5

Performance Evaluation of Light Transmitting Concrete Made with Plastic Optical Fibers

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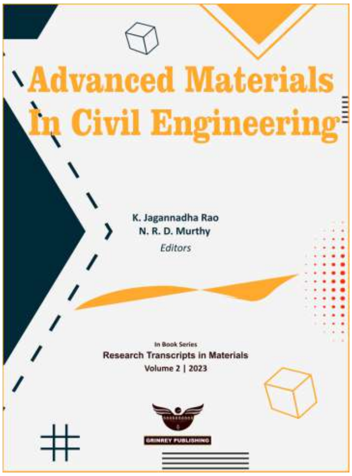

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Abstract

Light transmitting concrete (LTC) is a concrete made with light optical elements (e.g., plastic optical fibers) having the light transmitting property. In addition to its use as aesthetic purpose, LTC enhances the utilization of natural resource by the projection of light through the concrete. Thus, this translucent concrete can be used in structures to make energy efficient and environment friendly structures through the minimization of artificial energy usage. This chapter deals with the performance evaluation of light transmitting concrete (LTC) made with plastic optical fibers (POFs). For this purpose, compressive strength and light transmitting properties of LTC have been investigated and compared with conventional concrete. Experimental results show that the compressive strength at 7 days, 14 days, and 28 days have been increased by 3.47-12.23%, 4.82-14.85%, and 4.07-9.78%, respectively for the LTC made with various percentage of POFs. From the simple light transmission test, it has been found that the LTC made with 0.75 mm, 1 mm, and double layer 0.75 mm POFs can transmit 8%, 9.44%, and 14.8% light, respectively. Results of the present study imply that light transmitting concrete made with POFs can be used for aesthetic and energy saving purpose without compromising the strength.

1. Introduction

Concrete is a key construction material needed for the development of structures and infrastructure systems. In the past few years, ongoing development and modernization has become significant in the construction. With the economic growth and advancement of technology, civil structures including tall buildings, underground structures, large span bridges, tunnels, and other structures are being built around the world. High-rise building structures have significant demands for lighting, even at daylight. This led to development of a novel, and sustainable construction materials which can utilize sunlight to illuminate the interior spaces of buildings providing healthy environment.

Optical elements (e.g., fibers, translucent glass rods, etc.) can be utilized to produce light transmitting concrete. Among the optical element optical fibers are most effective. The flexible, thin, and transparent e.g., plastic optical fibers (POFs) can efficiently transmit light through the fibers at their two ends. Light transmitting concrete (LTC) enhances the utilization of natural resource by the projection of light through the concrete (Fig. 1). In addition to its use as aesthetic purpose, it also saves energies by decreasing the consumption of electricity for artificial lightings. Thus, LTC can be used as an aesthetic, eco-friendly, and energy-saving construction material.

The first concept of LTC was introduced in 2001 by Aron Losonczi, a Hungarian architect, and the first concrete panel with translucent properties was developed back in 2003 as LiTraCon [1]. Some experimental studies have been performed for the evaluation of the LTC. Zhou et al. [2] discussed about transparent concrete using plastic optical fibers (POFs) and suggested that LTC can be green energy saving material with steady light transmitting property. Salih et al. [3] studied LTC prepared with POFs using mortar with self-compacting property (SCM) and found that the inclusion of POFs decreased the compressive strength as well as flexural strength. They suggested that LTC with 2 mm fibers produces concrete of higher compressive strength compared to 1.5 mm and 3 mm fibers. It is also found from their results that LTC with higher volume of POFs (more than 4 %), use of 2 mm fibres gives higher flexural strength. Pagliolico et al. [4] studied transmittance properties of the light translucent concrete (LTC) panels which was made with coarse aggregates from waste glass and suggested that LTC can be used reducing the energy demand for daylighting. Li et al. [5] assessed compressive strength of LTC made with sulfo-aluminate cement and reported that the compressive strength decreases linearly with the increase of optical fibers at various curing conditions. Li et al. [6] assessed properties of polymethyl methacrylate (PMMA) fibers-based LTC and estimated the compressive and flexural strength and found that strengths were less than the normal concrete. Besides, they found the increase of volume of fibers affects the compressive and flexural strength of LTC with reduction. Altlomate et al. [7] performed experimental investigation to assess the strength and light transmittance of LTC made with POFs and found improvement of compressive strength of strength as well as high light transmittance. Spiesz et al. [8] performed experiments to assess properties of transparent concrete and reported that LTC can achieve good mechanical and durability properties as well as light transmittance. Mosalam and Casquero-Modrego [9] studied the permeability of sunlight of translucent concrete panels (LTP) used as building envelope. They discussed about the inclination of the panel and numerical aperture of a POFs or incident angles according to results of their study for the better effectiveness of the LTC. Tuaum et al. [10] developed translucent concrete facade with 2%, 4%, and 6% of POFs and evaluated the bulk density along with the compressive and flexural strength. Their experimental results represented that using POFs up to 6% did not affect the bulk density. However, the strength properties (compressive and flexural) of the LTC exhibited lower values, relatively. Their study also revealed that increase of the volumetric ratio of POFs can increase the compressive strength of the translucent concrete, whereas the flexural strength was to be at reduced vaules. Huang and Lu [11] performed compressive strength test, and also evaluation of thermal and light transmit properties of translucent concrete panel (TCP) for building envelope. Results from the study revealed that TCP can have higher compressive strength, higher thermal insulation property, and excellent energy-efficient performance. Navabi et al. [12] found less compressive strength in LTC made with Portland cement, silica fume, polymethylmethacrylate fibers, and superplasticizer; though light transmittance shows good result. Shen and Zhou [1] evaluated light transmission property and thermal conductivity of LTC made with resin translucent cement material through energy and daylighting simulation. Results from their simulation revealed that RTCM can improve the daylight condition of indoor environment and comfort as it has excellent light transmitting property and also thermal conductivity. Su et al. [13] performed simulation of daylighting performance of translucent concrete envelopes and found that numerical aperture (NA) has great effect on effective daylight use in translucent concrete building envelope. Shen and Zhou [14] examined the light transmit performance of LTC and energy-saving capacity of plastic optical fibre-based transparent concrete and found that LTC reduces energy consumption through light transmittance from sunlight. Tahwia et al. [15] performed compressive strength and light transmittance test of self-compacting LTC and found higher compressive strength along with good light transmittance performance.

Fig. 1. Italian Pavillion Made with Light Transmitting Concrete [16]

The present study deals with the investigation of strength and light transmissibility performance assessment of light transmitting concrete (LTC) made with plastic optical fibers (POFs). Compressive strength at various ages and light transmitting properties of the LTC were investigated experimentally. The following sections describes the materials and methodology for the work, experimental process, along with results and discussions.

2. Materials and Method

2.1. Materials Used

For the strength and light transmit performance evaluation of light transmitting concrete, concrete specimens were made using ordinary Portland cement, natural sand, coarse aggregate, and plastic optical fibers. Ordinary Portland cement, river sand (passes through 4.75mm sieve), readily available coarse aggregate (retains on 4.75 mm sieve) was used. Properties of the materials were tested and results of various properties of the materials i.e., cement, fine aggregate (sand), and coarse aggregate are tabulated in Table 1.

Table 1. Material Properties

Material	Properties	Results
Cement	Grade	53
	Specific gravity	3.15
Fine Aggregate	Fineness Modulus	2.6
	Bulk Specific Gravity (SSD)	2.6
	Absorption Capacity	0.18 %
	Surface Moisture	0.0588
Coarse Aggregate	Aggregate Size	9.5 mm
	Absorption Capacity	1.5%
	Dry rodded unit weight	101.7 lb/ft^3

2.2. Mix Proportion and Sample Preparation

The selected maximum size of coarse aggregates is 3/8″ and slump value for workability is 25–50 mm. Mix design were performed to obtain the target compressive strength of 20MPa at 28 days age with the selected workability property. In the mix design the guideline, American Concrete Institute ACI 211.1 [17] was followed. Mix proportion of the concrete specimen is shown in Table 2. At first, the materials were dry mixed. After mixing of the materials, slump test was performed to check the workability of the concrete. Then the concrete was placed in 150 mm cube mould, compaction was done and surface finishing was done with a smooth steel trowel. The compacted and hardened concrete material was kept for 24 hours within the mould in moist condition. After that concrete was demoulded and placed under water for curing in water tank for target curing period before testing.

Table 2. Mix Proportions of Concrete

Properties	Values
Target Compressive Strength at 28 Days	20 MPa
Ratio of Cement, Fine and Coarse Aggregate	1: 2.83: 3.17
Water-Cement Ratio	0.40

2.3. Preparation of optical fibers

Plastic Optical Fibers (POFs) of 0.75 mm, 1.0 mm and double layer 0.75 mm were used to make the concrete transparent. The fibers were split into specific lengths for the concrete cubes. Eventually, the fibers were implanted, through holes made in the 150 mm cubic wooden mould. The difference between two POF layers is 15 mm. The volumetric percentages of POFs in LTC are 0.1%, 0.17% and 0.38% for the cubic concrete specimen made with 0.75 mm, 1.0 mm and double layer 0.75 mm POFs, respectively. Plastic optical fibers are shown in Fig. 2.

a) b)

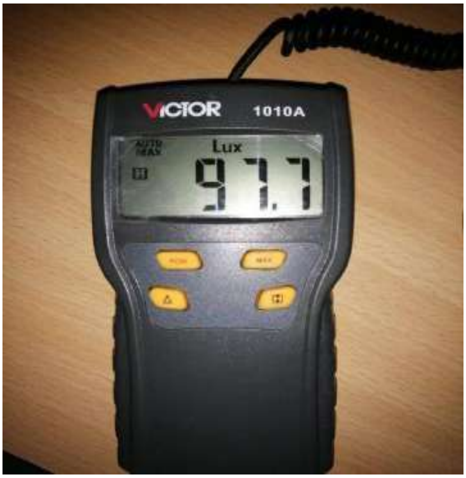
Fig. 2. Plastic optical fibers – a) without light source, b) with light source

3. Experimental Investigations

3.1. Light Transmission Test

Light Transmission Test was carried out with a lux meter. A light source of 60-Watt bulb was set behind the LTC specimens and the light passed through LTC. Sensor of lux meter which was placed opposite side of source of light measured the amount of light passed through the concrete because of using the POFs in the concrete specimens. LTC specimen with source, lux meter, and measured lux of light at opposite side by lux meter are shown in Fig. 3.

a)



b)

Fig. 3. Light transmission test – a) source, b) lux meter

3.2. Compressive Strength Evaluation

For compressive strength test, concrete cube of 150mm x 150mm x 150mm were casted in wooden mould for light transmitting concrete and for control concrete steel cubic mould of same dimension were used. These concrete specimens were then kept under water for curing purpose for 7, 14 and 28 days. After the specified curing period is complete, compressive strength were evaluated for both the concrete specimens, LTC and control concrete. Fig. 4 represents the preparation for specimen with POFs in wooden mould, hardened concrete specimen and also setup for the compressive strength test of the specimens.

a)  b) 

c) 

Fig. 4. LTC– a) sample preparation, b) hardened concrete, c) compressive strength test

4. Results and Discussions

4.1. Compressive Strength

Three specimens were made for each concrete group, i.e., plain concrete, LTC made with 0.1%, 0.17% and 0.38% POFs. The specimens were tested after target curing period to determine the compressive strength at 7, 14, and 28 days. Results from the compressive strength test of the concrete specimens are presented in Table 3.

Table 3. Results of Compressive strength test

Age (Curing Period)	Compressive Strength (MPa)			
	Plain Specimen	LTC		
		0.1% POFs (0.75 mm)	0.17% POFs (1.0 mm)	0.38% POFs (2x0.75 mm
7 days	12.67	13.11	13.64	14.22
14 days	15.56	16.31	17.16	17.87
28 days	19.64	20.44	21.16	21.56

Fig. 5 represents the compressive strength of cured concrete specimens after 7, 14, and 28 days both for the plain concrete specimen as well as for the light transmitting concrete made with 0.1% POFs (0.75 mm), 0.17% POFs (1.0 mm), and 0.38% POFs (2 x 0.75 mm). It is clear from the results that the compressive strength has been increased by 3.47%, 7.66%, and 12.23% for 7 days; 4.82%, 10.98%, and 14.85% for 14 days; 4.07%, 7.34%, and 9.78% for 28 days for the LTC made with 0.75 mm, 1 mm, and double layer 0.75 mm POFs, respectively.

The results of the compressive strength tests as represented in Fig. 5 indicate that all the light transmitting concrete specimens made with plastic optical fibers have higher compressive strength than the plain concrete, for all the cases (i.e., in all specimens with specified percentage of POFs) for all the curing periods as specified for 7, 14, and 28 days. It is also clear that the strength of LTC increases with the percentage increase of plastic optical fibers as used in the present study, i.e. the compressive strength of LTC with 0.38% POFs is highest among the specimens.

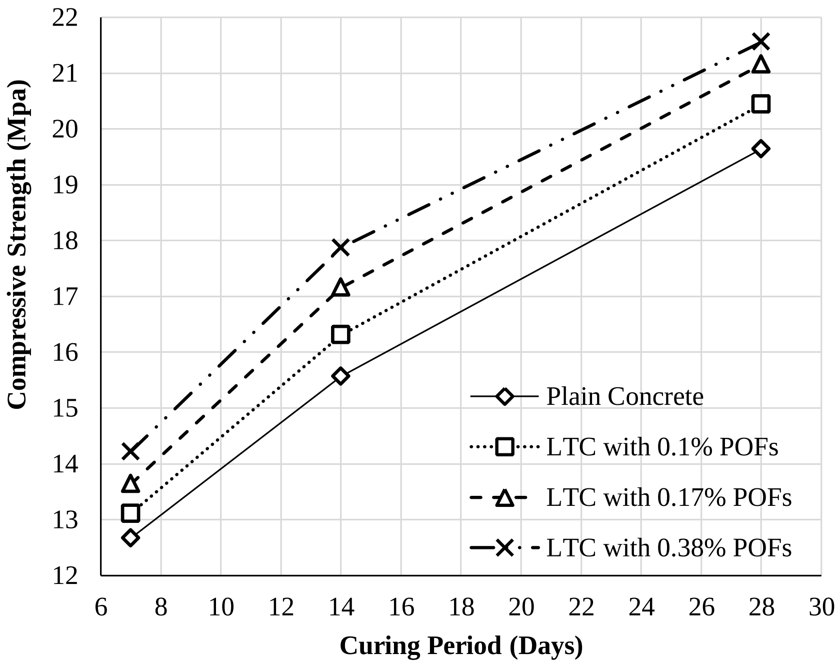


Fig. 5. Compressive Strength of Concrete Specimens

4.2. Light Transmission

Comparison of the transmission of light through the LTC made with different plastic optical fibers (POFs) is shown in Fig. 6. It has been found that the source 1220 lux, and the light passed through the LTC was found 97.7, 115.2, and 180.4 lux for the LTC made with 0.75 mm, 1.0 mm, and double layer 0.75 mm POFs, respectively. It has been found that the LTC made with plastic optical fibers can transmit light through the POFs. For 0.75 mm, 1.0 mm, and double layer 0.75 mm POFs used in LTC, light passes through LTC is 8%, 9.4%, and 14.8% of light source, respectively.

Thus, it is clear from the simple light transmission test of the LTC that light can be passed through the concrete made with POFs. It is found that the percentage of light transmission is more for the concrete with more POFs.

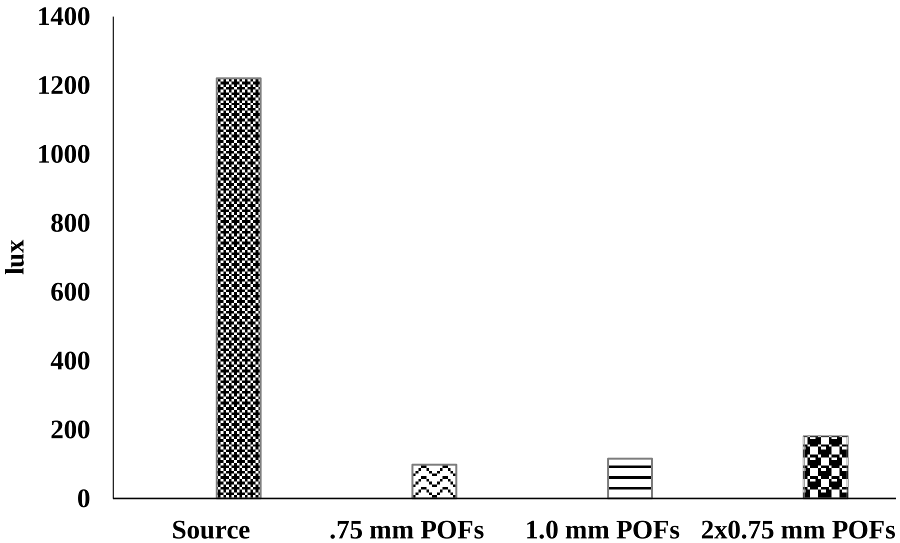


Fig. 6. Comparison of light transmission

5. Conclusion

This study investigates the performance of light transmitting concrete as an alternative sustainable energy efficient concrete through compressive strength and light transmissibility testing. The following conclusions can be made from the findings of the present study.

- It has been found that the compressive strength at various ages of light transmitting concrete is higher than the plain concrete. However, future investigation can include testing of light transmitting concrete made with higher percentage of plastic optical fibers and cured for higher period (e.g., 56 days, 120 days, 180 days, etc.) to find the effect on compressive strength.
- It has been found from the simple light transmitting test that light transmitting concrete can pass light through it. Thus, it can be used as energy efficient and environment friendly alternative concrete. However, rigorous light transmitting test can be done in future to consider other effect like acceptance angle.

Light transmitting concrete can be an alternative environment friendly concrete which can be used for aesthetic purpose as well as for energy minimization using daylight without compromising with its compressive strength. The present study does not include experimental testing of some other physical properties, mechanical properties, and also durability test of LTC. However, some important properties can be evaluated in future studies for more comprehensive performance assessment, e.g., the optimum dosage of POFs considering the strength and light transmitting efficiency of the LTC.

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