Performance Evaluation of Eco-Friendly Translucent Concrete: A Noval Approach in Saving Energy Consumption in Buildings

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Abstract:

The cement manufacturing industry is a significant contributor to greenhouse gas emissions, thereby exacerbating global warming and depleting natural resources through the extensive use of raw materials. To address these environmental concerns, the present study investigates the development of eco-friendly translucent concrete incorporating industrial by-products such as fly ash (FA) and ground granulated blast furnace slag (GGBFS) as partial replacements for ordinary Portland cement (OPC). M20 grade translucent concrete specimens were fabricated with optical fibres embedded at 4% of the cross-sectional area to enhance light transmission. The study evaluated the compressive strength, light transmittance, and workability of various concrete mixes. Results revealed that conventional translucent concrete achieved the highest compressive strength, both with and without optical fibres. Among the modified mixes, the inclusion of 30% FA yielded superior performance compared to 50% GGBFS and combined FA-GGBFS replacements. These findings demonstrate the potential of using FA and GGBFS in translucent concrete for sustainable building applications, promoting energy efficiency by enabling natural light penetration and reducing reliance on artificial lighting.

Keywords: Eco-friendly translucent concrete, Light emittance test, Energy reduction

1. Introduction:

Transparent concrete—also referred to as translucent or light-transmitting concrete—is an innovative composite material that integrates optical fibres or glass elements within a concrete matrix to enable the transmission of natural light. This modern development, known by various names such as Light Transmitting Concrete (LiTraCon) and Translucent Concrete (TC), represents a significant advancement in sustainable building technologies, combining functionality with aesthetic appeal. The concept was first introduced by Hungarian architect Áron Losonczi in 2001, with the successful fabrication of the first transparent concrete block in 2003. The foundational principle involves embedding optical fibres in a uniform, horizontal arrangement within the concrete prior to casting. This allows light to travel through the material via waveguiding mechanisms, while maintaining the mechanical strength and integrity of conventional concrete. Materials used for the optical components include polymethyl methacrylate (PMMA) fibres, plastic optical fibres (POF), and glass optical fibres (GOF), each offering varying degrees of light transmittance and durability. Translucent lightweight concrete has gained traction across a wide range of applications in construction, architecture, interior design, and furniture manufacturing. Modular elements such as panels and blocks can be prefabricated for both structural and decorative use. The dual functionality of the material offering structural support and passive lighting makes it particularly valuable in urban environments, where increased building height has reduced access to natural daylight. Presently, lighting accounts for approximately 30% of domestic electricity consumption. By enabling natural illumination within interior spaces, transparent concrete has the potential to significantly reduce energy demand related to artificial lighting. The use of light-transmitting concrete aligns with global efforts toward green building practices, providing an energy-efficient alternative that does not compromise on design. This research explores the development, material properties, and applications of translucent concrete, highlighting its role in shaping the future of sustainable architecture.

2. Literature Review:

A.B. Sawant et al. (2014) explored the use of optical fibres in high-performance concrete to improve aesthetics and reduce energy consumption. Compressive strength and light transmission tests were conducted, revealing that light transmittance increased with higher fibre content, peaking at 1:00 PM. Despite being 12 times more expensive than conventional concrete, cost analysis showed the additional investment could be recovered in 3.5 years for domestic use and 2.1 years for commercial and industrial applications. The study highlights the material's potential for energy savings and reduced carbon emissions, promoting sustainable building practices.
Amlan Kumar Sahoo and Sachin Sahu (2017) conducted a study to develop translucent concrete using optical fibres and compare its properties with conventional concrete. Specimens were tested for compressive strength and light transmission. While the compressive strength of translucent concrete showed a slight reduction, it demonstrated an average light transmissibility of 4%, measured using a Lux Meter and a 100-watt light source. The study concludes that incorporating such innovative materials can support sustainable development by promoting the use of renewable energy and reducing dependence on artificial lighting.
Shreyas (2018) investigated the impact of incorporating plastic optical fibres into concrete. The study observed a 5–10% increase in 7-day compressive strength and a 10–15% increase at 28 days for fibre content up to 3%. However, further increases in fibre content led to a gradual decline in both initial and final compressive strength. The research concludes that optical fibres can be effectively used up to 5% in the mix, offering improvements in strength and quality. Translucent concrete produced in this manner is best suited for non-structural applications such as partition walls.
Shradha Nimbalkar (2019) studied the performance of light-transmitting concrete and confirmed its potential as an innovative construction material. The research showed that compressive strength varied with optical fibre content—increasing at 4% and decreasing at 5%. Light intensity improved as fibre content increased from 2% to 3%, with peak transmission observed in the afternoon. However, larger surface areas led to reduced light intensity. Despite its higher cost, the study concludes that light-transmitting concrete offers significant aesthetic and energy-efficient benefits, justifying its use in modern construction.

Summary:

A review of existing research reveals that most experimental studies on translucent concrete have primarily focused on the use of optical fibres and glass rods as light-transmitting elements. These studies consistently report that optical fibres offer superior light transmission and higher compressive strength compared to glass rods, with optimal performance observed at approximately 4% fibre content. However, there is a noticeable gap in the literature regarding the integration of eco-friendly supplementary materials such as fly ash, ground granulated blast furnace slag (GGBS), and nano clay composites (NCC) in translucent concrete mixes. The potential of these sustainable materials to enhance the environmental performance and durability of translucent concrete remains underexplored. To address this gap, the present study aims to develop and evaluate translucent concrete incorporating 4% optical fibre along with fly ash, GGBS, and NCC, thereby contributing to the advancement of green and energy-efficient construction technologies.

3. Objectives the current study:

1. To compare the strength characteristics of translucent concrete and Conventional cement concrete.
2. To measure the light transmission of the translucent concrete by using optical fibres.
3. To prepare eco-friendly translucent concrete using fly ash and GGBS.

4. Methodology and Experimental Details:

In the current study, the compressive strength, light transmittance test and the properties related to workability of fresh concrete such as slump cone, compaction factor test are performed on the translucent concrete prepared with OPC and by replacing the OPC partially with GGBFS and FA.

The proposed methodology is presented in figure no.1. The materials are procured from locally available vendors and physical properties were evaluated. The mix design is prepared as per standard code specification of Indian standards. Fresh cement properties such as slump cone and compaction factor tests were performed on all the mix combinations. Then the specimens were prepared and cured for 28 days water curing. The compressive strength and light translucent test were performed.

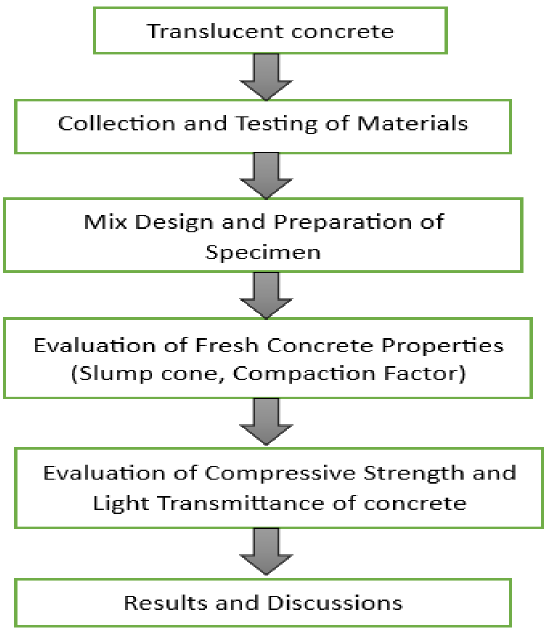

Figure.1 Methodology

4.1 Materials used:

The Ordinary Portland cement (OPC), coarse aggregates, fine aggregates, ground granulated blast furnace slag (GGBFS), fly ash (FA), Optical fibres and water were used for the preparation of the conventional and eco-friendly translucent concrete. The physical properties of the materials used are displayed in the below Tables.

Table No 4.1.1 Physical properties of cement

Sl. No	Physical properties	Results
1	Normal consistency	30%
2	Setting time	
	a. Initial setting time	80 minutes
	b. Final setting time	430minutes
3	Fineness by Dry sieving	2%
4	Specific gravity	3.14

Table No. 4.1.2 Physical properties of coarse aggregates

Sl.No	Physical properties	Results
1	Specific gravity	2.50
2	Crushing strength	11.50%
3	Water absorption	2.3 %

Table No. 4.1.3 Physical properties of fine aggregates

Sl.No	Physical properties	Results
1	Specific gravity	2.60
2	Fineness modulus	2.6 (Zone-II)
3	Bulking	34 %

An optical fibre is a flexible, transparent fibre made of glass (silica) or plastic, slightly thicker than a human hair. It functions as a waveguide or light pipe, to transmit light between the two ends of the fibre. The field of applied science and engineering concerned with the design and application of optical fibres is known as fibre optics. The typical optical fibre is shown in figure 2.

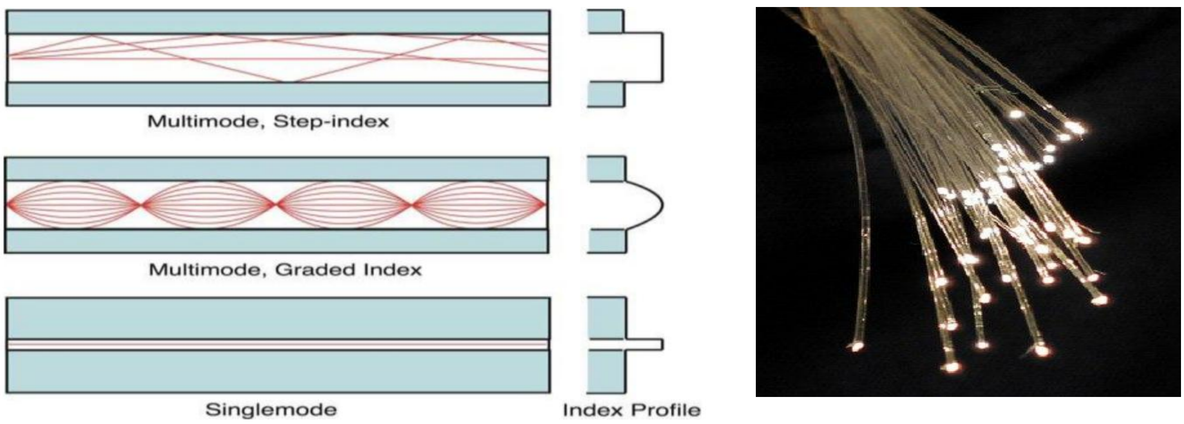

Figure.2 Optical fibre (source: Internet)

4.2 Mix Design

Compressive strength is widely recognized as a fundamental indicator of hardened concrete's performance and durability. It is significantly influenced by various factors, including the quality and proportioning of cement, water, and aggregates, as well as the procedures employed during batching, mixing, placing, compaction, and curing. Among these, the preparation of an optimal mix design is crucial in achieving a balance between structural performance, durability, and cost-effectiveness. A well-structured mix design aims to meet the characteristic compressive strength requirements specified by structural engineers, while minimizing the use of materials to ensure both economic and environmental sustainability. Key considerations in the mix design process include the selection of an appropriate water-cement ratio, aggregate gradation, and the inclusion of admixtures or supplementary cementitious materials, all tailored to meet performance expectations within budgetary constraints. Consequently, the actual cost of concrete is not solely dependent on material prices but is also significantly affected by the level of quality control maintained throughout the production process. In the present study, mix designs for M20 grade concrete were developed in accordance with the Indian Standards IS 10262:2019 and IS 456:2000. The mix proportions were formulated for various types of translucent concrete, including conventional translucent concrete with ordinary Portland cement (OPC), OPC partially replaced with ground granulated blast furnace slag (GGBFS), OPC partially replaced with fly ash (FA), and a combination of OPC, GGBFS, and FA. The detailed mix proportions for each variant are presented in the subsequent sections.

Table No. 4.2 Mix proportion details of translucent concrete

Sl.No	Description	Details of Material proportions for M20 Grade Concrete					
		Cement, kg	Coarse aggregates, kg	Fine aggregates, kg	Water, kg	GGBFS, kg	FA, kg
1	Conventional Translucent concrete	392	888	862	196	-	-
2	Translucent concrete with 30% FA & 70% OPC	302	831	839	196	-	129
3	Translucent concrete with 50% GGBFS & 50% OPC	190	894	859	196	190	-
4	Translucent concrete with 30% GGBFS, 20% FA & 505 OPC	216	837	845	196	129	86

4.3 Customised Mould:

A customized cube mould was fabricated using plywood, with standard dimensions of 150×150×150 mm. To facilitate the integration of optical fibres, two opposite faces of the mould were drilled at uniform intervals of 1.5 cm. These drilled holes are specifically designed to accommodate optical fibres with a diameter of 1.5 mm and a length of 155 mm. The insertion of optical fibres into the mould is carried out with care to ensure they remain securely in place and undamaged during the concrete casting process. Concrete is poured in layers, and the placement of fibres is done in such a way that their alignment and integrity are maintained throughout the filling and compaction stages. This approach ensures uniform light transmission through the finished concrete specimen. The customized mould and the optical fibre arrangement are illustrated in the figures provided below.

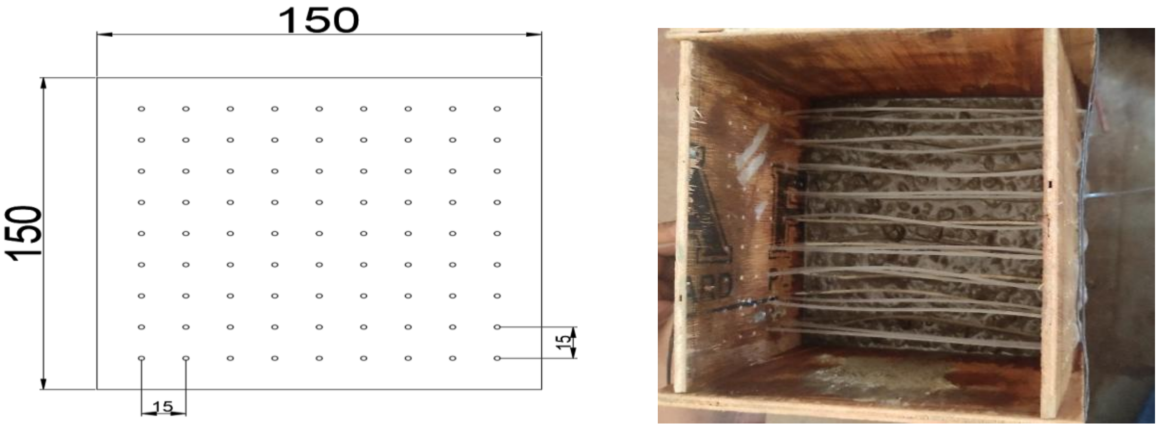

Figure No.3 Customised mould dimensions and prepared mould

5. Results and Discussions:

5.1 Fresh concrete properties:

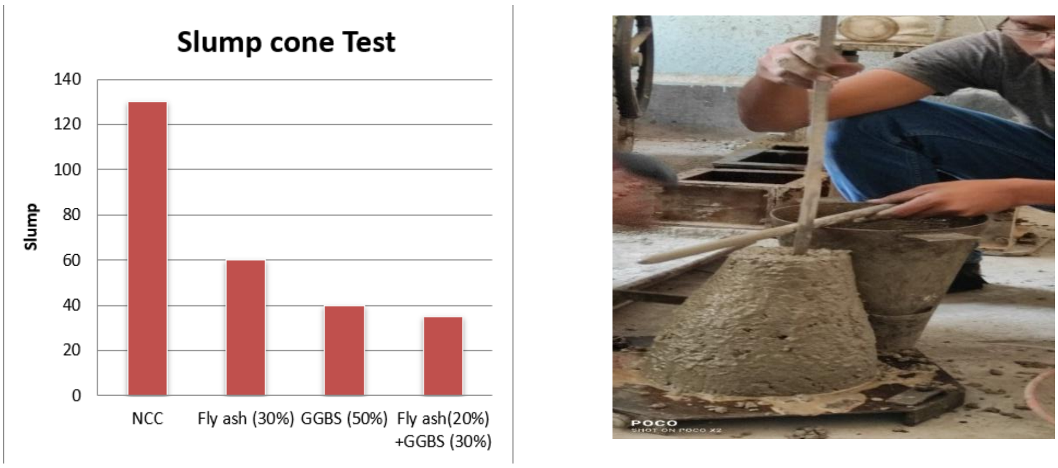

Figure No. 4 Slump cone Test

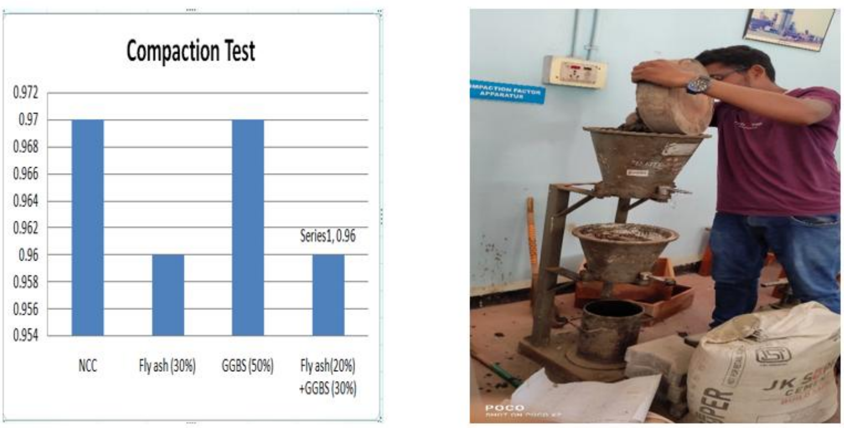

Figure No.5 Compaction factor test

The workability of various translucent concrete mixes was evaluated using slump and compaction factor tests. The results revealed that the conventional concrete mix with 100% ordinary Portland cement (OPC) exhibited the highest workability, recording a slump value of 130 mm. In contrast, the mix incorporating a combination of OPC, ground granulated blast furnace slag (GGBFS), and fly ash (FA) showed the lowest slump value of 35 mm. Among the modified mixes, the blend with 30% FA replacement demonstrated higher workability compared to the mix with 50% GGBFS replacement. The compaction factor values for all mixes ranged between 0.95 and 0.97, indicating relatively good workability across the board. Overall, the OPC-based translucent concrete exhibited the best workability characteristics. However, among the sustainable alternatives, the FA-based mix offered better workability than both the GGBFS-based mix and the combined FA-GGBFS mix, making it a more viable eco-friendly option from a workability perspective.

5.2 Compressive strength:

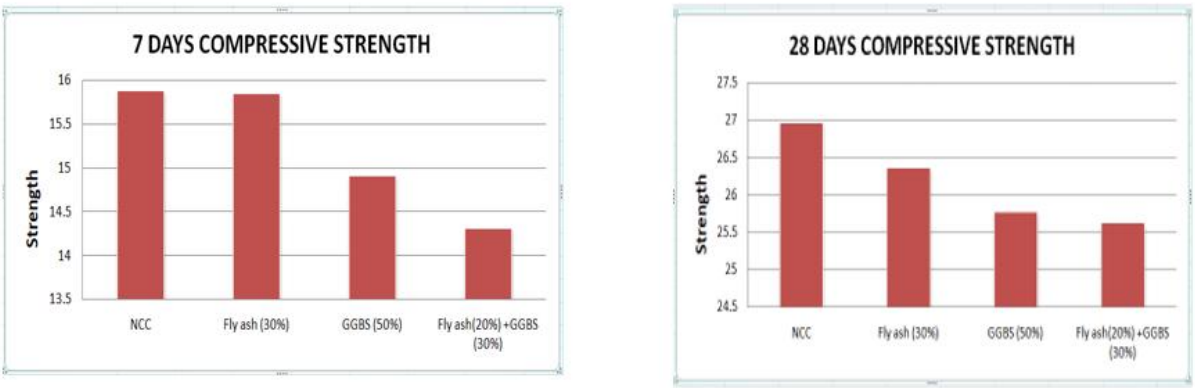

Figure No.6 Compression strength of specimen without Optical fibres

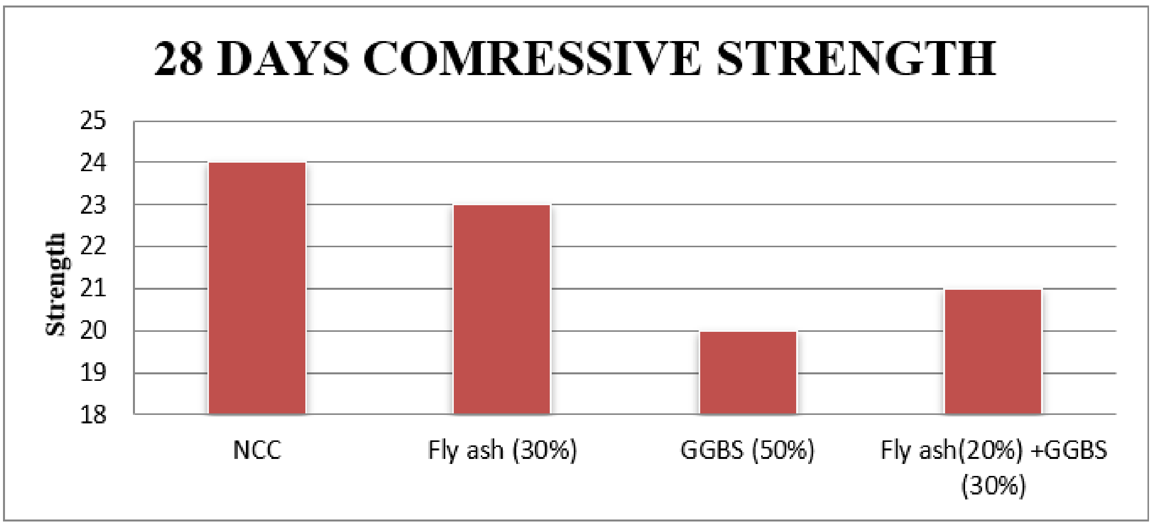

Figure No.7 Compression strength of specimen with Optical fibres

Figures 6 and 7 illustrate the compressive strength results of various translucent concrete mixes, both with and without the inclusion of optical fibres. It was observed that the

OPC-based translucent concrete consistently exhibited the highest compressive strength across both conditions. For specimens without optical fibres, all mix combinations achieved compressive strengths exceeding the M20 grade requirement (20 MPa), indicating satisfactory performance. However, when optical fibres were embedded in the moulds, only the mix with 30% fly ash (FA) as a partial replacement for OPC maintained compressive strength above the M20 threshold. In contrast, the mixes with 50% GGBFS and the combination of 30% GGBFS + 20% FA achieved compressive strengths close to, but not significantly above, 20 MPa. These findings suggest that while all mixes are structurally viable in the absence of optical fibres, the incorporation of fibres can impact compressive strength, with FA-based mixes showing better compatibility in maintaining strength in translucent concrete applications.

5.3 Light Transmittance test:

The light which transmitted through concrete can be measured by a photo diode or light dependent resistors (LDR) A 60 W incandescent bulbs taken here, throughout the test, to ensure no light escapes. At the top of the specimen light source and at the bottom LDR is placed. Between light and LDR concrete is placed and test is carried out. Reading is taken by differing the voltage. Two values are taken, one without concrete sample (A1) and one with concrete sample (A2). Amount of light transmitted is calculated as follows:

$$\text{Light transmittance} = 100 - \left[\frac{A1-A2}{A1} \times 100 \right]$$

A1 = ammeter reading without specimen, A2 = ammeter reading with specimen

The study demonstrates that light transmittance in translucent concrete is primarily governed by the type and placement method of optical fibres, with all mix combinations showing similar light emittance values. This indicates that the optical properties are independent of the cementitious composition of the concrete. The findings also confirm the feasibility of incorporating industrial by-products such as fly ash (FA) and ground granulated blast furnace slag (GGBFS) in the production of translucent concrete. Among the various mix combinations tested, the mix with 30% FA replacement for OPC delivered the most favourable balance between compressive strength and workability, making it the most effective alternative for sustainable construction. Embedding optical fibres at 4% of the specimen area was found to be sufficient for effective light transmission without significantly compromising compressive strength. However, increasing the fibre content may lead to a reduction in strength and should be carefully evaluated. Translucent concrete represents an innovative approach to enhancing energy efficiency in buildings by allowing natural light to penetrate interior spaces. Despite the added complexity, cost of optical fibres, and the need for skilled labour, the integration of recycled industrial materials alongside optical fibres positions this technology as a promising eco-friendly, cost-effective, and energy-saving solution in modern construction practices.

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