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Transparent Concrete by Using Optical Fibre as A Green Material for Building

Anuj Yadav[1*] and Devesh Ojha[2]

[1,2]Civil Engineering Department, Amity University, Lucknow, Uttar Pradesh, India

Corresponding Author: *Anuj Yadav

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Abstract

Transparent concrete, a contemporary innovation in the construction realm, is swiftly garnering attention within the industry. This advancement in material technology not only marks a milestone in modern material production but also underscores a commitment to environmental sustainability and energy efficiency. Incorporating the creative dimension of design is essential to align with current environmental design paradigms. Transparent concrete emerges as a promising solution to contemporary environmental challenges, particularly in the context of reducing artificial lighting dependency in buildings. Developed to address this pressing need, it boasts impressive attributes. For instance, achieving a commendable 28-day compressive strength of 26.4 N/mm² for M20 grade concrete showcases its structural viability. Additionally, its light transmittance capabilities are notable, with values ranging from 9.47% to 7.76% at fibre spacings of 1.5 cm by adding Optical fibres of 1%, 2 %, 3 % 4 % 5% respectively. The integration of optical fibres enables both natural and artificial light to permeate through the translucent concrete, aligning with the overarching goal of reducing energy consumption attributed to lighting. By harnessing sunlight as a primary light source and leveraging optical fibres to detect structural stress, transparent concrete epitomizes a multifaceted approach towards sustainable construction practices. In essence, transparent concrete embodies a convergence of technological innovation, environmental consciousness, and pragmatic design principles, poised to redefine the landscape of modern construction by offering both aesthetic appeal and functional efficiency.

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1. INTRODUCTION

Transparent concrete, augmented by the integration of optical fibres, stands at the forefront of contemporary construction as a green material poised to revolutionize building practices. This innovative construction material represents a significant stride in sustainable architecture, offering a harmonious blend of functionality, environmental consciousness, and aesthetic appeal. At its core, transparent concrete embodies a paradigm shift towards eco-friendly building materials, addressing the pressing need for sustainability in the construction industry. By leveraging optical fibres within its composition, transparent concrete not only facilitates the transmission of light but also embodies the ethos of green building practices. The incorporation of optical fibres in transparent concrete serves a dual purpose. Firstly, it enables the passage of natural and artificial light through the material, effectively reducing the reliance on conventional lighting systems. This inherent property aligns with the principles of energy efficiency, mitigating the environmental impact associated with excessive energy consumption in buildings. Secondly, the integration of optical fibres equips transparent concrete with the capability to detect structural stress. This functionality enhances the material's utility beyond its aesthetic appeal, contributing to the overall safety and longevity of the built environment. By proactively identifying areas of potential structural compromise, transparent concrete promotes proactive maintenance practices, thereby fostering sustainable building management. Furthermore, transparent concrete embodies an ethos of innovation and adaptability in architectural design. Its versatile nature allows for creative exploration in building aesthetics, enabling architects and designers to conceive spaces imbued with natural light while maintaining structural integrity. This flexibility not only enhances the visual appeal of built environments but also fosters a deeper connection between occupants and their surroundings. In conclusion, transparent concrete, fortified by optical fibres, emerges as a quintessential green material for building construction. Its ability to harness natural light, detect structural stress, and facilitate architectural innovation underscores its pivotal role in advancing sustainable building practices. As the construction industry continues to prioritize environmental stewardship, transparent concrete stands as a beacon of innovation, offering a compelling solution towards a greener, more sustainable built environment.

Optical Fibers Properties

Optical fibres are slender, flexible strands typically made of glass or plastic, designed to transmit light signals over long distances with minimal loss or distortion. These fibres possess several key properties that make them indispensable in various fields, particularly telecommunications and data transmission:

(a) **Light Transmission:** Optical fibres excel in transmitting light signals over long distances. Due to the principle of total internal reflection, light signals propagate along the length of the fibre with minimal loss, enabling efficient transmission of data.

(b) **Low Attenuation:** Optical fibres exhibit low attenuation, meaning that light signals experience minimal loss in intensity as they travel through the fibre. This property allows for the transmission of signals over vast distances without significant degradation.

(c) **High Bandwidth:** Optical fibres offer high bandwidth capabilities, enabling the transmission of a large volume of data simultaneously. This high data-carrying capacity is crucial for modern telecommunications networks, supporting high-speed internet, video streaming, and other data-intensive applications.

(d) **Immunity to Electromagnetic Interference:** Unlike traditional copper cables, optical fibres are immune to electromagnetic interference (EMI) and radio frequency interference (RFI). This immunity ensures reliable signal transmission, particularly in environments prone to electrical noise.

(e) **Lightweight and Flexible:** Optical fibres are lightweight and flexible, making them easy to install and maneuver in various applications. Their flexibility allows for seamless integration into complex systems and facilitates deployment in challenging environments.

(f) **Durability:** Optical fibres are highly durable and resistant to environmental factors such as moisture, temperature fluctuations, and corrosion. This durability ensures long-term reliability and stability in demanding operational conditions.

(g) **Security:** Optical fibres offer enhanced security for data transmission due to their ability to confine light within the fibre core. This property makes it difficult for intruders to intercept or tamper with transmitted data, enhancing the overall security of communication networks.

Versatility: Optical fibres find applications beyond telecommunications, including medical imaging, sensing, and industrial instrumentation. Their versatility makes them indispensable in various fields, driving innovation and technological advancement.

Figure 1: Optical Fibers

2. LITERATURE REVIEW

The integration of optical fibres into transparent concrete marks a significant advancement in the realm of sustainable construction. This literature review aims to explore the multifaceted benefits and applications of transparent concrete infused with optical fibres as a green material for building. Transparent concrete, also known as translucent concrete or light-transmitting concrete, is a novel construction material that combines traditional concrete components with light-transmitting elements such as optical fibres or embedded glass. This innovative approach to construction offers a plethora of advantages, ranging from enhanced aesthetic appeal to improved energy efficiency. One of the primary benefits of transparent concrete lies in its ability to harness natural light, thereby reducing the dependency on artificial lighting systems. By integrating optical fibres into the concrete matrix, natural light can permeate through the material, illuminating interior spaces and reducing energy consumption associated with lighting. This feature aligns with the principles of sustainable design and green building practices, contributing to energy efficiency and environmental conservation. Furthermore, transparent concrete offers architectural versatility, allowing designers to create visually stunning structures that blur the boundaries between indoor and outdoor spaces. The interplay of light and transparency adds a dynamic dimension to building facades, enhancing the overall aesthetic appeal, and creating unique spatial experiences for occupants. In addition to its aesthetic and environmental benefits, transparent concrete infused with optical fibres offers practical advantages in terms of structural integrity and safety. The incorporation of optical fibres enables real-time monitoring of structural stress and strain, enhancing the resilience and durability of buildings. This proactive approach to structural health monitoring contributes to the longevity of infrastructure and reduces the risk of structural failures. Moreover, the use of transparent concrete as a green material for building extends beyond its immediate environmental and structural benefits. Its potential applications in areas such as urban design, interior architecture, and sustainable infrastructure underscore its versatility and relevance in contemporary construction practices. In conclusion, the integration of optical fibres into transparent concrete represents a promising avenue for sustainable construction, offering a synergistic blend of aesthetic, environmental, and practical advantages. As the construction industry continues to prioritize sustainability and innovation, transparent concrete emerges as a compelling solution for creating resilient, energy-efficient, and visually captivating built environments.

3. METHODOLOGY

Initial tests adhered to IS standards and specifications were conducted on conventional concrete materials to assess their physical and engineering properties. Cubes were cast in standard metallic moulds and vibrated to achieve the desired specimen size. Before pouring the concrete, moulds were meticulously cleaned and coated with oil on all sides. The concrete, thoroughly mixed, was poured into the moulds in three uniform layers and compacted using a vibrating table for five minutes. Excess concrete was then removed with a trowel, and the surface was smoothed for a uniform finish. The manufacturing process for transparent concrete closely resembles that of regular concrete blocks, with the primary difference being the inclusion of glass rods dispersed throughout the fine aggregate and cement mix. Small layers of concrete were poured successively into a wooden casted box, embedding the glass rods. Transparent concrete's light-transmitting properties were achieved by incorporating varying percentages of glass rods (1%, 2%, 3%, 4%, and 5% by weight) into the concrete mixture, which exclusively comprised fine aggregate materials, omitting coarse aggregates. Glass rods and concrete were alternately inserted into moulds at approximately 1.5cm intervals. The resulting casted materials were then cut into small panels or blocks of specified thickness, with the surface polished to achieve a semi-gloss to high-gloss finish. After 24 hours, samples of both conventional and translucent concrete were demoulded and placed in a curing tank for periods of 7, 14, 21, and 28 days. A set of five samples was prepared for each stage of curing. The curing tank maintained a temperature of around 25 degrees Celsius during the analysis of characteristic strength, and the results were systematically tabulated for evaluation.

Arrangement of Optical Fiber

The volume ratio of optical fibres in concrete directly influences its light transmission properties. By incorporating optical fibres with cement in the mortar during the manufacturing process of transmitting concrete, the material's ability to transmit light can be enhanced. However, to precisely understand the impact of optical fibre ratio on the characteristics of transmitting concrete, it is necessary to evaluate concrete panels based on the appropriate ratio and arrangement pattern of optical fibres. In evaluating the effectiveness of translucent concrete in terms of light transmission properties and the transmission ability of optical fibres, researchers concluded that the volume ratio of optical fibres to the concrete mixture correlates with light transmission and affects the compressive strength of the concrete. Furthermore, the influence of plastic optical fibres on the properties of transmitting concrete was investigated. Experimental results showed that compressive strength increased with the rise in the ratio of plastic optical fibres. Compression testing using a compression testing machine (CTM) was conducted across six ratios (1%, 2%, 3%, 4%, and 5%). The highest value was recorded with plastic optical fibres at a ratio of 3% and a diameter of 1.5 mm after a 28-day test period. Another study examined the impact of a 1% volume ratio of plastic optical fibres with 1 mm diameter strands on a 150 mm cube, resulting in a notable increase in compressive strength to 26.4 N/mm², as determined by compression testing using a compression testing machine (CTM).

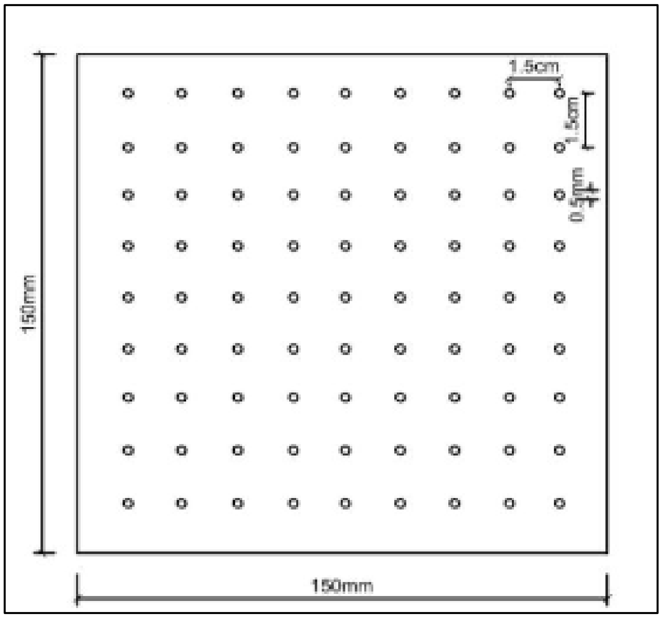

Figure 2: The arrangement pattern of Fibers

Tests conducted on Concrete Materials

Test on Cement

(a) Fineness of cement.

(b) Normal Consistency of cement.
(c) Soundness test.
(d) Specific gravity.
(e) Initial setting time of cement.
(f) Final setting time of cement.

Table 1: Test on Cement

Sr. No	Test	Method of test	Average Result	Permissible value
1	Fineness of cement	IS 269-1976	8%	Max 10%
2	Normal consistency	IS:4031-Pt-4	30%	26 to 33%
3	Soundness	IS:4031-Pt-3	7 mm	< 10mm
4	Specific gravity	IS:2720-Pt-3	3.16	3.12 to 3.19
5	Initial setting time Min	IS 4031-1968	35 mins	30 mins
6	Final setting time	IS 4031-1968	370 mins	Max 600 mins

Test on fine aggregates (Size <4.75mm)
(a) Specific gravity test,
(b) Water absorption test

Table 2: Test on fine aggregates

Sr. No.	Test	Method of test	Average Result	Permissible value
1	Specific gravity	IS:2720-Pt-3	Bulk specific gravity = 2.51	2.53 to 2.67
2	Water absorption	IS:2386-Pt-3	1.5	<2%

Tests Conducted on Plain concrete.
(a) Slump test.
(b) Compaction factor.
(c) Compressive strength of concrete.
(d) Split tensile strength of concrete.
(e) Flexural strength of concrete

Table 3 Test on Plain cement concrete

Test	Slump test	Compaction factor test	Compressive strength			
			7 Days	14 Days	21 Days	28 Days
Method of test	IS-7320-1974	IS-1199-1959	IS 1489-1991	IS 1489-1991	IS 1489-1991	IS 1489-1991
Average Result	True slump for 0.45 w/c ratio	0.9	19.2 N/mm2	23.5 N/mm2	23.7 N/mm2	26.3 N/mm2
Permissible value	–	–	Min 17 N/mm2	Min 22 N/mm2	Min 23.5 N/mm2	Min 25 N/mm2

Table 4: Test on Plain cement concrete

Test	Split tensile strength		Flexural strength	
	7 Days	28 Days	7 Days	28 Days
Method of test	IS 5816-1976	IS 5816-1976	IS: 516-1959	IS: 516-1959
Average Result	5.1 N/mm2	5.7 N/mm2	5.2 N/mm	5.6 N/mm2
Permissible value	_	_	_	_

Tests conducted on Transparent Concrete
(f) Slump test.
(g) Compaction factor.
(h) Compressive strength of concrete.
(i) Split tensile strength of concrete.
(j) Flexural strength of concrete

Table 5: Test on Transparent Concrete

Test	Slump test	Compaction factor test	Compressive strength			
			7 Days	14 Days	21 Days	28 Days
Method of test	IS-7320-1974	IS-1199-1959	IS 1489-1991	IS 1489-1991	IS 1489-1991	IS 1489-1991
Average Result	True slump for 0.45 w/c ratio	0.8	18.2 N/mm2	21.5 N/mm2	22.7 N/mm2	25.2 N/mm2
Permissible value	–	–	Min 17 N/mm2	Min 22 N/mm2	Min 23.5 N/mm2	Min 25 N/mm2

Table 6: Test on Transparent Concrete

Test	Split tensile strength		Flexural strength	
	7 Days	28 Days	7 Days	28 Days
Method of test	IS 5816-1976	IS 5816-1976	IS: 516-1959	IS: 516-1959
Average Result	5.3 N/mm2	5.9 N/mm2	5.4 N/mm	5.8 N/mm2
Permissible value	_	_	_	_

MIX DESIGN

Volumetric batching is employed to determine the precise material quantities necessary for casting each cube specimen, adhering to a design mix of M25 grade (cement: fine aggregate) at a ratio of 1:1, following IS 383-1970 & IS 456-2000 specifications. The aggregate-cement mixture is adjusted to achieve up to 35% porosity by modifying materials with minimal or zero fine aggregates. This blend, with a water-cement ratio of 0.5, is utilized to cast moulds for assessing the compressive strength at 7, 14, 21, and 28 days, with an average of 5 specimens.

To create light-transmitting concrete, glass rods are incorporated into the concrete mixture at proportions of 1%, 2%, 3%, 4%, and 5% by weight. This translucent concrete blend exclusively comprises fine aggregate materials, devoid of coarse aggregates. Glass rods and concrete are alternately introduced into moulds at intervals of approximately 1.5cm. Subsequently, the casted materials are cut into small panels or blocks of specified thickness, with the surface typically polished to achieve a semi-gloss to high-gloss finish. Following a 24-hour period, samples of both conventional and translucent concrete are demoulded and placed in curing tanks for respective periods of 7, 14, 21, and 28 days. A set of 5 samples is prepared for each stage of curing.

4. RESULTS & DISCUSSION

The addition of glass rod fibres in varying proportions of 1%, 2%, 3%, 4%, and 5% contributes to a gradual increase in the strength of concrete up to a certain threshold, beyond which it begins to decline. Through experimental analysis, it has been observed that incorporating glass rods by weight leads to an enhancement in the initial compressive strength of transparent concrete blocks up to a specific percentage. An increase in the initial compressive strength of up to 5% to 10% is noted for 7 days, and a further increase of 10% to 15% is observed for 28 days with glass rod mixes of up to 3%. However, both the initial and final characteristic compressive strength experience a gradual decrease with an increase in the percentage of glass rods in the concrete mix.

TABLE 7: Comparison of compressive strength for various specimens with varying % in Glass rods of 1.5cms spacing for 7, 14, 21 & 28 days in N/mm2

% of Glass rods in 1.5 cm spacing	1	2	3	4	5
Average strength at 7 days (N/mm2)	14.3	15.1	15.9	14.3	13.6
Average strength at 14 days (N/mm2)	16.0	17.1	17.8	16.2	15.4
Average strength at 21 days (N/mm2)	20.3	23.2	24.3	21.5	19.9
Average strength at 28 days (N/mm2)	24.0	25.7	26.4	24.3	22.6

5. CONCLUSION

(a) The mechanical properties of plain concrete cubes were examined through compressive, split tensile, and flexural strength tests over curing periods of 7, 14, 21, and 28 days, revealing a characteristic improvement in strength behaviour.

(b) Incorporating optical fibres in concrete up to 3% resulted in a notable increase in initial compressive strength, with enhancements of 5% to 10% observed at 7 days and 10% to 15% at 28 days.

(c) However, both the initial and final characteristic compressive strength exhibit a gradual decrease as the proportion of optical fibres in the concrete mix increases.

(d) Moreover, this incorporation of optical fibres can contribute to the reduction of hazardous carbon emissions, thereby qualifying as a high-performance concrete solution.

(e) Transparent concrete, composed of glass rods, is primarily suited for applications such as partition walls rather than serving as structural elements like columns and beams.

(f) The key advantage of translucent concrete lies in its lightweight nature, which effectively reduces the overall self-weight of concrete structures. Additionally, it serves as a decorative element in interior design, finding use as panels in slabs, walls, and other architectural features.

(g) Based on the findings of the study, it can be inferred that integrating optical fibres into concrete mixtures up to a 5% replacement ratio yields excellent results in terms of both strength and quality characteristics.

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