Influence of Graphite and Glass fibers on the compressive strength of Translucent concrete

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Abstract. Translucent concrete (TC) is an extraordinary and innovative construction material that not only exhibits structural performance but also incorporated a light transmitting option for sustainable design. This study will explore the effects of hybrid reinforcement consisting of 0.1% graphite and 0.5% glass fibers (GF) on the compressive strength (CS) and light transmittance (LT) of TC. As a first step, based on the generated performance, the most effective optical fiber content is found at 7.5% TC by mass. The graphite and GF are added one at a time and then a combination of both to the TC matrix. After 7 days and 28 days of typical curing under 27°C ± 2°C, the mechanical and optical properties are evaluated. The hybrid reinforced TC achieved a max CS of 26.36 MPa (69% increase in comparison to control) and a max LT of 97 lux (67% improvement). Both the CS and LT values for the hybrid reinforcement exceed those resulting from any other individual fiber addition. The results of this investigation demonstrate a possible synergistic effect of graphite and GF together serving to improve both mechanical performance and contribution to translucency. These results are significant as they show that hybrid fiber reinforcement is a viable option for successful balance between mechanical and aesthetics performing adjectives in TC in high end architectural application.

1 Introduction

Translucent concrete (TC), or light-transmitting concrete, is a novel composite material that includes optical fiber into a cementitious matrix to create controlled movement of light while taking on structural capacity [1].

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The combined useable capacities of light transmission with structural capacities make TC attractive for use in sustainable architecture applications (i.e., illuminated façades, interior partitions, and decorative panels) that will help regulate energy consumption while providing aesthetic benefits with natural daylighting [2].

However, there is a degradation of the mechanical resistance because of the incorporation of optical fiber in concrete, as the fibers disrupt the continuity of the matrix, the properties at the fiber-matrix interface are prone to concentration of stress points, and the overall porosity of the reinforced concrete increases [3]. A very common approach is the fiber reinforcement used to boost strength and durability with minimal impact to the optical performance. Between the optic fibers and hybrid fibers; glass fibers (GF) and graphite fibers, have potential for use as structural reinforcement [4]. GF have been used in cementitious composites because of their high tensile strength (~3,200 MPa), alkali resistant properties, optical transparency which helps to keep light transmission pathways intact and reduces micro-cracking [5]. When GF are compatible with the concrete matrix, it improves the structural cohesion of the material and improves longevity [4]. Graphite fibers have offered excellent compressive strength, high stiffness and low chemical sensitivity, making them suitable for structural improvement, in a severe environment [6]. Yet graphite fibers are dark in color, diminishing light transmission, a concern for translucent products [10]. While there are numerous studies utilizing their use of single types of fibers such as optical fibers [11], GF [6], or carbon/graphite fibers [10]; few studies have investigated using them in TC and have considered either mechanical properties or optical properties as the primary concern with very few considering both optical and mechanical properties during TC optimization and validation process. It is important to consider and study the synergistic effects of combining the GF with graphite fibers in TC. No other study to date, has studied how hybrid reinforcement could help balance the impact of compressive strength improvement and maintaining or improving light transmission. Most studies either focus primarily on improving structural performance at the expense of aesthetics, or prioritize translucency without providing adequate mechanical validation [7,8]. To fill this void, this study proposes a hybrid reinforcement strategy using 0.1% graphite and 0.5% GF by volume, incorporated into TC matrix with optical fibers. The aim of this study is to determine the subsequent effect on compressive strength and light transmission of the optical fibers combination after 7 and 28 days of curing. This paper aims to combine the crack resistance and transparency of GF, with the stiffness and compressive strength of graphite for a high performance, balanced TC suitable for architectural and semi-structural applications.

2 Methodology

The research included multiple stages where the effect of graphite and GF is evaluated on the CS and Light Transmission (LT) of TC. The methodology is structured in the following manner:

2.1 Collection of resources

In this study, the materials used are Ordinary Portland Cement (OPC)-based, as per IS 8112-2013 specifications, river sand sourced locally having 2.65 fineness modulus (Zone II, IS 383), and potable water. The optical fibers used are polymethyl methacrylate (PMMA)-based, with a diameter of 2 mm, a length of 10 mm, light transmittance of about 92%, and a refractive index of 1.49. The glass fiber (GF) material, alkali resistant is a chopped strand; 36 mm long, diameter is 13 µm, tensile strength 3.2 GPa, and Young's modulus of 72 GPa. The 2 mm diameter and 10 mm length of PMMA optical fibers were chosen based on the results from the previous trials and the reviewed literature [10]. The published research and trials suggest that fibers in this fibre diameter and length range have higher light transmission characteristics with low stress concentration and higher workability features. Fibres shorter than (<5 mm) light guiding characteristics are noticeably poor and fibers longer than (>15 mm) fibres led to snagging and reduction in evenness and homogeneity. The 36 mm GF length fibres were selected as they exceeded the critical length needed for adequate stress transfer in a cementitious matrix (typically 20-30 mm) and took into consideration the maximization of the reinforcement [13]. The graphite powder (99.9% pure) average particle size is 10 µm, bulk density of 0.2 g/cm³, and selected because it is stiff and could guide light. The water-cement ratio is 0.45 for sufficient workability and minimum porosity.

2.2 Preparation of TC Specimens

To ensure the homogeneous distribution of the cement and sand, the mixing started with a dry blend. Optical fibers, GF, and graphite are already weighed and added during the wet stage without excessively mixing them to prevent clumping. A mechanical mixer is used to aid in the mixing of the fibers. Water is added incrementally to allow the workability of the mixture to be suited for each project while minimizing air entrapment. The optical fibers are precut for dispersion as well as to eliminate any knots in the fibers, while the GF were mixed with a dispersing agent which dispersed the fibers to avoid bulk or clumping. The wall of the mixer is scraped periodically to scrape down the fibers, and overmixing was limited to avoid damage to the fibers. Upon completion of the mixing, the specimens are demoulded after a period of 24 hours and cured in a water tank at 27°C ± 2°C for 7 and 28 days. This temperature falls within the limit set by IS 516-1959 for testing concrete when hot weather represents the conditions of placement. Portable water is used for the mixing process in the event that it may leach the fibers. The optical fiber content is determined at 6%, 6.5%, 7%, 7.5%, 8%, and 8.5% by volume to observe the effects on compressive strength and light transmission.

2.3 Testing and Determination of Optimum Fiber Percentage

Ascertaining the most appropriate concentration of fibers, CS, and LT tests are carried out on the samples containing respective fiber percentages. CS testing is done by applying compressive loads on the samples until the samples failed with the maximum load being considered to be the CS. At the same time LT is also taken using a light passing test where concrete samples are quantized to ascertain the amount of light passing through the concrete and how that changes with the different fiber volume fractions to assess translucency. The optimum fiber concentration is determined according to the test results by achieving appropriate balance between the CS and LT in order to come up with the best translucent concrete mixture. This optimum concentration acted as the control for the next stage of experiments which involved the addition of more reinforcement.

2.4 Addition of Graphite and Glass Fibers (GF)

After determining the optimal optical fiber percentage, two additional materials—graphite and GF—are introduced as reinforcing agents. Graphite is added at 0.1% and GF at 0.5% by volume to improve CS while maintaining translucency. Separate TC specimens are prepared with only graphite or only

GF, and their CS and LT are measured after 7 and 28 days of curing. Figure 1 shows the optical fibers, graphite powder and GF utilised in this investigation.

Fig. 1. (a) Optical fibers (b) Graphite powder (c) GF

2.5 Combined Additive Analysis

Ultimately, a hybrid additive specimen was developed, which comprises a mix of graphite (0.1%) and GF (0.5%), added to the improved TC formulation. The CS and LT are tested at two curing periods: 7 days and 28 days. The purpose of this stage is to assess the simultaneous effects of graphite and GF on the physically and optically active features of TC.

2.6 Data Analysis and Comparison

The evaluation of CS and LT for each of the test specimens is made with regard to the conventional cement mortar in order to demonstrate the influence caused by the fiber reinforcement. The enhancement of CS and increase in LT are plotted in a graph where the reinforcing ability of graphite and GF in reinforcing the TC from structural and aesthetic aspects is clearly emphasized. This study outlines the recommendations on fiber composition to be used and illustrates the potential in using both graphite and GF for applications aimed at producing high-end TC.

3 Results and Discussions

3.1 Compressive Strength (CS)

Optical fibers are included in the cement mortar at different percentages as: 6%, 6.5%, 7%, 7.5%, 8%, and 8.5%. The CS for each of these mortar specimens is ascertained as shown in Figure 2 and Figure 3 represents the CS values related to each percentage of added optical fiber. The CS occurs at a fiber content of 6% and presents values of 12.43 and 15.6 MPa at 7 and 28 days, respectively. Thus, the incorporation of 6% optical fiber does indeed impart some degree of reinforcement which allows for an increase in strength over time with the curing period. Adjusting the fiber content slightly higher by 0.5% to 6.5% shows CS performance at 7 days and 28 days of 12.03 MPa and 14.8 MPa respectively which is a relative drop in performance compared to the former fiber content. This reduction could be due to the fact that at this fiber level, the mortar is reaching the fibers bondability limits which could lead to formation of voids present that weaken compressive strength [9]. CS register slight enhancement over the previous fiber content at 8% as values stand at 15.64 MPa at 7 days and 18.8 MPa at 28 days. This figure could be the maximum fiber content possible as more strength is gotten without ruining the mortar structure. CS increases further at 7.5% fiber content where the values are 19 MPa by 7 days and 20.9 MPa after 28 days. This indicates that the incorporation of 7.5% optical fiber strikes the right balance between enhancement of the properties of the fiber itself with the bonding of the mortar achieving tremendous gains in strength [10]. With an 8% fiber content, the CS slightly reduces to 14.44 MPa after 7 days and 18 MPa after 28 days. This drop in strength could suggest that the ideal range of fiber content in the mix to achieve structural validity of the cement heads over the CS of the cement matrix is being exceeded. A further increase in fiber content to 8.5% results in a CS of 13.4 MPa and 17.5 MPa at 7 days and 28 days respectively slowing down the strength recovery. In this case, the concentration of optical fiber appears to be too beneficial and destroys the structure of the matrix, thus increasing the level of strength reduction caused by poor bonding and high level of porosity [11]. Thus, the optimal optical fiber percentage is identified as 7.5%, at 7 days, the compressive strength is 19.0 ± 0.4 MPa while at 28 days is 20.9 ± 0.6 MPa, demonstrating consistent performance.

Fig. 2. TC specimens

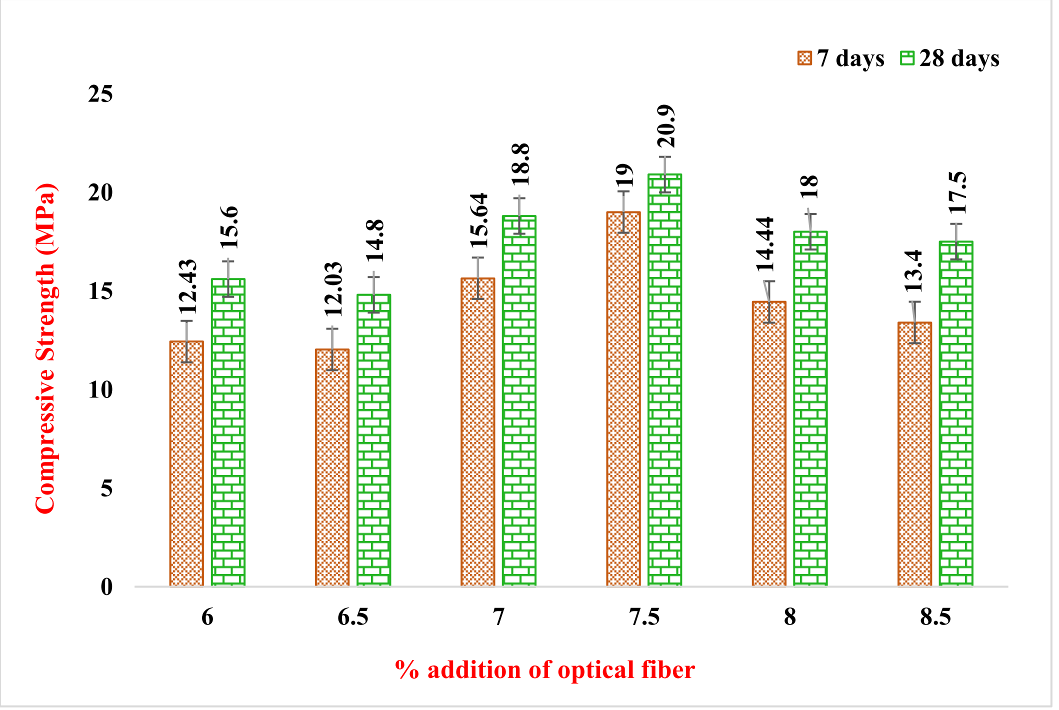

Fig. 3. CS of TC specimens at 7 and 28 days with optical fibers

3.2 Compressive Strength (CS) with Additives

Graphite, at a concentration of 0.1%, and GF, at 0.5%, is incorporated into the mix. CS test is performed after 7 and 28 days of curing, and the results are presented in Figure 4 for analysis. The reference sample has cement sand mortar with a CS of 15.17 MPa. This value illustrates the strength of conventional cement in the absence of any fiber reinforcement thus offering an ideal point of reference in determining the degree of effect that will be brought about by fiber inclusion. The standard cement mortar after age of 28 days is able to have a CS of 18.72 MPa. This value indicates that the mortar has also been curing and gaining strength over a period of time but it is still the lowest value as compared to the other specimens [12]. After an addition of 7.5% optical fiber, the CS improves to 19.95 MPa. It indicates that the optical fibers are effective in enhancing the strength of the concrete, probably by load distribution and reinforcement of the matrix. The increase in the strength shows that optical fibers do not only improve translucency but also serve some structural purposes. The CS of the TC which contains 7.5% optical fiber increases further to 21.95 MPa. This indicates that even though the optical fibers work to enhance their strength, this is markedly enhanced after a much longer elongation period which somehow may be attributed to the bonding characteristics of the fibers and the matrix being more improved. The addition of GF also raises the CS of the sample even further to 20.32 MPa. Added GF have high tensile properties, are used to combat cracking, and assist in stress transfer throughout the concrete thereby resulting in an increase the strength modestly as compared to the sample with only optical fibres used. Following the addition of the GF, the CS rises to 22.73 MPa. The effect of GF becomes more pronounced after 28 days, as the fibers continue to reinforce the matrix, enhancing load capacity and resistance to crack development [13]. The CS experienced a slight increase of up to 20.19 MPa, with the incorporation of 0.1% graphite. As a result of the ability of graphite to provide stiffness and resistance to wear from repeated use, the addition of graphite to the mix improves the overall hardiness and strength of the concrete. When assessed on its own, the composite containing only optical fibers showed a higher strength, but this is nonetheless a somewhat small rise. When the percentage of graphite is raised to 0.1% the compressive strength reaches 25.16 MPa after 28 days. The inclusion of GF seems to impart a significant degree of strengthening of the concrete, maintaining its structure over time. This indicates how the incorporation of graphite improves the capacity to carry loads and withstand destructive processes. The use of optical fibers, graphite and GF causes the strongest compressive stress, equalling 22 MPa after 7 days. This is the most effective combination of additives, as the optical fibers perform the function of light, while mechanical properties are improved by graphite and GF. All three fibers, when used together produce the highest strength in this curing period [10]. The combination of optical fibers, graphite and GF provided the highest CS at 28 days, reaching values of 26.36 MPa. This is indicative of the combined action of three different fibers. The GF helps prevent cracking, graphite increases the stiffness and strength of the matrix while the optical fiber remains clear. Such a combination of reinforcements will provide the excess efficiency in terms of strength and clarity.

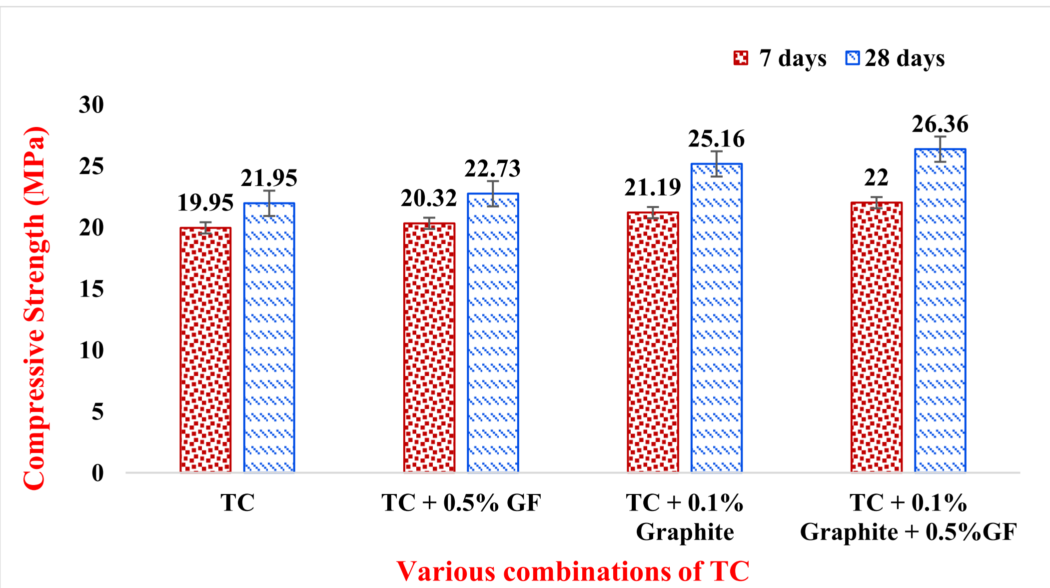

Fig. 4. CS of TC specimens at 7 and 28 days

3.3 Amount of Light Transmission (LT)

The optical fibers are included in the percentages as : 6%, 6.5%, 7%, 7.5%, 8%, and 8.5%, the LT values (measured in lux) are 58,65,74,88,75 and 66 respectively as shown in Table 1. With 6% optical fiber, LT starts at 58 lux. This represents the baseline translucency provided by optical fibers in the mix. While light is transmitted, the relatively low percentage of fibers limits the overall light-passing capacity. At 6.5% fiber content, LT increases to 65 lux, showing a moderate improvement. The additional fibers provide more pathways for light, enhancing the translucency of the concrete. With

7% optical fiber, LT reaches 74 lux, indicating a continued positive correlation between fiber content and translucency [10]. This suggests that as the number of fibers increases, the concrete matrix supports greater LT. At 7.5%, light transmission peaks at 88 lux. This represents the optimal percentage of optical fibers, where the combination of sufficient fibers and proper bonding with the mortar matrix creates the best conditions for LT. Beyond this point, additional fibers begin to interfere with the effectiveness of light passing. Increasing the fiber content to 8% results in a reduction of LT to 75 lux. This decrease may be due to overlapping or clustering of fibers, which can block light paths and reduce the efficiency of light passing through the concrete. At 8.5% fiber content, LT further decreases to 66 lux. This trend suggests that excessive fiber content negatively impacts light transmission by disrupting the homogeneity of the concrete and creating voids or misaligned fibers that block light.

Table 1. Light Transmission of TC with Varying Optical Fiber Percentages at 28 days

% of optical fiber	Light passing (Lux)
6	58
6.5	65
7	74
7.5	88
8	75
8.5	66

3.4 Amount of Light Transmission with Additives

Table 2 presents the LT (in lux) of TC specimens with additives. The base TC with 7.5% optical fiber achieves a light transmission of 88 lux. This value reflects the effectiveness of optical fibers in creating pathways for light to pass through the concrete matrix. At this percentage, the fibers are optimally distributed without excessive overlapping or clustering, allowing efficient light passage while maintaining the structural integrity of the matrix. The inclusion of 0.5 GF in the mix slightly increases light transmission to 90 lux. GF, while primarily reinforcing the concrete structurally, do not hinder the pathways created by optical fibers for light transmission. Instead, they may contribute to maintaining the integrity of the concrete by reducing micro-cracking and ensuring a more uniform dispersion of fibers. This results in a marginal improvement in translucency compared to the base TC specimen. Adding 0.1% graphite to the TC further increases light transmission to 93 lux. Graphite's fine particles may help fill microvoids in the matrix, reducing light scatter and allowing more focused pathways for light to travel through the optical fibers. Additionally, the reflective or light-guiding properties of graphite could enhance the overall light transmission efficiency. The combination of 0.1% graphite and 0.5% GF achieves the highest light transmission of 97 lux. This result suggests a synergistic effect, where : Graphite enhances the matrix's light-guiding properties by reducing scatter and aiding in better light focusing. GF contribute to structural cohesion, minimizing micro-cracks that could otherwise obstruct light transmission pathways. The combined effect optimizes the translucency of the concrete, allowing the highest level of light passage while maintaining mechanical reinforcement. Figure 5 shows the LT of TC.

Table 2. Light transmission of TC with 7.5% optical fiber, Graphite and GF at 28 days

% of optical fiber	Light passing (Lux)
TC	88
TC + 0.5% GF	90
TC + 0.1% Graphite	93
TC + 0.1% Graphite + 0.5%GF	97

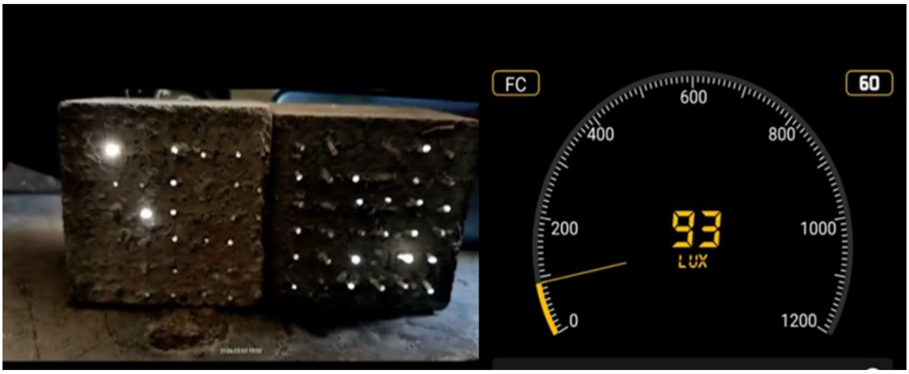

Fig. 5. Light Transmission through TC

4 Conclusions

This experimental investigation provides insights into creating a Translucent Concrete (TC) material that meets both structural and aesthetic demands, paving the way for its adoption in modern, sustainable architecture. TC using graphite and glass fibers support the sustainability aims through the development of more durable materials while minimizing the waste of usage through improved performance of structures. However, the concern of lifecycle environmental impacts such as energy-consuming production processes and recycling at the end of life calls for more research into sustainable alternatives and end-of-life management. The following important conclusions that can be drawn are:

- 7.5% of optical fiber found in Translucent Concrete (TC) is considered optimum because it gives a balance between compressive strength (CS) and Light Transmission (LT).
- This composition improved CS by a margin of 40 (from 15.6MPa of normal concrete to 21.95MPa) and LT by a margin of 52 (from 58lux to 88 lux) after 28 days of curing as compared to the baseline mortar with 0 percent optical fibers.
- By adding 0.5 percent glass fibers (GF) to the mix, CS is enhanced by an additional 4 percent at 22.73 MPa and LT is enhanced by 2.3 percent at 90 lux. Structural integrity is preserved by these GF by avoiding micro-cracks while maintaining the light pathways.
- With a 15 percent increase in CS as opposed to a value of 25.16 MPa, and above 5.6 percent in LT - Graphite increases LT by comprising 0.1 percent. Graphite improves timber stiffness by lessening the scattering and filling voids, enhancing wear and light-guide properties.
- The combination of 0.1% graphite and 0.5% GF gives the maximum benefits, where the CS reaches a maximum of 26.36 MPa, which shows an improvement of 69% and maximum LT

is achieved at 97 lux which shows an improvement of 67% referred to the baseline. It shows the interaction of reinforcing effects from these materials.

- Hybrid reinforcement greatly improved mechanical properties plus TC translucency making it able to work in high-performance applications where light traveling and strength are concerned.

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