

# Experimental Investigation on Strength and Light Transmittance Characteristics of Optical Fibre Reinforced Transparent Concrete

Dr. Vivek M. Shete<sup>1</sup>, Sanket Kiran Bhoite<sup>2</sup>, Shweta Anil Patil<sup>2</sup>, Pranita Manohar Khot<sup>2</sup>, Mayuri Sambhaji Patil<sup>2</sup>, Disha Dhanaji Patil<sup>2</sup>

<sup>1</sup>Assistant Professor, Department of Civil Engineering, Tatyasaheb Kore Institute of Engineering and Technology, Warananagar, Kolhapur, Maharashtra, India

Email: vmshete@tkietwarana.ac.in

<sup>2</sup>Department of Civil Engineering, Tatyasaheb Kore Institute of Engineering and Technology, Warananagar, Kolhapur, Maharashtra, India

Emails: bhoitesanket5616@gmail.com, patilshweta3018@gmail.com, pranitakhot11@gmail.com, mayuri9427@gmail.com, dishapatil020604@gmail.com

**Abstract:** Conventional concrete, despite its strength and durability, remains opaque and fully blocks the passage of natural light, forcing modern buildings to rely heavily on artificial illumination and thereby increasing energy consumption. Transparent concrete is an emerging construction material that addresses this limitation by embedding optical fibres within a fine concrete matrix, allowing light to be conducted from one face of the element to the other while the concrete continues to provide structural support. This study aimed to fabricate and evaluate small-scale transparent concrete specimens prepared using ordinary Portland cement, Artificial sand, water and plastic optical fibres of 2 mm diameter, arranged in parallel orientation within wooden moulds of 70 mm × 70 mm × 70 mm. Specimens were cast, demoulded after 24 hours and water-cured for 28 days. A series of experimental investigations comprising compressive strength, fire resistance, scratch resistance, boiling water resistance, water percolation, heat transfer and light transmission tests were carried out to characterise the behaviour of the developed material. Results indicate that the transparent concrete specimens retained their structural integrity, exhibited resistance to water percolation and surface abrasion, and transmitted a measurable percentage of incident light through the embedded fibres, with transmission decreasing as fibre length increased. The findings confirm that optical fibre reinforced transparent concrete is a technically feasible, aesthetically appealing and potentially energy-saving alternative for partitions, facades and decorative structural elements, while highlighting areas requiring further large-scale investigation.

**Index Terms:** Transparent concrete; Optical fibre; Light transmission; Compressive strength; Sustainable construction; Green building material; Energy efficiency; Smart infrastructure

## I. INTRODUCTION

Artificial lighting accounts for a significant share of global building energy consumption, and as urban centres expand vertically, access to natural daylight within interiors continues to decline. This dependence on electrical lighting raises operating costs and carbon emissions. Conventional concrete, while valued for its strength, durability and economy, is entirely opaque and contributes nothing towards daylighting strategies.

Transparent or light-transmitting concrete addresses this gap by embedding optical fibres within a fine concrete matrix so that light can travel from an illuminated face to an opposite shaded face through total internal reflection, while the surrounding cementitious matrix continues to carry structural loads. First demonstrated as a prefabricated light-transmitting block in the early 2000s, the material has since attracted growing interest as part of sustainable construction, smart buildings and green architecture, since it can reduce reliance on artificial lighting during daytime while also offering distinctive aesthetic qualities suited to museums, corridors, decorative walls and smart infrastructure elements.

Despite these advantages, transparent concrete remains under-explored at a practical level, with most studies confined to laboratory-scale specimens using varying fibre types, proportions and arrangements. There is a need for localised experimental studies examining fabrication, structural performance and light-transmitting behaviour using readily available materials. The present study undertakes such an investigation, focusing on the casting, curing and multi-parameter testing of transparent concrete specimens prepared using plastic optical fibres embedded in a fine concrete matrix.

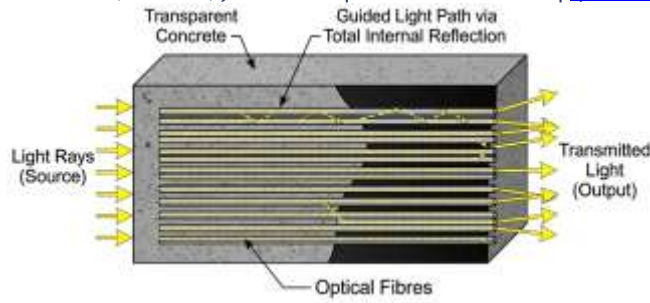


Fig. 1. Schematic diagram showing the concept of light transmission through optical fibre reinforced transparent concrete.

## II. LITERATURE REVIEW

Several studies over the past decade have examined the composition, behaviour and performance of transparent or light-transmitting concrete (LTC), focusing mainly on how optical fibre type, diameter, spacing and volumetric fraction influence mechanical strength and light-transmitting capability. Early work described transparent concrete as a combination of fine concrete and optical fibres, noting that its industrial use remains limited mostly to precast and prefabricated blocks and panels [1]. Comparative studies between optical-fibre and glass-rod specimens reported that fibre-based samples allow greater light transmission, though with marginally lower compressive strength than rod-based cubes [2].

Several investigations linked increasing optical fibre content with reduced compressive strength, although this reduction could be partially offset through supplementary materials such as rice husk ash, steel fibre or silica fume [3, 5, 7]. Other studies comparing transparent and conventional concrete reported strength values that were comparable to, or in some cases slightly exceeding, conventional concrete under specific mix conditions [4, 6, 9]. Workability, measured through slump values, was generally observed to increase with higher optical fibre content [7].

Broader reviews synthesising findings across numerous studies have generally confirmed that light transmission increases with fibre volumetric fraction and diameter, while compressive and flexural strength tend to decrease as fibre content increases, mainly due to weak bonding at the fibre-matrix interface [10, 11, 12]. These reviews identify durability, long-term environmental performance and the absence of standardised testing protocols as significant gaps requiring further research. A concise summary of representative studies is presented in Table I.

TABLE I: Summary of Previous Research

Author	Year	Material / Focus	Key Finding
Kamdi [1]	2013	Optical fibre + fine concrete	Manufacturing process and environmental benefits; limited to precast applications
Momin et al. [2]	2013	Optical fibre vs glass rod cubes	Optical fibre cubes: 7.41–9.5% light transmission vs 0.25–1.57% for glass rod; slightly lower strength
Paul & Dutta [8]	2013	Optical fibre (1–6%) + glass fibre	Light transmission directly proportional to optical fibre content
Tiwari & Saharan [3]	2016	Optical fibre + rice husk + steel fibre	Strength decreased with fibre content, partially restored by additives
Sonali & Kankriya [9]	2016	Optical fibre vs glass rod	Strength reduced; suitable mainly for partition walls
Shreyas K [4]	2018	Glass rod (1–5%)	Strength increased characteristically up to 28 days curing; 5% replacement optimal
Durga Raghavi & Rajasekar [7]	2019	Plastic optical fibre	Strength and workability increased with fibre % up to 4%
Poomima et al. [5]	2019	M25 + silica fume + plastic fibre	Split tensile strength up 13.61% (10% silica fume), 8.26% (15%)
Dileep Kumar et al. [6]	2019	Optical fibre concrete	Strength slightly higher than conventional concrete; green energy potential
Altlo mate et al. [11]	2016	Optical fibre concrete	Larger fibre diameter/spacing did not significantly affect light intensity
Henriques et al. [12]	2018–2020	Polymer optical fibre concrete	Increasing fibre fraction increased water absorption and porosity
Luhar et al. [10]	2021	1 mm POF, 70 mm cubes	LTC strength (36.70 MPa) close to OPC (39.50 MPa) at 5% fibre content

### III. RESEARCH GAP AND OBJECTIVES

The literature reveals that practical implementation of transparent concrete remains largely confined to laboratory-scale specimens, with high material costs, considerable variation in reported strength values across different fibre types and mix proportions, insufficient documentation of long-term durability under thermal cycling and moisture exposure, and a scarcity of localised studies that simultaneously evaluate mechanical and light-transmitting performance using readily available materials, particularly in the Indian context. In view of these gaps, the present study was undertaken with the following objectives: (1) to fabricate transparent concrete specimens of standard cube dimensions using plastic optical fibres embedded in a fine concrete matrix through a simple, replicable casting procedure; (2) to evaluate compressive strength relative to conventional concrete cubes of identical dimensions and curing conditions; (3) to assess durability through fire resistance, boiling water resistance, scratch resistance and water percolation tests; (4) to investigate heat transfer behaviour under natural sunlight exposure; (5) to quantify light transmission using a lux meter and examine the relationship between optical fibre length and transmitted light intensity; and (6) to compare the obtained results with findings from existing literature and identify practical implications and limitations of the developed material.

### IV. MATERIALS AND METHODOLOGY

#### A. Materials

The transparent mortar specimens were prepared using constituent materials selected on the basis of standard construction practice and information available in the literature. White Ordinary Portland Cement (OPC) was used for its lighter colour, which enhances visual contrast with the embedded optical fibres. Artificial sand passing through a 1.18 mm IS sieve was used as the primary fine aggregate, along with silica and ennore sand of similar fineness to adjust workability and texture. Potable water was used for mixing and curing at a water-cement ratio of 0.45. Plastic optical fibres (POF) of 2 mm diameter, cut to a length of 90 mm, were used as the light-transmitting medium, with 100 individual strands arranged per mould. The mortar mix was proportioned at 1:1.5:3 (cement:Artificial sand:silica and ennore sand) by volume, corresponding to an M20-equivalent grade, with a dry volume correction factor of 1.52.

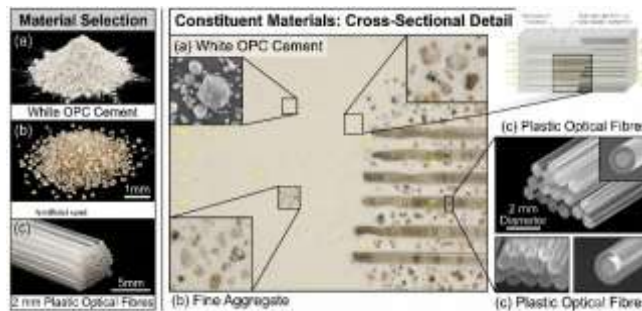


Fig. 2. Constituent materials used in the study: (a) white OPC cement, (b) Artificial sand, (c) plastic optical fibres of 2 mm diameter.

#### B. Mould Preparation and Fibre Arrangement

Wooden moulds of internal dimensions 70 mm × 70 mm × 70 mm were fabricated from plywood sheets. Two opposite faces were drilled with a regular grid of 2 mm holes at approximately 7 mm centre-to-centre spacing, and internal surfaces were coated with glycerin as a release agent. Optical fibre strands of 90 mm length were threaded through the pre-drilled holes in parallel orientation, perpendicular to the anticipated direction of light incidence, so as to facilitate transmission from one face of the block to the opposite face. Approximately 10 m of optical fibre, corresponding to 100 strands, was used per block.



Fig. 3. Wooden mould with pre-drilled holes showing optical fibre arrangement in parallel orientation prior to casting.

### C. Mixing, Casting and Curing

The mortar was prepared by dry-mixing the cement and Artificial sands in the specified proportions, followed by gradual addition of water to achieve the required consistency, with hand mixing adopted owing to the small batch quantities involved. The mix was poured into the prepared moulds in stages while maintaining alignment of the optical fibres, and compacted with a tamping rod to eliminate entrapped air. The top surface was finished smooth with a trowel. Cast specimens were allowed to undergo initial setting for 24 hours before demoulding, after which they were immersed in a clean water curing tank maintained at approximately  $27 \pm 2^\circ\text{C}$  for 28 days, in accordance with standard mortar curing practice, to achieve the required strength gain and ensure adequate bonding between the matrix and the embedded optical fibres.

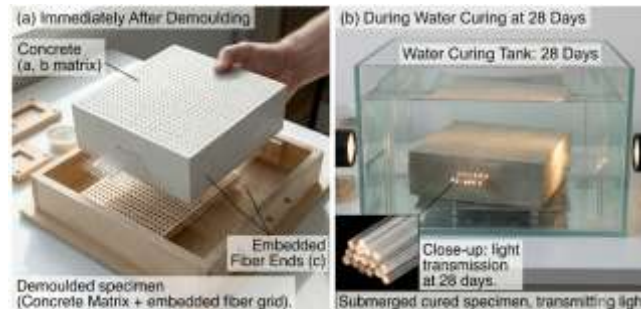


Fig. 4. Transparent concrete specimens: (a) immediately after demoulding, (b) during water curing at 28 days.

## V. EXPERIMENTAL PROGRAM

Following the 28-day curing period, the transparent mortar specimens were subjected to a series of tests to evaluate their structural, thermal, durability and optical performance, summarised below.

### A. Compressive Strength Test

**Purpose & Procedure:** To determine the load-carrying capacity of the transparent mortar specimen relative to a conventional mortar specimen of identical dimensions. Cube specimens of  $70\text{ mm} \times 70\text{ mm} \times 70\text{ mm}$  were wiped clean and placed centrally in a Compression Testing Machine (CTM); load was applied gradually and continuously until failure, and the maximum load was recorded. Compressive strength is a fundamental indicator of suitability for load-bearing or semi-structural applications and provides a direct basis for comparing transparent and conventional mortar.

### B. Fire Resistance Test

**Purpose & Procedure:** To assess the behaviour of embedded optical fibres and the surrounding mortar matrix under direct flame exposure, and any resulting loss of light transmission. A lit flame source was held against exposed fibre ends at the specimen surface for 10–15 seconds, and the specimen was observed for melting, smoke characteristics, self-extinguishment and any change in light transmission before and after exposure.

### C. Scratch Resistance Test

**Purpose & Procedure:** To evaluate surface hardness, abrasion resistance and bonding quality. A controlled scratching force was applied to the cured specimen surface using a steel point, and the resulting scratch depth, surface damage and any exposure or breakage of optical fibres were recorded.

### D. Boiling Water Resistance Test

**Purpose & Procedure:** To examine durability and thermal resistance of the fibre–mortar bond under prolonged exposure to high-temperature water. The cured specimen was fully immersed in boiling water (approximately  $100^\circ\text{C}$ ) for 3–4 hours, after which it was examined for cracking, fibre damage and changes in fibre dimensions.

### E. Water Percolation Test

**Purpose & Procedure:** To assess permeability and potential water ingress along the optical fibre–matrix interface. The specimen was placed under a running tap with one face exposed to continuous flow for 5 minutes, while the opposite face was monitored for water penetration.

### F. Heat Transfer Test

**Purpose & Procedure:** To evaluate thermal conduction behaviour under natural sunlight exposure. The specimen was placed in direct sunlight with one face exposed and the opposite face shaded, and the shaded-face surface temperature was recorded before and after one hour of exposure.

### G. Light Transmission Test

**Purpose & Procedure:** To determine the percentage of incident light transmitted through the specimen via the embedded optical fibres, and the influence of fibre length on transmitted intensity. A constant-intensity LED source was positioned at a fixed distance from one face, and a lux meter recorded the incident intensity ( $I_0$ ) without the specimen and the transmitted intensity ( $I_t$ ) with the specimen in place. Light transmission percentage was calculated as  $(I_t / I_0) \times 100$ , repeated for fibre samples of varying cut lengths (10 mm to 40 mm).

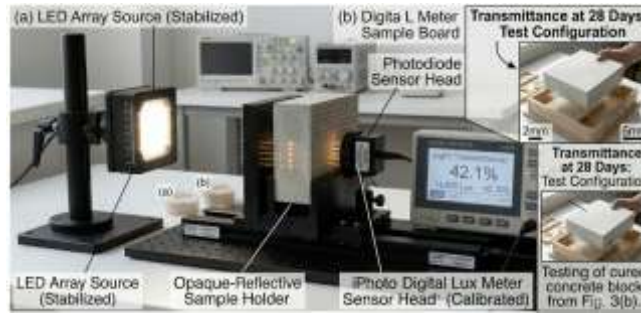


Fig. 5. Experimental setup for light transmission test showing LED source, specimen and lux meter arrangement.

## VI. RESULTS AND DISCUSSION

### A. Compressive Strength

The compressive strength of the conventional mortar cube was recorded as 22.34 N/mm<sup>2</sup>, while the transparent mortar cube containing embedded optical fibres recorded 33.87 N/mm<sup>2</sup>, indicating that under the mix proportions and curing conditions adopted, the transparent mortar specimen exhibited a higher compressive strength than the conventional specimen.

This finding contrasts with much of the existing literature, where optical fibre inclusion generally reduces compressive strength due to weak fibre–matrix bonding and additional voids, although certain studies have similarly reported transparent mortar strengths comparable to or marginally exceeding conventional mortar under specific conditions [6]. The relatively higher strength observed here may be attributable to the use of white cement, the small specimen size, the limited number of specimens tested, and possible variation in compaction quality between the two cubes. Given the limited sample size, this result should be interpreted with caution, and a larger testing programme with multiple replicate specimens would be required for statistically reliable conclusions.

### B. Fire Resistance

The exposed optical fibre ends underwent localised charring on direct flame contact but did not sustain continuous combustion once the flame was removed, and the surrounding mortar matrix remained structurally intact with no visible cracking near the fibre locations. This indicates limited flammability of the embedded fibres, which is favourable from a fire safety perspective, although the localised loss of light transmission at charred fibre ends suggests that aesthetic and functional performance may be compromised in fire-exposed regions.

### C. Scratch Resistance

The scratch resistance test produced no visible indentation, surface flaking or exposure of embedded optical fibres, indicating satisfactory surface hardness and bonding quality and adequate resistance to superficial abrasive contact under the conditions tested.

### D. Boiling Water Resistance

Following prolonged immersion in boiling water, no melting or structural degradation of the optical fibres was observed; however, a measurable contraction in fibre length was recorded, with an 80 mm fibre segment reducing to approximately 73 mm, corresponding to a contraction of approximately 8.75%. This indicates that the plastic optical fibres undergo dimensional changes under sustained high-temperature exposure, which may affect long-term fibre–matrix bond integrity in applications involving repeated thermal cycling.

### E. Water Percolation

No evidence of water passing from the wetted face to the opposite dry face was observed during the test duration, indicating that the fibre–matrix interface, at least under short-duration exposure, does not provide a continuous pathway

for water ingress, supporting potential suitability for applications involving direct water contact such as decorative elements near water bodies.

**F. Heat Transfer**

The temperature on the shaded face remained essentially unchanged between initial and final readings after one hour of sunlight exposure on the opposite face, suggesting minimal heat conduction through the mortar matrix and optical fibres over the tested duration, a favourable thermal insulation characteristic for slab and facade applications where excessive heat transfer is undesirable.

**G. Light Transmission**

The light transmission test recorded a transmitted intensity of 150 lux against an incident intensity of 1575 lux, corresponding to a light transmission percentage of approximately 9.52%. This value falls within the range reported in several prior studies for plastic optical fibre based transparent mortar, although it remains lower than the higher transmission percentages reported for specimens with higher fibre volumetric fractions or shorter optical paths.

The relationship between optical fibre length and transmitted light intensity, summarised in Table II, demonstrates a clear inverse relationship, with transmitted light decreasing progressively as fibre length increases from 10 mm to 40 mm. This trend is consistent with total internal reflection, wherein longer fibre paths result in greater cumulative attenuation due to internal scattering and minor surface imperfections along the fibre length, indicating that thinner sections or shorter light paths are preferable where maximising light transmission is a design priority.

TABLE II: Light Transmission vs Optical Fibre Length

Length of Optical Fibre (cm)	Transmitted Light Intensity (lux)
10	1135
15	896
20	836
25	628
30	480
35	346
40	250

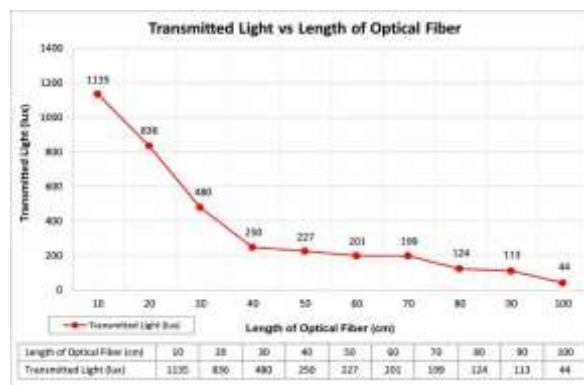


Fig. 6. Graph showing variation of transmitted light intensity (lux) with optical fibre length (mm), illustrating the inverse relationship between fibre length and light transmission.

**H. Overall Discussion**

Collectively, the results indicate that the developed transparent mortar specimens retained adequate structural integrity, demonstrated favourable durability under fire, boiling water, scratch and water percolation tests, and transmitted a measurable proportion of incident light through the embedded optical fibres. The light transmission percentage of approximately 9.52%, while modest, confirms the functional viability of the light-conducting mechanism, and the observed reduction in transmission with increasing fibre length reinforces the importance of optical path length as a key design parameter. Where direct quantitative comparison with literature values was not possible due to differences in fibre type, dimensions or test methodology, this has been noted explicitly rather than assumed.

**VII. COMPARATIVE ANALYSIS**

Table III presents a qualitative and, where available, quantitative comparison between conventional mortar and the developed transparent mortar, based on the experimental observations of this study together with general trends reported in literature. The higher compressive strength recorded for the transparent mortar specimen in this study is based on a

single specimen comparison and should not be generalised, since broader literature predominantly reports a reduction in compressive strength with increasing optical fibre content. The table therefore reflects both the specific experimental observations of this study and the broader trends established in prior research, and should be read with this distinction in mind.

TABLE III: Comparison of Conventional Mortar and Transparent Mortar

Parameter	Conventional Mortar	Transparent Mortar
Compressive Strength	22.34 N/mm <sup>2</sup> (this study)	33.87 N/mm <sup>2</sup> (this study, single specimen)
Light Transmission	Nil (fully opaque)	Approximately 9.52% (this study)
Energy Efficiency	Requires artificial lighting throughout occupied hours	Potential reduction in daytime artificial lighting demand
Durability (Fire)	Generally fire resistant	Matrix intact; localized fibre charring observed
Durability (Water)	Low permeability with proper mix design	No percolation observed in short-duration test
Cost	Relatively low, using locally available materials	Higher, due to optical fibre material and labour-intensive placement
Aesthetics	Plain, opaque finish	Distinctive light-emitting visual effect
Sustainability	Established but energy-intensive in use phase	Potential daylighting benefit; embodied fibre cost not assessed
Maintenance	Standard maintenance practices apply	Scratch resistance satisfactory; long-term fibre durability needs study
Applications	General structural and non-structural use	Partitions, facades, decorative panels, non-load-bearing elements

## VIII. FUTURE SCOPE

Based on the findings of this study, the following directions are identified for future research and application development:

- 1) Integration of transparent mortar into smart building systems, where natural daylighting combined with building automation could further reduce daytime electricity consumption and support smart city infrastructure.
- 2) Architectural applications in decorative facades, feature walls and display elements for museums, galleries and commercial spaces, leveraging the distinctive light-emitting appearance of the material.
- 3) Optimisation of optical fibre volumetric fraction, distribution and hybrid fibre systems to achieve a more favourable balance between light transmission and structural performance, supporting green building certification.
- 4) Development of structural design guidelines through research on fibre orientation, spacing and mix proportions, along with long-term durability studies under cyclic thermal and moisture exposure.
- 5) Industrial applications such as partition walls in factories, illumination elements in underground structures and tunnels, and safety lighting integration in emergency egress routes.

## IX. CONCLUSION

Based on the experimental investigation carried out in this study, the following conclusions are drawn:

- 1) Transparent mortar specimens incorporating 2 mm diameter plastic optical fibres arranged in parallel orientation were successfully fabricated using a simple wooden mould casting technique suitable for small-scale laboratory production.
- 2) The compressive strength of the transparent mortar specimen (33.87 N/mm<sup>2</sup>) exceeded that of the conventional mortar specimen (22.34 N/mm<sup>2</sup>) under the conditions tested; however, this result is based on a single-specimen comparison and contrasts with strength-reduction trends commonly reported in literature, indicating the need for further testing with larger sample sizes before generalising this observation.
- 3) The fire resistance test confirmed that the embedded optical fibres underwent localised charring without sustaining continuous combustion, and the surrounding mortar matrix remained structurally intact, indicating limited flammability under the tested exposure conditions.
- 4) The scratch resistance test indicated satisfactory surface hardness, with no indentation or fibre exposure observed, suggesting adequate bonding between the optical fibres and the mortar matrix at the surface level.
- 5) The boiling water resistance test revealed a measurable thermal contraction of the optical fibres (approximately 8.75% reduction in length), indicating that prolonged high-temperature exposure may influence the dimensional stability of the embedded fibres.
- 6) The water percolation test demonstrated that the specimen resisted water ingress under short-duration exposure, supporting its potential suitability for applications involving moisture contact.

7) The heat transfer test indicated minimal change in shaded-face temperature after sunlight exposure, suggesting favourable thermal insulation behaviour over the tested duration.

8) The light transmission test recorded a transmission percentage of approximately 9.52% for the tested specimen configuration, confirming the functional capability of the embedded optical fibres to conduct light through the mortar matrix.

9) A clear inverse relationship was observed between optical fibre length and transmitted light intensity, with transmission decreasing from 1135 lux at 10 mm length to 250 lux at 40 mm length, highlighting optical path length as a critical parameter in the design of transparent mortar elements.

10) Overall, the developed transparent mortar demonstrates technical feasibility as a structurally functional and light-transmitting material, with promising applications in non-load-bearing architectural elements, although further research involving larger sample sizes, varied fibre proportions, and long-term durability assessment is recommended before wider practical adoption.

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