due to their higher surface roughness (Figure 4). Moreover, due to its hygroscopic properties, incorporation of cellulose fibers resulted in a denser microstructure. Statistical analysis revealed that the increases in the compressive strength values at 7 and 28 days were statistically significant ($p=0.03$). These findings confirmed the hypothesis that cellulose fibers increased the strength of the concrete over time consistent with the previous findings reported for the use of cellulose fibers in concrete. In a study conducted by Nasery et al., it was determined that the increase in the amount of fiber added to concrete at different rates also increased the compressive strength [39]. Similarly, another study reported that adding only 2% of natural cellulose fibers to concrete provided an 11.6% improvement in tensile strength and an improvement of 20.2% noted in compressive strength compared to fiber-free concrete [40].

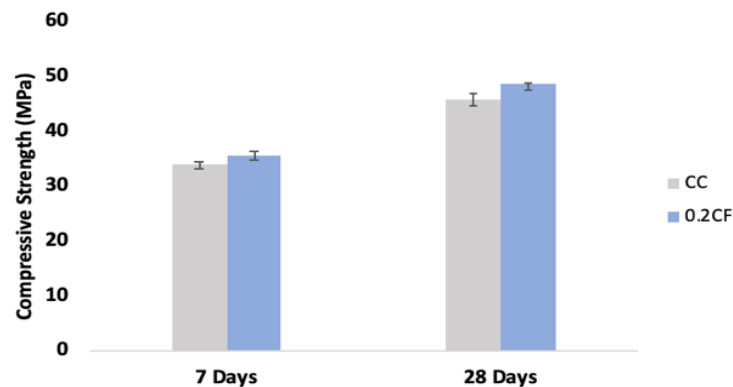


Figure 7. 7- and 28-days compressive strength.

The benefits of cellulose depend on dosage, mix design, and conditions. As shown in Table 4, it is seen that cellulose fibers used at low rates such as 0.2% w/w (0.5% volume) have the ability to increase the load bearing capacity of concrete and mortar. However, the use of fibers at very high dosages such as 20% caused heterogenous distribution of fibers which may compromise the strength development due to the uneven formation of hydration products in cement matrix. Overall, when properly used, cellulose fibers improve strength, crack resistance, and durability, making concrete more sustainable and resilient. The compatibility of sewage-derived cellulose with the cementitious matrix highlighted its potential as a sustainable and high-value material source for the construction sector. By repurposing waste-stream fibers, this approach aligns with circular economy principles while providing a viable alternative to traditional fibers in concrete production. While untreated sewage sludge poses risks, the cellulose fiber recovery process includes a series of purification steps as described in Section 2.1. Moreover, concrete's high alkalinity further neutralizes any possible harmful components. Extracting and using cellulose fibers from sludge offers a safe, sustainable way to reinforce concrete effectively.

Table 4. Comparison of concrete with different cellulose types.

Extraction cellulose	Cellulose concentration wt%	Compressive strength	References
Sewage sludge	5, 10, 15 and 20	Strength reduction	[4]
Office paper waste	0.25, 0.50, 0.75, and 1.00	Strength gain	[19]
Waste paper	0.50	Strength improvement	[30]
Slash pine	0.50	Strength reduction	[25]
Oil palm empty fruit bunch	0.20, 0.40, 0.60 and 0.80	Strength enhancement	[41]
Primary sludge	0.20	Strength increase	This study

3.3. Environmental Safety and Applicability Potential

Assessing environmental safety and practical utility is a prerequisite for incorporating recovered cellulose fibers from primary sludge into concrete [4]. Although the circular economy promotes waste reuse, the absolute priority is preventing toxic leaks into the ecosystem [42].

The environmental safety of the sewage-derived cellulose fibers comes from the cellulose recovery process procedure. The multi-step protocol comprising thermal-alkaline treatment (2% NaOH at 80°C), oxidative thermochemical bleaching at pH 4.6 (0.85% NaClO₂/0.85% acetate buffer at 70°C) for 18 hours, and acid hydrolysis (1 M H₂SO₄ at 50°C), subjects the raw sludge to extreme pH and temperature conditions. These stages are highly effective in degrading organic micro-pollutants, eliminating pathogens, chemically leaching soluble heavy metals prior to obtaining isolated cellulose fibers. The obtained high fiber purity of 67%, as confirmed by TGA and DSC analysis, indicated successful removal of the non-cellulosic sludge fractions that typically contain contaminants. Obtained fiber quality was consistent with the fiber quality obtained by Palmieri et al. [4], in which they reported that the rigorous chemical conditions during the recovery process transform the cellulose in raw sludge into chemically stable, inert fibers.

In addition to the stabilization obtained during cellulose recovery process, the cementitious matrix provides a secondary immobilization barrier, particularly for the metals. The high alkalinity (pH > 13) facilitates the stabilization of heavy metals through the precipitation of insoluble hydroxides and their subsequent encapsulation within the calcium-silicate-hydrate (C-S-H) gel structure [43-45].

The safety of sewage-derived cellulose is further supported by its growing application in sensitive sectors, including advanced bioplastic synthesis [46]. Offering a high-purity alternative to traditional wood-based sources, these recovered fibers are suitable for the synthesis of advanced bioplastic precursors [46]. Beyond chemical applications, this material serves a critical mechanical function as a

technical stabilizer in asphalt, where it effectively prevents binder drainage in stone mastic asphalt mixtures [47]. Research consistently demonstrates that sewage-derived cellulose fibers are effectively stabilized through both physical and chemical mechanisms within high-alkalinity composites [4,48]. Overall, the combination of harsh chemical processing and the inherent stabilizing environment of concrete ensures that sewage-derived cellulose fibers functions as a safe, secondary raw material, advancing circular economy goals within the construction sector.

4. CONCLUSION AND SUGGESTIONS

This study evaluated the effect of sewage-derived cellulose fibers on the fresh and hardened properties of concrete at a dosage of 0.2% cellulose fibers by weight (0.5% by volume). While slump tests indicated that fiber addition reduced the workability due to the hygroscopic nature of cellulose, 0.5CF mixtures exhibited superior mechanical performance. Compressive strength increased by 5% after 7 days and 6% after 28 days compared to the control concrete specimens. This enhancement was attributed to internal curing provided by the fibers' water-retention capacity and the high surface roughness of the recovered cellulose. The latter improved the fiber-matrix bond minimizing shrinkage related cracking and enhancing autogenous healing potential of the early-age cracks. These findings pave the way for upcycling sewage-derived cellulose into viable and eco-friendly fibers to reinforce concrete effectively. Future research should optimize the fiber dosage and assess the long-term durability metrics, such as chloride penetration, shrinkage resistance, freeze-thaw resistance to further validate this sustainable material within a circular economy framework.

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Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

Contributions of the Authors

Ayse Gul: Writing – original draft, Data curation, Formal analysis, Conceptualization, **Azize Yıldız:** Writing – original draft, Data curation, Funding acquisition, **Yusuf Cagatay Ersan:** Conceptualization, Methodology, Writing – Review & editing, Supervision, Funding acquisition

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