An Assessment of Strength Characteristics of Transparent Concrete in Pavement

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ABSTRACT

This study explores the potential of transparent concrete for use in roadway applications, focusing on its ability to transmit light through the incorporation of Plastic Optical Fibres (POFs) within the concrete matrix and evaluating both its mechanical strength and its light transmission capabilities. This material can be applied to various road elements, such as surface illumination, signage, roadblocks, medians, curbs, and areas with changing geometry. The light transmission performance was evaluated using voltage, light sources, and Light-Dependent Resistors (LDRs). A comparative analysis was performed between samples with varying POF content and spacing and traditional concrete. The findings reveal that compressive and flexural strengths remain largely unaffected by the inclusion of POFs up to 1.5% by weight, beyond which a decrease in strength is observed. Additionally, the light transmission efficiency improves significantly with an increase in the POF volume ratios.

Keywords-transparent concrete; light-transmitting concrete; Plastic Optical Fibers (POFs); pavement materials; compressive strength; flexural strength

I. INTRODUCTION

A. Background

The accelerated consumption of fossil fuels has led to significant environmental degradation, a growing energy deficit, and escalating threats to human life. As the primary source of global energy, fossil fuels have been deeply integrated into various sectors, but their overuse has raised critical environmental and economic concerns [1]. The deleterious effects of fossil fuel dependence are multifaceted, impacting air quality, contributing to global warming, and creating volatility in energy markets due to the scarcity and instability of supply and prices [2]. These issues are not limited to the energy sector but extend to industries such as construction, contributing significantly to these global challenges. The construction industry, known for its substantial consumption of natural resources and energy, plays a critical role in exacerbating these problems. As a response, there has been a global push toward making construction more environmentally friendly and sustainable, a trend that has gained momentum over the past few decades.

In India, for instance, it is estimated that approximately 20% of the total electrical energy consumption is attributed to lighting in buildings [1]. This statistic underscores the urgent need for energy-efficient solutions in the construction sector. One promising approach that has emerged in recent years is the concept of green building construction, which focuses on minimizing energy consumption, particularly through the implementation of indoor thermal systems [2]. However, the scope of sustainable construction extends beyond buildings to infrastructure such as roads, which cover vast areas and are constantly exposed to solar radiation. This raises the question of how to maximize the solar energy harvesting from these surfaces. The answer may lie in innovative solutions such as solar roadways.

During the past few decades, road design has undergone incremental changes, primarily driven by the need to enhance durability, safety, and cost-effectiveness. Traditionally, concrete and asphalt have been the primary materials used in the construction of roadways for motor vehicles, as well as paths for pedestrians and cyclists. However, with an increasing focus on sustainability, the construction industry is exploring alternative materials and technologies that can contribute to energy conservation and environmental protection. One such innovation is the concept of solar roadways using transparent concrete, which has the potential to revolutionize the way we think about infrastructure. Transparent concrete, also known as translucent or light-transmitting concrete, integrates optical fibers within the concrete matrix to allow light transmission.

This technology proposes a novel product that serves not only as a structural material but also as a medium for energy harvesting. The basic concept involves placing optical fibers uniformly in a horizontal configuration within the concrete mold before the casting process. These fibers enable the transmission of light through concrete, allowing it to be used for various applications such as illuminating tunnels and subway stations, and even serving as speed bumps or lane markers on highways [3-5]. The potential applications of transparent concrete are vast, and its use in pavements could significantly enhance road safety by improving visibility in critical areas such as medians, curbs, and lane markers. Additionally, by harnessing solar energy, transparent concrete can help reduce the energy consumption associated with road lighting, thus aligning with global sustainability goals. The performance of transparent concrete is determined by several critical parameters, including its flexural strength, compressive strength, and light transmissibility. These properties are crucial to ensure that transparent concrete not only meets the structural demands of conventional concrete but also provides the added benefit of light transmission. Recent studies have thoroughly investigated the impact of optical fiber spacing on these mechanical properties and light transmittance. Flexural strength and compressive strength are key indicators of the load-bearing capacity and durability of concrete. In the case of transparent concrete, the presence of optical fibers can influence these properties depending on factors such as their size, type, and arrangement. For instance, closely spaced fibers may enhance light transmission but could potentially reduce the overall strength of the concrete. On the contrary, wider spacing might improve mechanical strength but at the cost of reduced light transmissibility. Therefore, finding the optimal balance between these factors is critical to the successful application of transparent concrete in construction.

Light transmittance is another crucial aspect of transparent concrete, as it directly affects the material's ability to function as a light-transmitting medium. The effectiveness of light transmission depends not only on the quality and arrangement of the optical fibers but also on the overall thickness and composition of the concrete. Sustainability has become a central focus in modern construction, and materials like translucent concrete are at the forefront of this movement. Translucent concrete, despite its name, is not inherently translucent but the embedded optical fibers enable light transmission. This innovative material is also known by other names, such as transparent concrete or light-transmitting concrete, with the latter being the most precise descriptor. The sustainability of transparent concrete is attributed to its ability to contribute to energy savings, enhance aesthetic appeal, and reduce environmental impact. By allowing natural light to penetrate buildings and infrastructure, translucent concrete can reduce the need for artificial lighting, thus reducing energy consumption and associated greenhouse gas emissions. This aligns with the broader goals of sustainable development, which seek to minimize environmental degradation while meeting the needs of the present without compromising the ability of future generations to meet their own needs.

The production of translucent concrete involves two primary approaches. The first replaces traditional components of ordinary concrete with materials that have light-transmitting properties, such as translucent aggregates or resins. This method focuses on creating a concrete mixture that can transmit light without the need for additional light-conducting elements. The second approach, which is more commonly adopted, involves embedding light-transmitting components, typically optical fibers, into fine concrete. This method is preferred because it allows for greater control over the light-transmitting properties of concrete.

Self-Compacting Concrete (SCC) [6-9] has been the subject of extensive research aimed at improving its properties and expanding its applications. SCC is known for its excellent flowability and ability to fill complex forms without the need for external vibration. This makes it particularly suitable for use in structures with dense reinforcement, such as those incorporating optical fibers for light transmission. Research on SCC has focused mainly on its fresh properties, such as workability, flowability, and resistance to segregation, as well as its hardened properties, including strength and durability [7]. Some studies have explored the use of industrial by-products as replacements for fine aggregates in SCC, making it a more sustainable material [8, 9]. Additionally, the incorporation of various types of fiber, such as steel or polymeric fibers, has been investigated to enhance the mechanical properties of SCC [10, 11]. In the context of translucent concrete, SCC offers several advantages. Its high fluidity ensures that the optical fibers are evenly distributed throughout the concrete, resulting in consistent light transmission. Moreover, SCC's ability to fill intricate molds and forms without the need for mechanical compaction makes it ideal for producing complex architectural elements that require precise placement of optical fibers.

Optical fibers are the key component that allows light transmission in translucent concrete. These fibers are typically made from polymethyl methacrylate (PMMA) and consist of three main layers: the core, the cladding, and the buffer coating. The core is the central part of the fiber that carries the light, while the cladding surrounds the core and reflects the light into the core to minimize signal loss. The buffer coating provides mechanical protection to the fiber. In the production of translucent concrete, the preferred optical fibers are those without an outer jacket or buffer coating, as this enhances the bond between the fiber and the concrete matrix. The core's refractive index is typically higher than that of the cladding, which is essential to maintain light transmission through total internal reflection. This principle is crucial for ensuring that light travels efficiently through optical fibers and is transmitted through concrete. It is important to ensure that the fibers are evenly distributed and properly aligned to achieve optimal light transmission [12, 13]. The light transmittance in translucent concrete can be measured using various methods, depending on the specific requirements of the application. Common tools used for this purpose include power meters, lux meters, light meters, and photometers. Additionally, light transmittance can be measured by setting up an electrical circuit with a photoresistor or Light-Dependent Resistor (LDR) [13-15]. These measurements are critical to ensure that the concrete meets the required standards for light transmission, particularly in applications where sufficient illumination is essential for safety and functionality. The versatility of translucent concrete extends to a wide range of applications in architecture, construction, and design. Its ability to transmit light while maintaining structural integrity makes it an ideal material for various uses, including walls, ceilings, flooring, and decorative elements. In addition to its aesthetic appeal, translucent concrete can enhance the functionality and energy efficiency of buildings and infrastructure. Some notable examples of buildings that have incorporated translucent concrete include the Italian Pavilion at the Shanghai World Expo 2010 in China and the Al-Aziz Mosque in Abu Dhabi [2]. These projects demonstrate the potential of translucent concrete to create visually striking and energy-efficient structures that align with contemporary architectural trends.

In summary, the development and application of translucent concrete is a significant step in the pursuit of sustainable construction. By integrating optical fibers within concrete, this material offers a unique combination of structural strength, energy efficiency, and aesthetic appeal. As the construction industry continues to evolve, materials such as translucent concrete can play an increasingly important role in addressing the challenges of environmental degradation, energy consumption, and resource scarcity. Research and innovations in this field highlight the potential of translucent concrete to revolutionize not only its production but also the relationship between construction materials and sustainability. As global demand for energy-efficient and environmentally friendly solutions grows, translucent concrete is poised to become a key player in the future of construction, offering new possibilities for architects, engineers, and designers. This study aims to determine the strength and durability of translucent concrete specimens.

B. Traditional and Transparent Concrete Comparison

Traditional concrete is generally more affordable due to the easy availability of its components, such as aggregates, cement, and water, as well as its well-established production techniques. In contrast, transparent concrete is typically more expensive because it incorporates Plastic Optical Fibers (POF) and requires specialized mixing processes. Although upfront costs are higher, energy savings and aesthetic enhancements may help balance investment over time. Traditional concrete is well-known for its high compressive strength and durability, making it ideal for load-bearing applications, although it does not transmit light. Transparent concrete, on the other hand, allows light to pass through while maintaining a reasonable degree of strength. However, POF inclusion may reduce its flexural strength, requiring careful engineering to ensure structural stability. Traditional concrete is also highly versatile and widely used in various construction projects, including foundations, pavements, and structural elements. Its properties are well-documented, making it a dependable option. Transparent concrete, while offering innovative ways to enhance natural light in buildings and increase visibility on roadways, may face limitations due to its reduced strength and higher costs. Its most effective applications are in projects where aesthetics and light transmission are prioritized.

In conclusion, transparent concrete provides distinct advantages in terms of aesthetics and light-transmitting abilities, but it is generally more costly and may present some performance challenges compared to traditional concrete. Understanding these differences is crucial for stakeholders to make informed decisions based on specific project needs and budgetary considerations.

II. MATERIALS AND METHODS

A. Environmental Impact and Sustainability of Plastic Optical Fibers (POF) in Concrete

Incorporating POF into transparent concrete not only enhances its aesthetic and functional properties but also presents significant environmental benefits. POF, made of PMMA, can contribute to energy efficiency by allowing natural light to penetrate structures, thereby reducing the need for artificial lighting and lowering energy consumption. Additionally, the use of POF in concrete can help minimize the carbon footprint associated with traditional lighting solutions. It is essential to consider the lifecycle of POF, including production, usage, and disposal, to fully understand its sustainability profile. Future research should focus on optimizing POF usage in concrete to maximize its environmental benefits while ensuring structural integrity.

B. Materials

In this experimental study, various materials were used to produce transparent concrete, with specific choices depending on the type of block that was cast. Ordinary Portland Cement (OPC) of grade 43, conforming to IS 8112:1989 standards, was employed. The cement was tested according to the guidelines of IS 4031:1988, and Table I presents the preliminary test results. For aggregates, locally sourced natural river sand was used as the fine aggregate, while natural gravel served as the coarse aggregate. Table II details the physical properties of these materials. This study also incorporated POF, which serves as a light-transmitting element due to its core material, PMMA, which provides high transparency. According to [15], the flexural strength of transparent concrete tends to decrease as both the content and the diameter of POF increase. Specifically, for POF content exceeding 2%, the average reduction in flexural strength was observed to be approximately 15.5% for every 1% increase in POF content. Additionally, as the POF diameter increased from 1.5 mm to 2 mm and 3 mm, the reduction in flexural strength was approximately 6.5% and 16.5%, respectively [4].

TABLE I. PRELIMINARY TEST RESULTS OF CEMENT

Physical properties	Experimental results
Specific gravity	3.09
Consistency of cement (%)	27.4
Bulk unit weight (kg/m^3)	1320
Initial setting time	85 min
Final setting time	460 min

C. Preparation of Test Specimens

In this study, POF was integrated into the concrete mix to facilitate light transmission. Wooden cube molds with dimensions of 150×150×150 mm were fabricated. Each mold had a hole drilled slightly larger than the POF diameter using a drill machine. The optical fibers were inserted into the wooden mold in one direction, extending from one side to the other, with varying spacings between the fibers. For the flexural strength tests, a wooden mold measuring 500×100×100 mm was prepared. This mold had different spacings for POF insertion, allowing for the assessment of how spacing affects flexural strength. Three samples were cast for each spacing configuration. The specific spacings used for each sample are detailed in Table III. Given the proximity of the optical fibers in the mold and the challenges associated with achieving adequate compaction and homogeneity within the mixture, coarse aggregates with a maximum size of 10 mm were selected for the concrete mix. Figure 1(a-c) illustrates the formwork setup, consisting of plywood and perforated wooden sheets, while Figure 1(d) displays an image of the illuminated transparent concrete.

TABLE II. PHYSICAL PROPERTIES OF FINE AND COARSE AGGREGATE

Properties	Fine aggregate (sand)	Coarse aggregate (gravel)
Specific gravity	2.68	2.62
Bulk unit weight (kg/m^3)	1740	1690
Fineness modulus	2.40	4.45
Maximum nominal size	Under 4.75 mm	Under 10 mm

TABLE III. POF SPACING IN SAMPLES.

Control sample	Sample 2	Sample 3	Sample 4	Sample 5
No POF	0.5 mm spacing	1 mm spacing	1.5 mm spacing	2 mm spacing

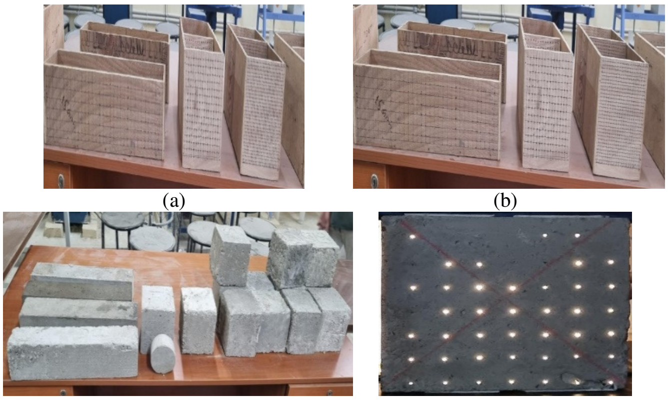
(a) (b)
(c) (d)

Fig. 1. Wood molds and samples cast.

A total of 15 concrete cubes were cast, along with 10 molds for the flexural strength tests. Among these, 3 cubes and 2 flexural test molds were designated as control specimens. The insertion of POF into the formwork was carried out with precision to ensure proper alignment. Subsequently, the prepared M-15 concrete mixture was poured into the form, and mechanical vibration was applied using a vibrator to achieve optimal compaction. After allowing the concrete to set for 24 hours, the formwork was carefully removed. The surfaces of the specimens were then polished using sandpaper to achieve a smooth finish. Subsequently, the samples were cured by immersing them in tap water at room temperature for 28 days before being tested.

III. RESULTS AND DISCUSSION

The cast specimens were subjected to a series of tests to evaluate their compressive strength, flexural strength, light transmittance, density, and water absorption. These tests were carried out to comprehensively analyze the impact of POF and its spacing within the concrete mix.

A. *Compressive and Flexural Strength*

The compressive and tensile strengths of concrete are critical parameters for assessing its resistance to compressive and tensile stresses. In this study, the effects of POF spacing on both tensile and compressive strengths were evaluated by performing compression tests using a Compression Testing Machine (CTM) and flexural tests with an apparatus sized 500×100×100 mm³. Figure 2 and Table IV show the average 28-day compressive and tensile strengths of light-transmitting concrete with a mix ratio of 1:2:4 (cement: sand: aggregate less than 20 mm) and a water-cement ratio of 0.5. These results are based on the average values obtained from three samples.

The results reveal that the compressive strength tends to decrease as the POF spacing decreases. The maximum compressive strength recorded without POF incorporation was 16.7 N/mm². Minimal changes in compressive strength were observed between specimens with 15 mm and 20 mm POF spacings. In particular, even with a POF spacing of 10 mm, the concrete mix designated M-15 achieved a compressive strength of 13.5 N/mm² after 28 days. In terms of flexural strength, the data indicate that providing a POF spacing of 10 mm or greater does not significantly alter the strength compared to larger spacings. However, spacings less than 10 mm resulted in weaker cubes and beams due to reduced interconnecting distances, which negatively impacted the structural integrity as cracks propagated under loading.

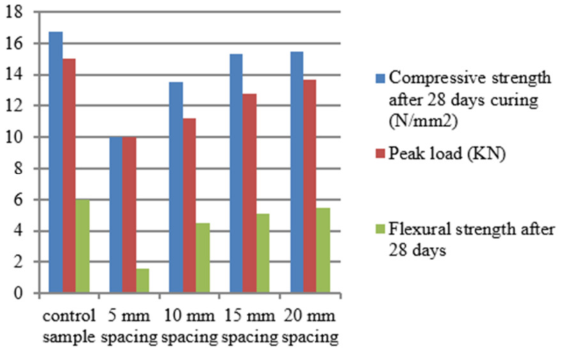

Fig. 2. Compressive and flexural strength after 28 days.

TABLE IV. COMPRESSIVE AND FLEXURAL STRENGTH TEST RESULT

POF spacing	Compressive strength (N/mm^2)	Peak load (KN)	Flexural strength (N/mm^2)
Control sample (No POF)	16.7	15	6
5 mm	10	10	1.6
10 mm	13.5	11.2	4.48
15 mm	15.3	12.8	5.12
20 mm	15.5	13.7	5.48

B. Light Transmittance Test

In this study, the light transmittance of each specimen was evaluated using an electric circuit incorporating an LDR as the sensing element. The experimental setup comprised a 100 W lamp, a 100-ohm resistor, and a constant DC voltage of 10 V applied across the circuit. Figure 3 illustrates the experimental arrangement, including the transparent concrete setup.

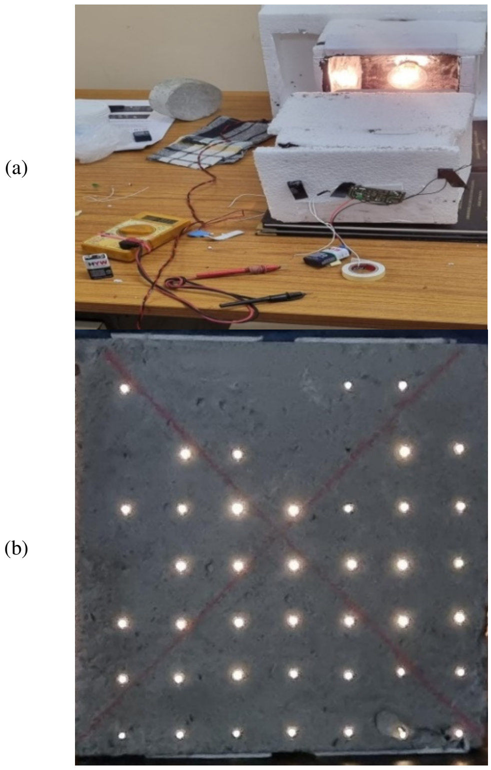

Fig. 3. Experimental set-up for light transmittance.

The transmission of light through the transparent concrete specimens was found to be influenced by the spacing of the POF incorporated within the concrete cubes. Specifically, the results indicated that light transmittance increased as the spacing between the POF decreased (Figure 4). This relationship highlights the impact of POF distribution on the effectiveness of light transmission through transparent concrete.

The maximum light intensity transmitted through the concrete cubes was recorded for various spacings of the optical fibers. Specifically, the highest intensity observed was 88.3 lux for cubes with a 5 mm spacing. In contrast, the intensity decreased to 52.5 lux for cubes with a 10 mm spacing, 38.31 lux for those with a 15 mm spacing, and 18.2 lux for cubes with a 20 mm spacing. These results indicate that the light transmittance capacity of the concrete decreases as the spacing between the optical fibers increases. Despite this reduction, concrete samples with a 20 mm spacing still exhibit adequate illumination, suggesting that even larger spacings can provide effective light transmission.

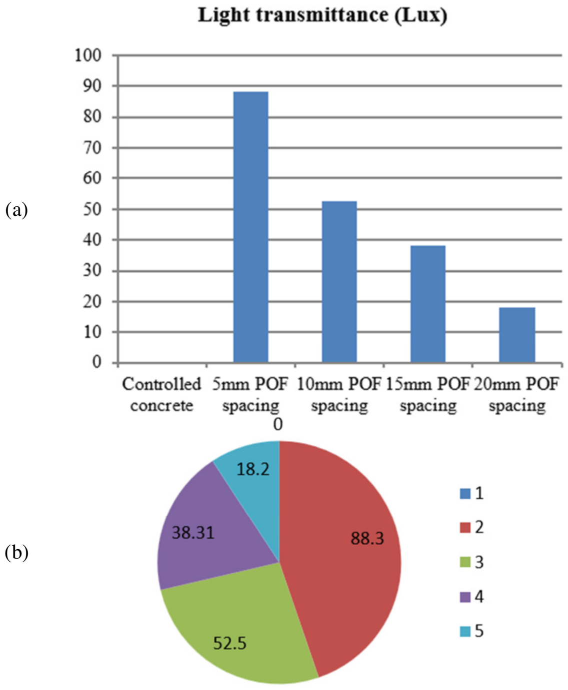

Fig. 4. Effect of POF spacing on light illumination in lux.

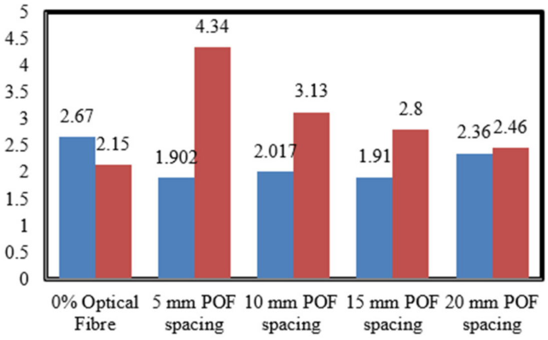

Fig. 5. Density and water absorption of cubes after 28 days.

C. Novelty and Contribution of this Work

This study presents a comprehensive evaluation of transparent concrete, specifically focusing on the integration of POF to enhance light transmission while maintaining mechanical strength. The novelty of this study lies in its systematic approach to assess the balance between the POF content and the resulting structural properties, which has not been extensively documented in the existing literature. Furthermore, this study contributes to understanding the transparent concrete's potential applications in roadway infrastructure, offering innovative solutions for energy-efficient lighting and improved visibility in critical areas. By addressing both the mechanical and light transmission characteristics, this study lays the foundations for future research and practical applications of transparent concrete in sustainable construction.

IV. CONCLUSION

Despite growing interest in transparent concrete as a novel construction material, there is a significant knowledge gap regarding its long-term performance and environmental implications. Previous studies have focused primarily on the mechanical properties and light transmission capabilities of transparent concrete, often overlooking the effects of varying environmental conditions on its durability and sustainability. Additionally, the integration of POF within the concrete matrix presents unique challenges and opportunities that have not yet been fully explored. Addressing these gaps is crucial for advancing the application of transparent concrete in real-world scenarios and ensuring its viability as a sustainable building material. Based on this study, several conclusions can be drawn.

- Transparent concrete blocks can be utilized in a variety of ways in construction. They can be used for esthetical views as well as in load-bearing structures requiring light illumination, such as on pavements as lane markers, medians, breakers, curbs, etc.
- The compressive and tensile strengths of the standard concrete mix sample were found to be 16.7 N/mm^2 and 6 N/mm^2. Adding POF to the same mix did not alter the results much, even with a POF spacing of 5mm. However, in load-bearing structures, it is advisable not to provide a POF spacing of less than 10 mm, as low spacing results in weaker cubes and beams due to improper compaction and a smaller interconnecting distance when cracks propagate under loading.
- POF spacing is proportional to light transmission but the mechanical properties of the concrete deteriorate with increasing the POF content.
- For better workability, compaction, and light transmissibility, coarse aggregate can be excluded from the mix.

This study highlights the potential of transparent concrete as an innovative material that integrates both functional and aesthetic attributes in construction. Its ability to transmit light while maintaining structural capabilities makes it a promising choice for various applications. The results demonstrate that while the inclusion of POF can enhance light transmission, it is essential to balance it with the material's mechanical properties to ensure structural integrity. Specifically, for load-bearing applications, it is crucial to maintain the appropriate POF spacing to avoid compromising strength. Additionally, this study underscores that for nonload-bearing structures, the omission of coarse aggregates can enhance both workability and light transmissibility. The findings provide valuable insights for optimizing transparent concrete in construction, paving the way for its broader adoption and application in innovative architectural and infrastructural projects.

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REFERENCES

[1] A. M. Tahwia, A. Abdel-Raheem, N. Abdel-Aziz, and M. Amin, “Light transmittance performance of sustainable translucent self-compacting concrete,” *Journal of Building Engineering*, vol. 38, Jun. 2021, Art. no. 102178, https://doi.org/10.1016/j.jobe.2021.102178.

[2] A. Altlomate, F. Alatshan, F. Mashiri, and M. Jadan, “Experimental study of light-transmitting concrete,” *International Journal of Sustainable Building Technology and Urban Development*, vol. 7, no. 3–4, pp. 133–139, Oct. 2016, https://doi.org/10.1080/2093761X.2016.1237396.

[3] A. Kumar and R. Ahlawat, “Experimental Study on Light Transmitting Concrete,” *International Journal of Innovative Science, Engineering & Technology*, vol. 4, no. 6, pp. 201–210, 2017.

[4] S. H. Said, “State-of-the-art developments in light transmitting concrete,” *Materials Today: Proceedings*, vol. 33, pp. 1967–1973, Jan. 2020, https://doi.org/10.1016/j.matpr.2020.06.128.

[5] D. R. Mohan, “Experimental Studies on POF and Epoxy-Resin Based Translucent Concrete,” *International Journal of Latest Technology in Engineering, Management & Applied Science (I*, vol. VII, no. III, pp. 130–134, 2018.

[6] C. Palanisamy, N. Krishnaswami, S. kumar Velusamy, H. Krishnamurthy, H. kumaar Velmurugan, and H. Udhayakumar, “Transparent concrete by using optical fibre,” *Materials Today: Proceedings*, vol. 65, pp. 1774–1778, Jan. 2022, https://doi.org/10.1016/j.matpr.2022.04.799.

[7] A. B. Kamdi, “Transparent Concrete as a Green Material for Building,” *Transparent concrete as a green material for building*, vol. 2, no. 3, pp. 172–175, 2013.

[8] H. Okamura, “Self-Compacting High-Performance Concrete,” *Concrete International*, vol. 19, no. 7, pp. 50–54, Jul. 1997.

[9] H. Prayuda, F. Monika, and M. D. Cahyati, “Fresh properties and compressive strength of self compacting concrete with fines aggregate replacement using red brick powder and rice husk ash,” *World Journal of Engineering*, vol. 17, no. 4, pp. 473–480, Jan. 2020, https://doi.org/10.1108/WJE-08-2019-0236.

[10] N. Gupta, R. Siddique, and R. Belarbi, “Sustainable and Greener Self-Compacting Concrete incorporating Industrial By-Products: A Review,” *Journal of Cleaner Production*, vol. 284, Feb. 2021, Art. no. 124803, https://doi.org/10.1016/j.jclepro.2020.124803.

[11] D. Ghosh, A. Abd-Elssamd, Z. J. Ma, and D. Hun, “Development of high-early-strength fiber-reinforced self-compacting concrete,” *Construction and Building Materials*, vol. 266, Jan. 2021, Art. no. 121051, https://doi.org/10.1016/j.conbuildmat.2020.121051.

[12] R. Pradheepa and S. Krishnamoorthi, "Light Transmission of transparent concrete," *International Journal of Scientific & Engineering Research*, vol. 3, no. 4, 2015.

[13] A. Tuaum, S. M. Shitote, and W. O. Oyawa, "Experimental Evaluation on Light Transmittance Performance of Translucent Concrete," *International Journal of Applied Engineering Research*, vol. 13, no. 2, pp. 1209–1218, 2018.

[14] W. E. Elemam, A. H. Abdelraheem, M. G. Mahdy, and A. M. Tahwia, “Optimizing fresh properties and compressive strength of self-consolidating concrete,” *Construction and Building Materials*, vol. 249, Jul. 2020, Art. no. 118781, https://doi.org/10.1016/j.conbuildmat.2020.118781.

[15] J. Sunil, K. Amol, K. Chetan, and T. Pravin, “A study on translucent concrete product and its properties by using optical fibers,” *International Journal of Modern Engineering Research (IJMER)*, vol. 5, pp. 53–57, 2015.