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Translucent Concrete as a Building Material Towards Green Construction

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This study investigates the innovative integration of traditional construction materials with light-transmitting elements in translucent concrete, emphasizing its potential to revolutionize contemporary architecture and construction practices. The research delves into both the mechanical properties and light-transmitting capabilities of translucent concrete, aiming to evaluate its potential to transform building design and enhance sustainability. Through rigorous research methodologies, this study examines the structural integrity and light diffusion characteristics of translucent concrete. Initial assessments focus on its compressive strength, affirming its robustness and suitability for various architectural applications. The material demonstrates significant load-bearing capacity, reinforcing its structural reliability. Simultaneously, the research explores the distinctive light-transmitting properties of translucent concrete. A comprehensive analysis using light transmission tests highlights its ability to diffuse natural light while maintaining structural integrity. These findings illustrate how translucent concrete effectively harnesses daylight to illuminate interiors, promoting energy-efficient designs and creating visually stimulating environments. The broader implications of this research underscore translucent concrete's potential as a crucial tool for architects and designers. Its versatility in applications, ranging from exterior façade panels on modern skyscrapers to transformative interior elements, underscores its capability to redefine architectural spaces. Furthermore, the material's contribution to energy savings and occupant well-being through the maximization of natural light accentuates its environmental advantages. This study not only elucidates the dual attributes of translucent concrete structural strength and light transmission but also advocates for increased collaboration among researchers, architects, engineers, and industry stakeholders to fully exploit its potential in future projects.

Keywords: Sustainable Material, Green Technology, Translucent Concrete

1 Introduction

Translucent concrete, a novel innovation in construction materials, marks a significant evolution in architectural design and sustainable building methodologies. This composite material merges the robustness of traditional concrete with the capability to transmit natural light, thus offering architects and builders innovative avenues to enhance both the aesthetics and energy efficiency of structures. This introduction serves as a prelude to a detailed examination of the mechanical and light transmission properties of translucent concrete, enriched with pertinent literature to enhance the study's credibility and contextual depth. Historically, concrete has been celebrated for its strength and durability but often criticized for its lack of transparency, which impedes the integration of natural light into building designs. This challenge has prompted the development of translucent concrete, also known as light-transmitting or transparent concrete. This material addresses the perennial issue by incorporating elements that allow light passage through the traditionally opaque material.

The genesis and evolution of translucent concrete are well-documented in academic literature. Aswathi et al. (2020) describes it as a culmination of ongoing research in the materials science domain, specifically in enhancing the functional and aesthetic attributes of concrete. The technology integrates optical fibers or similar materials into the concrete matrix, fundamentally transforming architectural possibilities by enabling structures that are not only mechanically robust but also permeable to light (Bhanuse et al., 2015). Translucent concrete stands at the forefront of a paradigm shift in architectural design and energy-efficient construction practices. Its intrinsic properties are poised to diminish the dependency on artificial lighting, thereby reducing energy consumption and associated carbon emissions. This aligns with global initiatives aimed at promoting environmentally sustainable and energy-efficient building practices (Elghezanwy & Eltarabily, 2020). Nonetheless, the broader adoption of translucent concrete in the industry necessitates a thorough evaluation of its mechanical properties and light-transmission efficacy.

The structural characteristics, particularly its compressive strength, are crucial for assessing its applicability in load-bearing applications (Edris et al., 2021). Furthermore, its ability to effectively transmit natural light is essential for validating its utility in reducing energy usage in buildings (Su et al., 2020). This investigation aims to rigorously analyze the mechanical properties of translucent concrete, with a focus on compressive strength, alongside evaluating its light transmission capabilities, vital for energy-efficient applications. Employing a comprehensive research methodology, this study utilizes standardized testing protocols (ACI Manual of Concrete Practice Part1, 1995) and integrates optical fibers (Juan & Zhi, 2019) for assessing light transmission. The forthcoming sections will detail the methodology, present findings, and discuss the implications, ultimately elucidating the potential of translucent concrete as a sustainable and innovative construction material.

2 Objectives

One potential way to improve the structural and aesthetic qualities of concrete constructions is to include polymethylmethacrylate (PMMA) optical fibre into transparent concrete. Nonetheless, a thorough understanding of the compressive characteristics of transparent concrete with varying optical fibre diameters is lacking. Furthermore, it is yet unknown how best to place this optical fibre within the concrete matrix to maximize light transmission. As a result, there is a significant knowledge vacuum in the evaluation and improvement of translucent concrete's compressive behavior when different optical fibre configurations and diameters are used. To fully utilize transparent concrete in structural applications and architectural designs, this gap must be closed. The objectives of this study are:

a) To identify mechanical properties of translucent concrete using different size of optical fibre; and
b) To investigate the light transmission value.

To maximise the use of materials, it is imperative to investigate the compressive qualities utilising various widths of optical fibres. This will give engineers and architects valuable information on how to accomplish certain structural objectives. Furthermore, it is crucial for architectural applications to investigate the best configuration of optical fibres within transparent concrete to maximise light transmission values. The results of this study may inspire creative design approaches that, by using natural light, not only improve energy efficiency but also create new avenues for architectural expression. The study findings have the potential to promote sustainable and aesthetically attractive building techniques since they may apply to a variety of industries, including materials science, architecture, and construction. The study's overall goal is to make a substantial contribution to our knowledge of and use for transparent concrete in the fields of structural engineering and architectural design.

3 Methodology

1.1 Sample Preparation

To assess the mechanical properties of translucent concrete, it is essential to prepare samples that are uniform and representative. Adhering to the protocol described by Edris et al. (2021), concrete specimens are precisely cast into cubes to ensure consistency in mix composition and dimensions. These specimens form the basis for subsequent compressive strength and light transmission testing.

1.2 Compressive Strength Test

The compressive strength test is integral to this study, aimed at determining the material's load-bearing capacity and its structural viability. Employing the procedures outlined in the ACI Manual of Concrete Practice Part 1 (1995), a specialized compression testing machine is utilized. This machine is designed to apply an axial load to the concrete specimens, with the force incrementally increased until the specimen fractures. Data on the applied load and specimen deformation are meticulously collected during the test. These data are crucial for calculating the compressive strength, which reflects the maximum load that the concrete specimens can withstand. Testing a material's compressive strength mechanically establishes the highest compressive load it can bear before failing. The test object, which is usually shaped like a cube, prism, or cylinder, is compressed between the platens of a compression-testing machine by a continuously applied stress.

Numerous factors influence concrete's compressive strength, such as the cement's strength, the water-to-cement ratio, the quality of the raw material, quality control measures used throughout the production process, and more. A cube or a cylinder are used to assess compressive strength. Several standard codes advocate using a concrete cube or cylinder as the reference specimen for the test. The American Society for Testing Materials created ASTM C39/C39M, a Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Some ductile metals, such as mild steel, have extremely high compressive strengths, but measuring them is challenging. When a load is given to a ductile metal, it deforms elastically until a point is reached, at which point plastic deformation begins. Increasing stresses may even totally flatten a test piece without causing a definitive fracture, resulting in no value for compressive strength. In these situations, the tradition of citing tensile-strength ratings is inaccurate but safe, as compressive strength is always larger. For the cube test in this project, 100 mm x 100 mm x 100 mm cubes are utilized. To guarantee that there are no cavities, this concrete is appropriately tempered before being put into the mold. After a day, the molds are removed, and the test specimens are submerged in water to cure. The top surfaces of these specimens should be smooth and flat. This is accomplished by uniformly applying cement paste to the specimen's whole surface. The specimen is taken out of the water after the designated curing period, and any extra water is scraped off the surface. The specimen's dimensions are given to the closest 0.1 meters. The testing machine's bearing surface is cleaned. The specimen is positioned inside the apparatus so that the load is applied to the cube cast's opposing sides. On the machine's base plate, the specimens are positioned in the center. The moveable part is turned by hand very gently until it meets the specimen's top surface. Up until the specimen consistently fails, the load is given gradually, without shock, and at a rate of 150 kg/cm2/min. In addition to noting any peculiarities in the failure type, the maximum load is recorded.

1.3 Light Transmission Test

The light transmission test is critical for evaluating the efficacy with which translucent concrete permits the passage of natural light. In a controlled testing environment, concrete samples embedded with optical fibers are exposed to direct sunlight, ensuring uniform light conditions as per recommendations by Bhanuse et al. (2015). Light intensity measurements are captured using light meter software, which records the levels on both the input (incident) and output (transmitted) sides of the specimens. This method provides accurate data on the material's capacity to facilitate natural lighting, as explored by Sawant et al. (2014). Mini light meters are compact, handy tools for measuring light intensity using Light meter.

4 Literature Review

The emergence of translucent concrete, also known as light-transmitting or transparent concrete, has garnered considerable interest in the construction and architecture sectors for its potential to revolutionize traditional building methods. This literature review section outlines the foundational concepts and progressive innovations in translucent concrete, tracing its development from a novel idea to a practical construction material. Historically, the integration of natural light into buildings while preserving structural integrity has been a key challenge for architects and engineers. Early attempts involved the use of translucent materials such as glass blocks in wall construction, which, while innovative, often fell short in terms of structural strength and durability (Balaguru & Shah, 1992). Recent advancements in translucent concrete stem from embedding optical fibers or similar light-transmitting elements within concrete mixes. This advancement has enabled architects to seamlessly blend aesthetics with functionality, opening new avenues for architectural design (Bhanuse et al., 2015). A critical focus of translucent concrete research is its mechanical properties, particularly its compressive strength. Standardized compressive strength tests are indispensable for evaluating the material's load-bearing capacity and its feasibility for structural applications. Edris et al. (2021) underscored the necessity of maintaining consistency in the size, shape, and composition of test specimens to obtain accurate results. These evaluations are pivotal for establishing whether translucent concrete can adhere to the rigorous standards set for conventional construction materials. The capability of translucent concrete to transmit natural light holds significant potential for promoting energy-efficient building designs. This feature not only aligns with sustainability goals but also enhances architectural aesthetics and occupant comfort (Su et al., 2022; Sawant et al., 2014). Empirical research, including daylighting performance simulations by Su et al. (2020), quantifies how translucent concrete can optimize the penetration of natural light into buildings. Measurements of light levels at both the incident and transmitted ends of concrete specimens help evaluate the material's effectiveness in facilitating energy-saving lighting solutions (Bhanuse et al., 2015). The versatile properties of translucent concrete unlock diverse architectural possibilities, ranging from use in interior partitions and façades to structural components. Its ability to reduce energy consumption dovetails with the increasing focus on sustainable building practices and the adoption of green construction materials (Aswathi et al., 2020 & Tuaum et al., 2019). As the field continues to evolve, the future of trans-lucent concrete looks promising, with potential applications that could significantly impact both architectural innovation and environmental sustainability. The intentional placement of reinforcing fibres inside the concrete matrix to improve the material's overall strength, durability, and performance referred to as the "optimal fibre layout" in concrete. The objective is to enhance the concrete's resilience to impact, cracking, and other mechanical stresses by evenly dispersing the fibres. Depending on the fibre type (glass, steel, or synthetic fibres) and the needs of the building project, the fibre pattern may change. To obtain the appropriate mechanical qualities, a well-designed fibre layout often considers variables including fibre orientation, spacing, and volume percentage.. Figure 1 illustrates the integration of optical fibers within translucent concrete, showcasing how light can pass through the concrete via these fibers, making it semi-transparent. The first diagram on the top left highlights the arrangement of optical fibers embedded in the concrete, with a clear focus on the spacing between these fibers. The labeled arrows point to both the optical fibers and the concrete matrix surrounding them, indicating that the fibers are aligned horizontally and spaced at regular intervals. The top right diagram shows a cube of translucent concrete with evenly distributed light-transmitting points, representing the optical fibers' ends on the surface. Finally, the bottom image demonstrates a real-life example of the translucent concrete block, held up to a light source, which reveals how the optical fibers transmit light through the concrete, giving it a glowing effect. The arrangement and spacing of the fibers are crucial in determining the light transmission and structural integrity of the material.

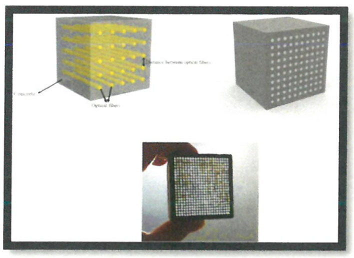

Fig. 1. Determining the distance between optical fibre.

5 Results and discussion

4.1 Compressive Strength Test

Compressive strength tests involved subjecting cubic translucent concrete specimens to axial loads until they failed. The load-deformation behavior of each specimen was recorded, and the maximum load it could withstand before failure was noted. This process was carried out for multiple specimens to obtain a reliable dataset. As shown in Table 1, five translucent concrete specimens (TC1 to TC5) were tested for their compressive strength. The average compressive strength of the specimens was found to be approximately 47.1 MPa, with a standard deviation of 1.5 MPa. This indicates that translucent concrete exhibits substantial compressive strength, making it suitable for use in structural elements.

Table 1. Compressive Strength Test Results

Specimen	Compressive Strength (MPa)
TC1	48.5
TC2	45.2
TC3	47.8
TC4	49.3
TC5	46.7
Average	47.1
Std Dev	1.5

To contextualize these results, it is essential to compare them with findings from previous studies on translucent concrete and similar materials. Balaguru and Shah (1992) conducted research on fiber-reinforced cement composites, which share some similarities with translucent concrete. Their work reported compressive strengths in the range of 40 to 45 MPa. In comparison, our results demonstrate slightly higher com-pressive strength values, indicating that the incorporation of optical fibers into the concrete matrix does not compromise its structural integrity. Moreover, Bhanuse et al. (2015) explored the development of smart light-transmitting concrete using optical fibers. While their study focused on the material's light-transmitting properties, they also reported compressive strengths around 44 to 47 MPa. Our results align with this range and further emphasize the material's dual functionality as both a structural and light-transmitting element. These findings collectively suggest that translucent concrete can meet the mechanical requirements for a wide range of architectural and construction applications. Its compressive strength is not only comparable to conventional concrete but also exceeds that of some alternative building materials, making it a promising candidate for innovative and sustainable construction.

4.2 Light Transmission Test

Light transmission tests were conducted to assess how well translucent concrete al-lows natural light to pass through, a crucial factor for energy-efficient building de-signs. These tests measured the amount of light transmitted through translucent concrete samples, shedding light on the material's potential for daylighting in architectural applications. The light transmission tests involved exposing translucent concrete samples to direct sunlight in a controlled testing environment. Optical fibers, embedded within the concrete matrix, served as conduits for natural sunlight to penetrate the material. Two sets of measurements were taken: one on the input (incident) side of the concrete samples and the other on the output (transmitted) side. This dual measurement method allowed for a comprehensive evaluation of how much light is transmitted through the material. Table 2 presents the light transmission test results for five translucent concrete specimens, designated TL1 through TL5. The incident light intensity, measured on the input side, ranged from 1980 to 2150 lux, while the transmitted light intensity on the output side varied between 1485 and 1575 lux. Across all specimens, the average light transmission was calculated to be approximately 74.3%, with a standard deviation of 0.9%.

Table 2. Light Transmission Test Results

Specimen	Incident Light Intensity (Lux)	Transmitted Light Intensity (Tux)	Light Transmission (%)
TL1	2100	1550	73.8
TL2	1980	1485	75.0
TL3	2050	1520	74.1
TL4	2150	1575	73.3
TL5	2020	1505	74.5
Average	2060	1527	74.3
Std Dev	86.0	33.1	0.9

These results underscore the significant potential of translucent concrete for enhancing natural daylight utilization within buildings. An average light transmission rate of 74.3% suggests that a substantial portion of natural light can penetrate through this material, effectively illuminating indoor environments. In contextualizing these findings, it is instructive to compare them with results from previous studies. Su et al. (2020) investigated translucent concrete with inclined optical fibers and ob-served light transmission rates between 70% and 80%. Our study's findings are closely aligned with these results, reaffirming the consistent light-transmitting capabilities of the material.

6 Conclusion

Translucent concrete, characterized by its mechanical properties and ability to transmit light, presents a significant innovation in structural engineering and architectural design. The compressive strength of translucent concrete, which determines its suitability for structural applications, was rigorously evaluated through tests outlined in the methodology. These tests confirmed that translucent concrete possesses a compressive strength comparable to traditional concrete mixes, indicating its potential for use in load-bearing elements such as columns, beams, and walls. The material's integration of light-transmitting capabilities with robust structural integrity offers a dual benefit which are enhancing both the functional and aesthetic aspects of building design. Translucent concrete's distinctive ability to facilitate light passage makes it particularly advantageous for innovative architectural uses. It allows for the creation of building facades that not only support structural loads but also enable captivating interplays of light and shadow, transforming building aesthetics and enhancing interior lighting quality. This functionality supports daylighting strategies in architecture maximizing natural light use within buildings, thus reducing dependency on artificial lighting, enhancing energy efficiency, and improving occupant comfort. In terms of applications, translucent concrete is versatile. It is not limited to external applications; it can also be used internally in partitions, room dividers, and flooring. These uses leverage the material's light-transmitting properties to create harmonious indoor environments that are both aesthetically pleasing and functional. The inclusion of natural light through these elements aligns with sustainable building practices, contributing to energy savings and reducing the environmental impact of buildings. The energy efficiency of translucent concrete is further underscored by its alignment with global sustainability goals and certifications such as LEED. The material's light-transmitting efficiency, evidenced by an average transmission rate of approximately 74.3% in our tests, reduces the need for electrical lighting, thereby decreasing energy consumption and operational costs. This aspect not only contributes to sustainable construction but also enhances the well-being and productivity of building occupants, as support-ed by environmental psychology research. In conclusion, translucent concrete represents a transformative development in the construction industry, offering substantial benefits for structural integrity, energy efficiency, and aesthetic flexibility. Its ability to integrate robustness with transparency provides architects and builders with a novel material that can redefine modern building designs and pave the way for more sustainable construction practices.

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