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Study on the effect of inducing optical fiber in matrix of light emitting concrete

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Abstract : The growing population has increased the demand for natural resources, raising concerns over sustainability. Climate change and environmental issues highlight the need for innovative and eco-conscious construction methods. Light Transmitting Concrete (LTC) emerges as a sustainable solution by allowing natural sunlight to pass through concrete. In this study, optical fibers of 0.75 mm diameter were embedded in M25 grade concrete in three different grid patterns - 6×6, 7×7, and 8×8 to analyze their effect on strength characteristics. Compressive strength and bond strength were evaluated after 28 days of curing. The results demonstrated that as the number of optical fibers increased, both compressive and bond strengths improved compared to specimens without fibers. An increase of approximately 6.65% in 28-day compressive strength and 24.52% in bond strength was observed compared to conventional concrete. The strength enhancement is attributed to the optical fibers acting as micro-reinforcements, improving the bond between the fibers and the concrete matrix. This study also evaluated the light-transmitting properties of concrete using an LED bulb as a light source, and light intensity was measured in lumens using a light meter. The results indicated that the addition and increased quantity of optical fibers significantly enhance the light intensity transmitted through the concrete.

***IndexTerms* -** Light transmitting concrete, Plastic optical fiber, Compressive strength, Bond strength, Light meter.

I. INTRODUCTION

Light transmitting concrete, also known as translucent concrete, represents a significant innovation in construction materials, merging aesthetic appeal with functional capabilities. This material is designed to allow the passage of light through its structure, which is achieved by embedding optical fibres into traditional concrete mixtures. The concept of Light Transmitting Concrete (LTC) was first introduced by Hungarian architect Aron Losonczi in 2001, who later developed the first product "LiTraCon" in 2003. Early research focused on integrating plastic optical fibres (POF) into concrete to enhance light transmission while evaluating mechanical properties. Over time, studies by Bashbash, Salih, and Sawant explored the impact of POF on compressive and flexural strength. The primary objective of this technology is to enhance natural lighting in buildings, thereby contributing to energy savings and improving the overall architectural experience. The methodology follows a systematic approach involving the casting of M25-grade concrete cubes embedded with optical fibres in 6×6, 7×7, and 8×8 grid patterns. Compressive strength and pull-out tests were conducted at 28 days to evaluate mechanical performance.

II. MATERIALS AND METHODOLGY

In this study Ordinary Portland Cement (OPC), fine aggregates, coarse aggregates, water, and optical fibers were used to prepare the light-transmitting concrete.

Cement:

Cement is a fine powder made by calcining limestone and clay minerals. It reacts with water to form a hard binding material.
In this study, Portland pozzolana Cement (PPC) is used.

Physical properties of cement:

For this experiment UltraTech Portland pozzolana cement was used and specific gravity, normal consistency, setting time test and compressive strength tests were performed in accordance with standard specification.

Table 1 Physical properties of PPC

Tests conducted	Experimental values	IS Code values	Reference code
Specific gravity test	2.8	2.9-3.0	IS 4031 (Part11) 1988
Consistency test on cement	32%	28%-35%	IS 4031(part 4) 1988
Initial setting time	150 min	Min. 30 min	IS 4031 (part-5) 1988
Final setting time	225 min	Max. 600 min	IS 4031 (part-5) 1988
28 days compressive strength test	42.187 Mpa	≥ 33 Mpa	IS 1489 (Part 1) – 2015 and IS 4031 (Part 6) – 1988

Fine Aggregate:

Fine aggregates are essential components in concrete. In this project, Manufactured Sand (M-sand) was used as fine aggregate. It is produced by crushing hard granite stones and is free from impurities such as clay, silt, and organic matter.

Physical properties of fine aggregate:

For this experiment locally available fine aggregates were used and specific gravity, water absorption and sieve analysis tests were performed in accordance with standard specification.

Table 2 physical properties of fine aggregate

Tests conducted	**Experimental values**	**IS Code values**	**Reference code**
Specific gravity	2.67	2.5 to 2.9	IS 2386 (Part 3) – 1963
Fineness test	2.112 % Zone II	2-3%	IS 383-2016

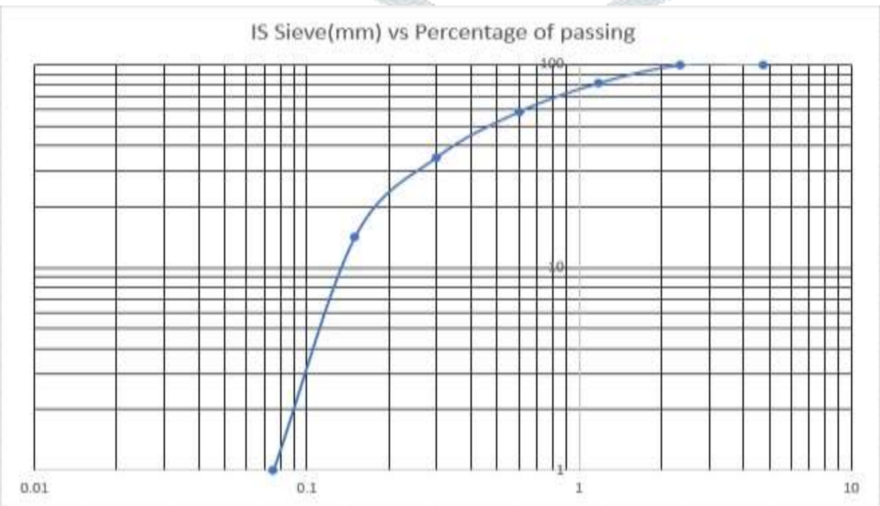

Figure 1 IS Sieve v/s percentage of passing

Coarse Aggregate:

Coarse aggregate contributes to the strength and volume stability of concrete. In this project, crushed granite aggregates of 10 mm downsize were used. The aggregates were clean, angular, and well-graded to improve bonding and reduce voids in the concrete mix.

Physical properties of coarse aggregate:

Table 3 physical properties of coarse aggregate

Tests conducted	Experimental values	IS Code values	Reference code
Specific gravity	2.63	2.5to 3.0	IS 2386(Part 3)-1963
Finess test	0.4%	Shouldn't exceed 0.6%	IS 2386 (Part 3)-1963

Optical fiber:

PMMA Optical fibers are flexible, transparent strands used to transmit light through the principle of total internal reflection, where light entering at a certain angle reflects entirely within the fiber core. PMMA (Polymethyl Methacrylate) optical fibers, specifically those with a 0.75 mm diameter, are a type of plastic optical fiber (POF) commonly used for short-distance light transmission in applications like light-transmitting concrete. These fibers are made with a PMMA core and a fluorinated polymer cladding, offering high optical clarity, flexibility, and cost-effectiveness. With a numerical aperture of around 0.5, they can efficiently transmit visible light (400–700 nm) with minimal loss over short ranges. PMMA fibers are known for their good mechanical strength, resistance to moderate heat (up to 70°C), and ability to maintain light transmission even when bent, making them ideal for embedded designs. However, they are less suitable for long-distance communication due to higher attenuation compared to glass fibers.

Figure 2 preparation of Mold

Designed a concrete mix for Grade M25 using IS 10262:2019.

Table 4 MIX DESIGN (AS PER IS 456-2000, IS 10262-2019**)**

Cement	**Fine aggregate**	**Coarse aggregate**	**Water**	**Water cement ratio**
446.33 kg/m3	809.15 kg/m3	809.89 kg/m3	214.24 kg/m3	0.48

Slump of concrete in mm = 100mm > 75 mm assumed (Medium workability)

True slump

III. RESULT and DISCUSSION

Compressive strength test:

Compressive strength is a key property that determines the load-bearing capacity of concrete blocks. To test this, a standard block of size 150 mm × 150 mm × 150 mm is placed in a compression testing machine. The procedure involves applying a gradually increasing load until the block fails. Before testing, the block should be properly cured (usually 28 days), surface dried. The load at failure is recorded and divided by the block's cross-sectional area to calculate the compressive strength, typically expressed in MPa. Due to variations in material quality, curing conditions, or manufacturing defects, results can vary

.Figure 3. Cube placed in compression test machine and cube after failure

Table 5 compressive strength test results

(1)

SI No.	Type of specimen	Length (mm)	Breadth (mm)	Load (kN)	Strength N/mm²	Average strength N/mm²
1	Conventional	150	150	800	34.62	35.4
2	Conventional	150	150	810	35.77	
3	Conventional	150	150	810	36.00	
1	LTC with 6x6	150	150	810	36.00	36.146
2	LTC with 6x6	150	150	820	36.44	
3	LTC with 6x6	150	150	810	36.00	
1	LTC with 7x7	150	150	860	37.22	36.71
2	LTC with 7x7	150	150	840	36.35	
3	LTC with 7x7	150	150	845	36.57	
1	LTC with 8x8	150	150	880	38.08	38.062
2	LTC with 8x8	150	150	885	38.305	
3	LTC with 8x8	150	150	875	37.8	

The above table presents the outcomes of compressive strength tests conducted on different concrete specimens. The specimens include conventional concrete and lightweight concrete (LTC) with varying grid pattern 6x6, 7x7, and 8x8. All samples had uniform dimensions of 150 mm in both length and breadth. The compressive load applied ranged from 800 kN to 885 kN. Among the samples, the conventional concrete exhibited an average compressive strength of 35.4 N/mm², whereas LTC with 6x6 grid showed a slightly higher average of 36.146 N/mm². The LTC with 7x7 grid yielded an even higher average strength of 36.71 N/mm². Notably, the LTC with 8x8 grid achieved the highest average compressive strength of 38.062 N/mm². This trend suggests that the integration of larger numbers of grid in LTC enhances compressive strength, possibly due to better reinforcement and load distribution properties. Overall, LTC specimens outperformed the conventional mix, indicating the effectiveness of grid pattern reinforcement in improving the structural capacity of concrete.

The below graph illustrates that for all grid patterns, LTC consistently exhibits higher compressive strength than conventional concrete. Specifically, while the conventional concrete maintains a fairly constant compressive strength around 35.4 MPa, the strength of LTC increases progressively with larger grid sizes: from approximately 36.15 MPa for 6x6 grids to 38.06 MPa for 8x8 grids. This trend confirms that not only does LTC outperform conventional concrete in compressive strength, but also that the size of the embedded grid plays a significant role, with larger grid patterns providing better reinforcement and strength characteristics. The results visually reinforce the findings from the compressive strength test table and highlight the structural advantages of integrating grid systems in LTC.

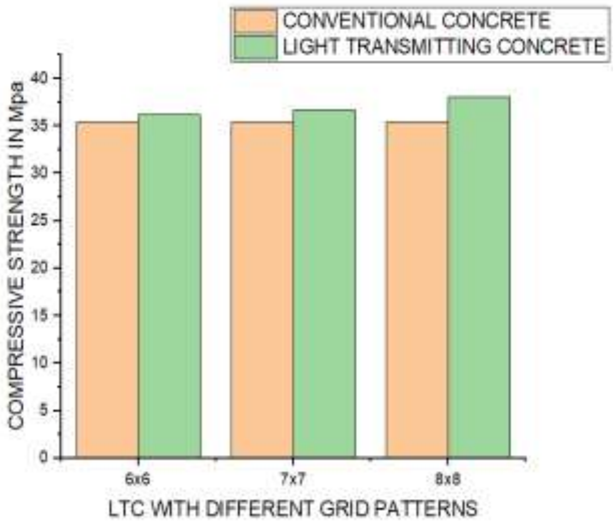

Figure 4 comparison of compressive strength of conventional concrete and LTC

Pull-out test:
The pull-out test is a method used to evaluate the bond strength between reinforcement bars and concrete. In this test, a 16 mm diameter steel rod of length 80–90 cm was embedded centrally into a concrete block of size 150 mm × 150 mm × 150 mm. The test was conducted for two types of concrete: conventional concrete and light-transmitting concrete (LTC).

Figure 5 Concrete cube after failure

Table 6 Pull out test results

SI no.	Type of specimen	Load (kN)	c/s area mm²	Strength N/mm²	Average strength N/mm²
1	Conventional	46.09	7539.822	6.2	6.00
2	Conventional	44.15	7539.822	5.9	
3	Conventional	44.12	7539.822	5.9	
1	LTC with 6x6	47.07	7539.822	6.24	6.11
2	LTC with 6x6	45.11	7539.822	5.98	
3	LTC with 6x6	46.091	7539.822	6.11	
1	LTC with 7x7	52.95	7539.822	7.02	7.06
2	LTC with 7x7	51.97	7539.822	6.89	
3	LTC with 7x7	54.91	7539.822	7.28	
1	LTC with8x8	60.80	7539.822	8.06	8.15
2	LTC with8x8	60.80	7539.822	8.06	
3	LTC with8x8	62.763	7539.822	8.32	

The results reveal that the average pull-out strength of conventional concrete is 6.00 N/mm², while LTC with 6x6 grid pattern shows a slight improvement with an average of 6.11 N/mm². A more notable increase is observed in LTC with 7x7 grid pattern, yielding an average strength of 7.06 N/mm². The highest strength is achieved by LTC with 8x8 grid pattern, averaging 8.15 N/mm². These findings suggest that incorporating grid pattern in LTC enhances the bond strength between the reinforcing material and the concrete matrix. The increase in pull-out strength with larger number of grids indicates improved anchorage and stress distribution, making LTC with larger grid patterns a superior alternative to conventional concrete in applications where bond strength is critical.

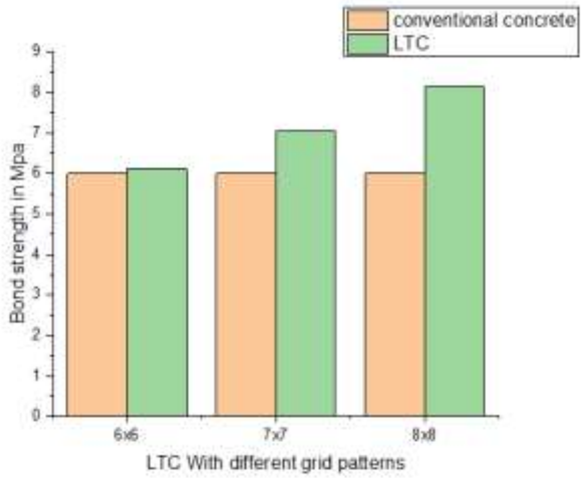

Figure 6 comparison of Bond strength of conventional concrete and LTC

Figure 6 shows that Light Transmitting Concrete (LTC) consistently has higher bond strength than conventional concrete across all grid sizes. The strength increases with larger grid patterns, peaking with the 8x8 grid pattern. Conventional concrete maintains a steady bond strength around 6 MPa. This indicates better bonding and load transfer efficiency in LTC, especially with larger grids.

Light transmittance test:

The light-transmitting test for Light Transmitting Concrete (LTC) was conducted to evaluate its ability to pass light through its structure. The test was performed in a completely dark room to eliminate any external light interference. A concrete cube of dimension 150 mm × 150 mm × 150 mm was used, and all sides of the cube except the front and back were covered with a wooden block to direct the light path. An LED bulb was placed behind the cube as the light source. A lux meter (light meter) was used to measure the intensity of light transmitted through the LTC at various distances—10 cm, 20 cm, 30 cm, 40 cm, and 50 cm—from the front face of the cube. At each distance, readings were taken at three positions: the center, the left side, and the right side of the cube.

Figure 7 Setup for light transmittance test

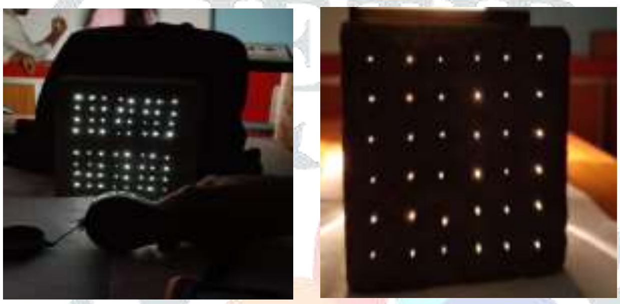

Figure 8 Light transmission test

Table 7 Light intensity measurements (in lux) for different LTC grids at various distances

	Position	10cm	20cm	30cm	40cm	50cm
Source	Left	1.1k	0.7	0.5	0.3	0.2
	Centre	1.1k	0.7	0.5	0.3	0.2
	Right	1.0	0.6	0.4	0.3	0.2
LTC with bundle 6x6grid	Left	1.8	0.8	0.6	0.5	0.4
	Centre	1.8	0.9	0.60	0.5	0.4
	Right	1.8	0.8	0.6	0.5	0.4
LTC with bundle 7x7 grid	Left	1.9	0.7	0.8	0.6	0.5
	Centre	1.9	0.9	0.8	0.6	0.5
	Right	1.9	0.7	0.8	0.6	0.5
LTC with bundle 8x8 grid	Left	2	2	2	1	1
	Centre	2	2	2	1	1
	Right	2	2	2	1	1
LTC without bundle 6x6 grid	Left	0.4	0.3	0.3	0.3	0.3
	Centre	0.3	0.3	0.3	0.3	0.3
	Right	0.3	0.3	0.3	0.3	0.3
LTC without bundle 7x7 grid	Left	0.5	0.3	0.2	0.2	0.2
	Centre	0.5	0.4	0.3	0.3	0.3
	Right	0.5	0.3	0.2	0.2	0.2
LTC without bundle 8x8 grid	Left	0.6	0.4	0.3	0.2	0.2
	Centre	0.6	0.4	0.3	0.3	0.3
	Right	0.6	0.3	0.3	0.2	0.2

Among all setups, LTC with bundle 8x8 grid exhibited the highest light transmission, consistently maintaining 2 lux up to 30 cm and gradually decreasing to 1 lux at 40 cm and 50 cm. LTC with bundle 7x7 and 6x6 grids also showed relatively strong light transmission, though slightly less than the 8x8 grid. In contrast, the LTC without bundles displayed significantly lower light intensities across all grid patterns and distances, demonstrating the importance of optical fiber bundles for effective light transmission. The results indicate that larger grid patterns and the inclusion of fiber bundles enhance light propagation through concrete, which can be useful for daylighting applications.

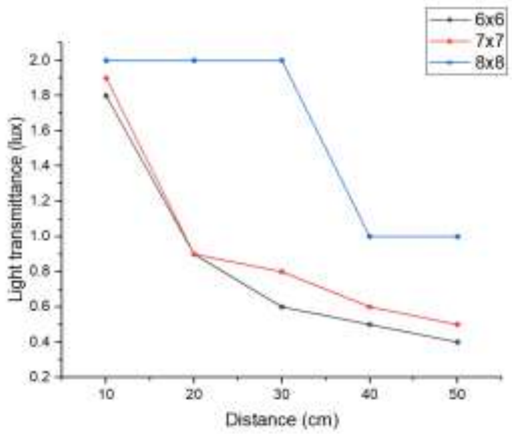

Figure 9 Light transmittance results for optical fibre bundled

The graph illustrates the light transmittance (in lux) of optical fibre bundles with three different configurations: 6x6, 7x7, and 8x8, over varying distances ranging from 10 cm to 50 cm. It is evident that light transmittance decreases as the distance increases for all configurations. Among the three, the 8x8 bundle consistently transmits more light, maintaining a high value of 2.0 lux up to 30 cm, before dropping sharply. In contrast, the 6x6 and 7x7 bundles show a more gradual and steady decline in light transmittance from the start. This suggests that denser fibre bundling (like 8x8) enhances light retention over longer distances, making it more efficient for light transmission applications.

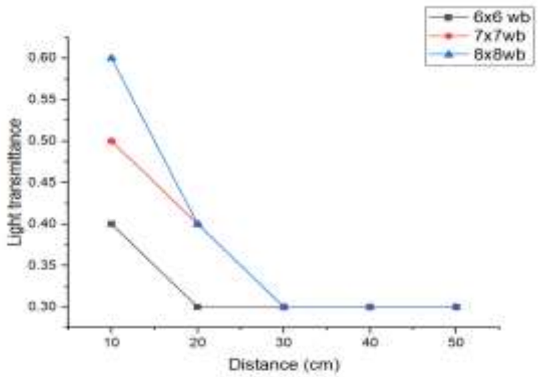

Figure 10. Light transmittance results for optical fibre without bundled

The graph displays light transmittance for optical fibres without bundling across various distances (10 cm to 50 cm) for three configurations: 6x6, 7x7, and 8x8. Light transmittance decreases noticeably with increasing distance for all configurations. Initially, the 8x8 configuration shows the highest transmittance (around 0.6), but its performance quickly drops and stabilizes at a lower level, similar to the others. The 6x6 and 7x7 configurations follow a more consistent downward trend and level off at around 0.3 from 30 cm onward. Overall, the results indicate that unbundled fibres transmit less light compared to bundled ones and show less efficiency in retaining light over longer distances.

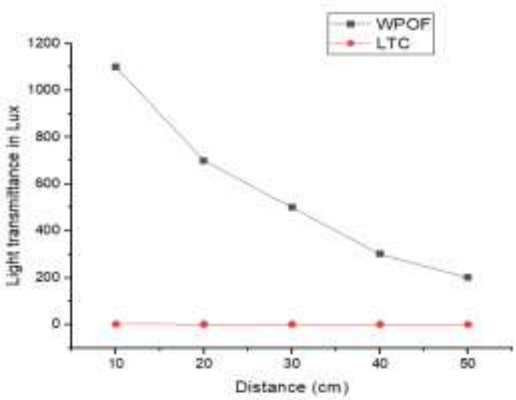

Figure 11 Comparison of light transmittance between source intensity

and LTC for Different Grid Pattern and at different distances

This graph compares the light transmittance of the source (WPOF) without any obstruction and with light-transmitting concrete (LTC) blocks placed in front.

IV. CONCLUSION

Light transmitting concrete is a viable solution for improving efficiency and design. The following conclusions are deduced from this study:

- The incorporation of optical fibers in light-transmitting concrete enhances both light transmittances. The study also assessed the optical behaviour of the concrete by measuring light transmittance at various distances and points. The results indicated that the addition of optical fibres significantly improves the light intensity transmitted through the concrete, making it a viable option for enhancing natural lighting in buildings.
- Optical fibers act as micro-reinforcement within the concrete matrix, leading to improved compressive and bond strength as compared to conventional concrete mix. A 6.67% increase in 28-day compressive strength was observed and 24.7% increase in bond strength was observed compared to conventional concrete.
- Light-transmitting concrete offers potential for applications where both aesthetic illumination and structural integrity are required because of increased of compressive strength.

V. ACKNOWLEDGMENT

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